Analysis and Management of Bottlenecks in Supply Networks

Towards a Structured Approach to Stabilization of Inbound Material Flow

by

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Abstract

Any organization whose business model is based on production relies, and is dependent, on providers of raw material which it transforms into products. Customers' demand for products, and thus the producing firm's demand for raw material, generally are not static but change with economic cycles, marketing, entries and exits of competitors, and changing consumer behavior, to name but a few factors. A variety of forecast methods support organizations in their effort to be prepared for demand changes, yet uncertainty about the volumes the market will demand cannot be fully eliminated. The design and management of supply networks has therefore increasingly shifted in the focus of attention as they provide levers for organizations to cope with variability.

This thesis aims to augment theory and practice in the management of supply networks by providing a different perspective, a new angle, from where to analyze and to steer the buying firm's inbound material stream. A bottleneck perspective will be developed in the course of the thesis, and it will be complemented by the identification and discussion of distinct bottleneck management activities, each of which comprised by a multitude of individual measures. Some of these measures fulfill very particular roles, and some serve multiple roles at once, so that the context in which to use these measures is important.

Moreover, the discussion of supply networks and activities aimed at securing supply provides clarification as to the popular notions of supply chains and Supply Chain Management (SCM). It will be demonstrated how these concepts collide with actual network structures as well as with common practice.

A comprehensive review of literature brings together insights from research fields as diverse as manufacturing systems, systems theory, complexity, and network theory. This review provides the backbone for the development of a

tentative conceptual model that will guide the processes of data collection and analysis. The insights from the data analysis and how they relate to the existing body of knowledge are used to devise the foundation of a theory of bottleneck management in supply networks.

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Abbreviations

B2B	Business-to-Business
B2C	Business-to-Consumer
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe - Federal Institute for Geosciences and Natural Resources
BM	Buffer Management
BOM	Bill of Material
CAS	Complex Adaptive Systems
CEO	Chief Executive Officer
CPFR	Collaborative Planning, Forecasting, and Replenishment
CSR	Case Study Research
DBR	Drum-Buffer-Rope
DERA	Deutsche Rohstoffagentur – German Raw Material Agency
ECR	Efficient Consumer Response
EDI	Electronic Data Interchange
EICC	Electronic Industry Citizenship Coalition
EPA	Environmental Protection Agency
ETA	Estimated Arrival Time

FTL	Full Truck Load
GPS	Global Positioning System
IOR	Interorganizational Relationship
JiS	Just-in-Sequence
JiT	Just-in-Time
LME	London Metal Exchange
LoC	Locus of Control
LSP	Logistics Services Provider
MRP	Material Requirements Planning
MRP II	Manufacturing Resources Planning
MTO	Make-to-Order
MTS	Make-to-Stock
NAFTA	North American Free Trade Agreement
NAO	Network Administrative Organization
NF metal	Non-ferrous metal
OEM	Original Equipment Manufacturer
OM	Operations Management
OPEC	Organization of the Petroleum Exporting Countries
OPP	Order Penetration Point (Decoupling Point)
PCF	Production Capacity Flexibility
PPA	Purchasing Portfolio Analysis

PSA	Peugeot Société Anonyme
RBV	Resource-based View
RDT	Resource Dependence Theory
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
ROC	Return on Capital
ROI	Return on Investment
SCM	Supply Chain Management
SCO	Supply Chain Orientation
SCRM	Supply Chain Risk Management
SME	Small and Medium-sized Enterprise
SN	Supply Network
SNA	Social Network Analysis
SWT	Strength of Weak Ties
TCE	Transaction Cost Economics
ToC	Theory of Constraints
TPS	Toyota Production System
VCR	Video Cassette Recording
VMI	Vendor-management Inventory
WiP	Work-in-Progress

1. Introduction

1.1. Problem Statement

1.1.1. Introduction

Firm borders are increasingly difficult to define and at the same time in some respects less important than they used to be. Complex products are manufactured in different locations by various firms which, in turn, are supplied by a host of suppliers from different countries. After manufacturing, these products are distributed to diverse remote areas. The different steps of value-creation thus involve multiple actors in various locations, tied to each other through operations, many of which could be summarized under the umbrella term logistics. Taking into account multi-product strategies, a variety of different firm networks emerge with different degrees of overlap. Firms in such networks are subject to influence from other firms both in the same network and in other networks to which only indirect ties exist that are neither intended nor purposely maintained. And yet the impacts evolving from this type of relationships can be of equal magnitude and importance as from direct and intentionally created relationships.

The result is a dense network of mutually dependent actors. A variety of parameters can be used to describe the characteristics of individual network positions that may or may not be one determinant of performance. A core theme of this thesis is that performance of individual firms will vary, not only based upon internal decisions and resources, but also with respect to other firms' decisions and resources, which the focal firm seeks access to. There is no widespread and generally accepted framework as to what the factors are that will determine individual firm performance the most in complex networks of interdependent actors.

This dissertation focuses on the physical material flow between organizations in supply networks as the object of interest. Reliable supply is not taken for granted by many supply management professionals, and, in fact, a broad variety of factors exerts influence the successful and timely completion of production and delivery. Organizational responses to those factors will be identified and discussed. Locations where impediments arise to the normal functioning of a system are often referred to as *bottlenecks*, though this term has not been widely used in the context of supply networks. The bottleneck metaphor will be elaborated on in Section 2.3. It turns out to be a useful base concept for the development of archetypal activities and principles relating to the improvement of material flow. This thesis will create a more complete picture of causes and effects on supply performance in manufacturing networks. By laying the groundwork for a theory of bottleneck management in supply networks it will provide a frame of reference that will support decisions with respect to important determinants of successful supply relationships.

1.1.2. Problems and Needs in Industrial Practice

Any organization whose business model depends on the production of goods requires raw material as input to its production process. This raw material is normally provided by suppliers. Most suppliers are external organizations; even in cases where suppliers are internal and belong to the same organization, the physical location may be as distant. It is only the first echelon of raw material producers, such as mining companies, that does not receive the main share of material from suppliers but extracts it as natural resources from the Earth's crust. Yet, even these companies are dependent on supply of tools, machines, human resources, knowledge, commodities, and scientific contributions. And they require a market to sell the goods they extract. There are no self-sufficient organizations.

The general need to receive raw material and other forms of supply has led to the development of theories, concepts, tools, and techniques that help organizations manage their inbound material stream. Cheaper and faster means of transportation have made companies less dependent on local sources of supply; at the same time, increasingly many companies go international, which, again reduces their local dependency. Both developments, however, seem to make them more vulnerable to the cyclical swings of the world market as well as to irregular peaks and recessions.

Material flow is preceded and accompanied by information flow: production of goods tends to follow demand for those goods. A customer's order thus often triggers a whole series of events at a multitude of other organizations, which remains largely unseen both by the customer himself as well as by the organization serving the customer. Yet, successful operation at *each* echelon of the network of organizations which contribute to the production of the final product is a requirement for the customer order to be met eventually. If only one component is missing, most products cannot be produced and delivered.

The inability to deliver a product interrupts the cash flow of a producer; cash flow tends to follow material flow. Money is lost for the moment – and money can be lost in the future as potential follow-up transactions will not occur. Customers might switch their preferred supplier, and the reputation of being unreliable may prevent potential customers from doing business with that organization. The cause of the interruption of material flow may lie entirely outside the control of an organization; nonetheless chances are the organization will have to deal with the consequences on its own, will face "punishment" by the customer and possibly loss of future business, the latter of which may be the more significant problem yet remains impossible to quantify. As an example for the magnitude of losses incurred by supply shortages, the fast-growing Indian car industry could have produced 20% more cars in 2010 if the supply of tires had met demand, according to some estimates (AutomotiveWorld.com 2011).

Loss of current and future business is but one type of impact producers face. Interruptions of supply lead to idle time in production plants. The implications differ for each organization. In some cases, only little additional cost is involved if operations are discontinued. In other cases, the cost can be significant as continuously running processes are interrupted, requiring lengthy periods of production ramp-up – and thus additional delay – once the inbound material flow could be reestablished. Any type of delay increases process variability. In most production processes, there is some type of process dependency, too. That is, process steps have to be performed in a certain order. The combination of variability and dependency in processes leads to perturbations and slows down the entire production process for a period of time that can be significantly longer than the original period of interruption (Goldratt & Cox 2004). Companies already operating at high capacity utilization will face severe difficulties catching up with demand once they fall behind.

The recent example of Takata, the Japanese supplier of automobile inflators, illustrates the case (Gough et al. 2014-11-18, Niedermeyer 2014): defective airbags supplied by Takata have caused the recall of millions of cars after several fatalities became public, and further recalls are pending. If the National Highway Traffic Safety Administration of the United States decides to force a recall of all US cars equipped with potentially faulty Takata airbags, it will take the company two years to produce enough replacement airbags *just for the United States* (Niedermeyer 2014). Without sufficient supply from Takata, car makers will be unable to solve the safety problem. Takata itself faces capacity constraints as the company has to balance production of replacement inflators for cars that have been recalled with production of inflators for continuing supply of production of new automobiles. The significant surge in demand will pose equal challenges on some of Takata's suppliers. Without all companies involved being able to meet the higher demands, car companies will be unable to repair recalled cars at a sufficiently high rate and customers will remain exposed to the threat of malfunctioning inflators.

High demands on existing production capacity – often a consequence of variability induced by shortages of supply and the resulting need to catch up with demand – often come with side effects. Quality can suffer as maintenance of tools and quality control are skipped for the sake of higher throughput. Machine defects and quality problems resulting from such practice further exacerbate the capacity problem. Quality defects may be detected immediately, but they might also remain undetected for long periods of time, creating situations such as the one at Takata described above.

The preceding discussion illustrates some of the problems related to questions of stable supply. The consequences of supply interruptions can be manifold and severe. The greater the share of value outsourced, the more an organization becomes dependent on reliable supply and vulnerable to irregularities. While the paradigm of economic growth has remained largely uncontested in practice, the paradigm concerning the means to achieve growth has changed. Many organizations have become “flat” and create only a fraction of the value within their legal boundaries of what they used to, giving a larger share of value – and higher importance – to suppliers. The difference between Ford’s vertically integrated River Rouge plant and today’s operating principles at the same company could hardly be bigger (Welch & Nayak 1992). At the same time, inventory has come to be considered a liability rather than an asset, creating fertile ground for projects aiming for its reduction, thereby reducing a buffer against variability while increasing the number of factors that give rise to higher variability.

Therefore, the importance of reliable supply has become one of the central tenets of modern production companies. Production companies cannot operate reliably without reliable supply. Supply-related problems can cascade along the entire supply network. This project aims to make a contribution to organizations’ ability to better manage their inbound material stream, thereby meeting one essential requirement for successful business.

1.1.3. Academic Gap

A review of the literature in related fields creates the appearance that the research community to date has not developed a satisfying theoretical foundation for *bottleneck management in supply networks*; the bottleneck perspective appears to be under-appreciated.

Research on *Supply Chain Management* (SCM) is plentiful. In a nutshell, the majority of research endeavors may boil down to the question how to match supply and demand so as to improve the financial situation of the organizations involved in the supply network. In order to achieve this end, researchers have focused on a broad variety of topics in SCM, such as information sharing and collaboration (e.g., Barratt 2004, Holweg et al. 2005, Slone et al. 2007), selection of the right supply chain strategy (e.g., Fisher 1997, Pagh & Cooper 1998, Mason-Jones et al. 2000, Harland & Knight 2001, Lee 2002, Christopher et al. 2006), sourcing strategies (e.g., Novak & Eppinger 2001, Lonsdale 2001, Roehrich 2008), performance measures and incentives (e.g., Beamon 1999, Narayanan & Raman 2004, Shepherd & Günter 2006, Slone et al. 2007), and power in supply relationships (e.g., Cox et al. 2001, Kumar 2005, Crook & Combs 2007). Some academics, even though only few, do discuss the management of supply networks from a bottleneck perspective. Mizgier et al. (2013) discuss several centrality measures from network theory and compare their ability to identify bottlenecks in supply networks. Their analysis is entirely based on structural properties of the network. The authors introduce a tool "for the quantification of losses due to supply chain disruptions from single suppliers". It seems impossible, however, to create any roughly precise quantitative estimation of losses without looking into supply relations, contingency measures, and demand characteristics in greater detail. The vein of this article is similar to that of, e.g., Craighead et al. (2007) and Choi & Kim (2008) in that these authors use structural measures from network theory to make predictions about risk in supply networks or, more generally, about supplier performance.

Academics and practitioners alike were influenced by Goldratt's *Theory of Constraints* (ToC) for the management of bottlenecks in production systems and business processes. Several authors attempt to relate concepts and ideas from ToC to supply networks. Lockamy III & Draman (1998) claim to introduce a "constraint-based approach for effective supply chain management" which turns out, however, to be a rather superficial discussion of ToC's "*5 Step Thinking Process*", its scheduling logic and its buffer management in the context of supply networks. The authors retreat to normative claims concerning the need for more supply network members to "recognize and embrace the global perspective" (as opposed to their own local optima). That is, the authors do understand each supplier as a whole as a potential bottleneck, yet they do not follow up this idea but merely recite often-heard normative claims. Simatupang et al. (2004) focus on collaboration in supply networks and attempt to provide means to break constraints that prevent organizations from effective collaboration. The constraints the authors discuss are conceptual or "mental" rather than physical, however, and they influence companies' *collaboration* decisions rather than their material flow. Serdar-Asan (2009) uses ToC tools such as *Evaporating Cloud* diagrams and *Current* and *Future Reality Trees* to express complexity problems in supply networks. She does not, however, adopt a bottleneck perspective for the physical flow of material through the supply network. Although the analogy between the management of bottlenecks in production systems – as treated in the Theory of Constraints – and the management of bottlenecks in supply networks – the topic of this thesis – seems striking, not much more seems to have evolved out of ToC for supply networks than a literal translation of the concepts and thinking processes, which is not satisfying because of the differing contextual conditions (cf. Section 3.7).

The field of *Supply Chain Risk Management* (SCRM) is focused on risk of disruption of supply relationships. Researchers discuss topics such as types of risk in supply networks (e.g., Zsidisin 2003, Christopher & Peck 2005), development of risk management tools (e.g., Harland et al. 2003), risk factors (e.g., Peck 2005, Wagner & Bode 2006), risk assessment (e.g., Blackhurst et al. 2008), risk management processes (e.g., Hallikas et al. 2004), and quantitative risk models (e.g., Tang 2006). That is, some of the problems authors in SCRM address are closely related to some of the problems discussed in this thesis, albeit from a different perspective. Although various authors develop tools, mitigation strategies and methodologies for the management of risk in supply networks – with *management* translating into identification, avoidance, and mitigation – the common approaches found in the literature do not invoke a prioritization of bottlenecks over non-bottlenecks, nor do they even induce discrimination. Moreover, the methodologies seem to fall short of addressing more specific aspects of physical material flow and generally tend to look at supply network risk at a more abstract level.

Hence, there seems to be a research gap in the broad vein of management of supply. Most scholarly work appears not to view supply networks as systems with multiple internal as well as cross-border interdependencies. Problems of material flow are not addressed with the same rigor as can be found in Operations Management with various competing and complementary production paradigms (e.g., Lean and Agile). A bottleneck perspective on supply networks has not evolved. The gap exists despite the fact that such a perspective could provide new, valuable insights and a platform for the development of practical management approaches. The bottleneck concept supports prioritization, both of nodes and of measures, and a methodology for bottleneck management would facilitate access to and use of appropriate measures. There is a need for a structured approach that supports the stabilization of physical material flow between firms in a network so as to reduce the chance of interruptions in production processes and to maintain production and delivery schedules.

1.2. Research Aims and Objectives

This thesis is to reduce the academic gap outlined above and to improve and facilitate information access of industrial organizations.

> The general aim of this PhD dissertation is (1) to complement and enrich the knowledge on and understanding of bottlenecks in general and of bottlenecks in supply networks in particular, (2) to lay the groundwork for a theory of bottlenecks in supply networks, (3) to create structured and methodological access to the management of bottlenecks in supply networks, (4) thereby facilitating access to this field for industrial organizations.

To accomplish this aim, research questions will be defined which will guide the study. The research questions will be defined in Section 4 after a careful review of the relevant literature was completed and before the study is continued with gathering of empirical data.[1] They represent the more specific objectives of the

[1] As Gillham (2005, p. 158) puts it: "You cannot sensibly ask questions of an area of research until you know something about it". Therefore the literature review is intended to identify important concepts which can lead to more pointed research questions that will guide empirical data collection and data analysis. In many papers and theses, research questions are defined at the outset. Medawar (1964) addresses the problem between the *apparent* chronological order of the research process as suggested in many research papers and the *actual* process of scientific discovery. For this thesis, it was decided to reflect the actual research process in order and structure of the document.

study, leading towards the more general aim.

The research aim provides the basis for a tentative conceptual model of bottleneck management in supply networks. The review of literature provides the basis for chapters 2, 3, and 4. In these chapters, the theoretical underpinning for the conceptual model and for the collection and analysis of empirical data shall be created.

1.3. Philosophical Perspective

This research project is to be understood as having been conducted within a *postpositivist* research paradigm. The paradigm selected for this work has implications for the research method chosen and for the interpretation and generalizability of its results. As Guba & Lincoln (1994, p. 108) propose,

> "The basic beliefs that define inquiry paradigms can be summarized by the responses given by proponents of any given paradigm to three fundamental questions, which are interconnected in such a way that the answer given to anyone question, taken in any order, constrains how the others may be answered."

These three questions are

1. The *ontological* questions: what is the form and role of reality?
2. The *epistemological* question: how can the relationship between researcher and the researched object be described?
3. The *methodological* question: how can the researcher attain knowledge?

The ontological position of postpositivism is commonly referred to as *critical realism*. That is, postpositivists believe there is one reality (which is a defining difference to constructionists who reject this notion; Easton 2010, p. 123), yet due to fallibility and imperfection of the human mind it is not possible to fully and correctly apprehend and describe it (Guba & Lincoln 1994). Or as Sayer (1992, p. 5) describes in his characterization of critical realism:

> "The world exists independently of our knowledge of it. Our knowledge of that world is fallible and theory-laden. Concepts of truth and falsity fail to provide a coherent view of the relationship between knowledge and its object. Nevertheless knowledge is not immune to empirical check, and its effectiveness in informing and explaining successful material practice is not mere accident."

In fact, the fallibility of the human mind is Sayer's (2000, p. 2) core argument for the independence of the existence of the world and our understanding of it:

> "What reason have we for accepting this basic realist proposition of the mind-independence of the world? I would argue that it is the evident fallibility of our knowledge – the experience of getting things wrong, of having our expectations confounded, and of crashing into things – that justifies us in believing that the world exists regardless of what we happen to think about it."

One aim of the research endeavor is to accumulate knowledge so as to able to explain phenomena and to increase one's ability to make predictions about the future (Guba & Lincoln 1994, p. 113). As Easton (2010, p. 122) points out,

> "The most fundamental aim of critical realism is explanation; answers to the question 'what caused those events to happen?'" This question implies that relations of cause and effect exist in critical realism: "Objects (. . .) having structures (. . .) and necessarily possessing causal powers and liabilities (. . .) will, under specific condition c1 (. . .) result in an event e1 (. . .), or alternatively under specific condition c2 (. . .) will result in an event e2 (. . .)."

The author adds, however, that this kind of clear-cut formal description is unlikely to be applicable in the real world. Nonetheless it can serve as "a logical framework to guide case researchers". In fact, causal explanations will play an important role in this study. Questions of interest relate, for instance, to the actions organizations take in order to stabilize their inbound material stream (i.e., "what do they do so as to cause inbound material stream to be stable") and to the conditions under which they take them.

The above discussion of the ontology of postpositivism – critical realism – already hints at the answer to the epistemological question. The researcher aims to approximate knowledge of the reality, accepting that due to his flawed mind he will not be able to fully see and apprehend it. Guba & Lincoln (1994) remark that "objectivity remains a 'regulatory ideal'" (p. 110). Replication of findings can serve as evidence that the findings approximate the truth until falsified.

As to the methodological question, postpositivism pays attention to contextual information as well as to the meaning social actors ascribe to actions. That is, it appreciates the interpretivist character of statements (as made, for instance, in interviews). As Easton (2010) puts it:

> "Critical realists accept that there are differences between the empirical, the actual and the real, and that data are collected from people as well as from, and about, material things. As a result they accept that any explanations are necessarily fundamentally interpretivist in character. In particular when analysing respondent based data the researcher faces the problem of the double hermeneutic (Woodside et al. 2005) ."

Simply put, the data analysis of case study research which uses interviews as a way of collecting information combines etic and emic interpretation of the events of interest and what caused them to happen as the researcher interprets the information he received by his interviewee which themselves are *already* an interpretation of the *actual* events. This setup emphasizes the importance of measures to ensure validity.

1.4. Methodology

1.4.1. Theory Building

This dissertation aims to establish a theoretical foundation for the management of bottlenecks in supply networks.

It is worth discussing the constituents of a good theory in order to specify this aim in greater details. Furthermore, editors of renowned scientific journals have indicated that rejection rates of articles they receive is significant due to weaknesses in theory building (Whetten 1989, Sutton & Staw 1995). Theory-building is one of the two "general objectives of research" (Wacker 1998, p. 371).[2] It seems sensible then to reflect on this criticism and to adopt the crucial concepts of good theory in this thesis.

Bacharach (1989, p. 498) defines theory as a "statement of relationships between units observed or approximated in the empirical world." These statements are valid within a set of boundaries. "In more detailed terms, a theory may be viewed as a system of constructs and variables in which the constructs are related to each other by propositions and the variables are related to each other by hypotheses"[3] (cf. Fig. 1.4.1).

Sutton & Staw (1995, p. 378) propose that theory "emphasizes the nature of causal relationships, identifying what comes first as well as the timing of such events. Strong theory, in our view, delves into underlying processes so as to understand the systematic reasons for a particular occurrence or nonoccurence." Whetten (1989) suggests that a complete theory needs to be built on four constituents: *What*, *How*, *Why*, and the *boundary definitions* (*Who*, *When*, *Where*).

[2]The other general objective of research, according to Wacker (1998), is fact-finding. This description of the two-parted nature of research is in accordance with Dubin (1969, pp. 7-9): "Theorizing is an integral part of empirical investigation, just as empirical analysis has meaning only by reference to a theory from which it is generated. (...) It is only on the grounds of empirical test that the theorist-model builder may be distinguished from the theologian." He specifies the relationship between theory building and empirical research (p. 8): "Coming from theory to [empirical] research, attention is focused on truth, the nature of reality, the processes of knowing, and the logic of meaning statements. Starting from [empirical] research and moving towards theory, attention turns to such issues as measurement in all its phases, translation of propositions into operational terms, and the reliability of empirical indicators".

[3]Bacharach (1989) distinguishes propositions and hypotheses based upon their specificity: „While both propositions and hypotheses are merely statements of relationships, propositions are the more abstract and all-encompassing of the two, and therefore relate the more abstract constructs to each other. Hypotheses are the more concrete and operational statements of these broad relationships and are therefore built from specific variables." Hypotheses are derived from propositions. A construct „may be viewed as a broad mental configuration of a given phenomenon, while a variable may may be viewed as an operational configuration derived from a construct" (Bacharach 1989, p. 500). This view on the differences between propositions and hypotheses is shared by Whetten (1989).

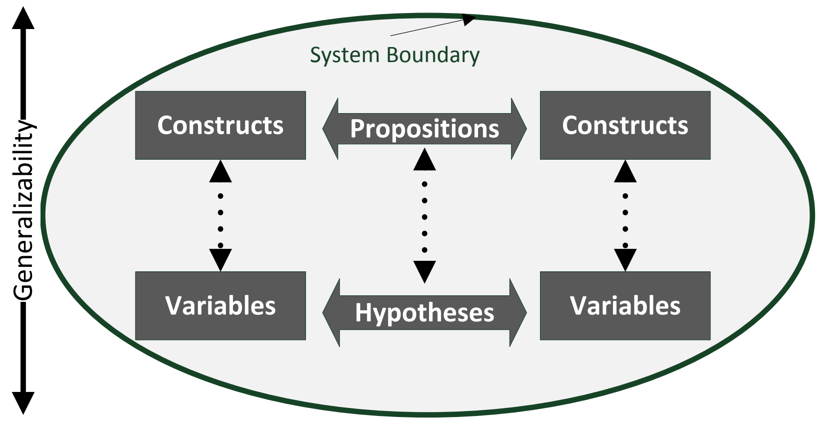

Figure 1.4.1. – Components of a theory (Bacharach 1989)

What stands for the factors that lead to the specific outcome or phenomenon the theory aims to explain. Such factors can be the units of analysis of research. More specifically, *What* is concerned with the *properties* of things of interest rather than with the the things of interest as wholes. The reason lies in the biological limitations of the researcher which lets him choose certain properties of the real life systems that he is able to observe and to comprehend. The fact that a researcher will select certain properties of real things to implement them in his model while (possibly unconsciously) ignoring other properties not only suggests that things as such are not as important for theory-building as the properties of things are, but also allows the researcher to speculate on the existence of additional properties not directly observed yet, which gives rise to creative theory-building (Dubin 1969, pp. 30 et seq.). Furthermore, the things (or "units") to whose properties we are referring with the question *What* can be elements or they can be classes of elements which share certain properties (Dubin 1969, pp. 47 et seq.). The problem here is related to the question as to which of the two general research perspectives – a reductionist view or a systems view – is to be adopted for the problem at hand. Research on Complex Adaptive Systems (CAS; cf. Section 2.5.4) suggests that a reductionist perspective can fail to explain effects that occur due to the interaction of units over time that exhibit complex behaviour. Dubin (1969) suggests that there are no laws governing or connecting the interaction between different levels of details. The research domain this project is embedded in demonstrates how one might refer to different levels of composition for the explanation of effects observed in practice. The researcher may refer to behaviour observed on the organizational level, on the departmental level, or on the personal level; he may find explanation in the particular social or cultural setting individuals inside the organization are part of. In fact, organizational theories that have been developed in order to explain the behaviour and strategy of organizations do refer to levels of detail as different as psychology of individuals members of the organization (e.g., opportunism in Transaction Cost Economics and Principal-Agent Theory) on the one hand and the unpredictable environment of the organization (as in, e.g., Transaction Cost Economics and Resource Dependence Theory) on the other hand. To be consistent in the level of aggregation or composition throughout the analyses without giving up possible insights that may be hidden in a higher level or lower level view may be one of the more difficult challenges in comprehensive research projects.

How such factors then are related is described by *How*, i.e., the factors are linked and often (albeit not necessarily) causality is invoked. Dubin (1969) refers to this as the *law of interaction*. These two elements, *What* and *How*, describe the functioning of the theory, i.e., they describe how the factors and their relationships to each other lead to a certain phenomenon. Thus, they provide the basis for propositions and hypotheses. Propositions and hypotheses do not include explanation, i.e., they are "statements about what is expected to occur, not why it is expected to occur" (Sutton & Staw 1995, p. 377). The accuracy of a proposition has to be ensured independent of its empirical truth; "[t]he sole test of the accuracy of a proposition is whether or not it follows logically from the model to which it applies" (Dubin 1969, p. 171). Hypotheses "mirror the proposition of the model" (ibid., p. 212) in that they employ empirical indicators to express in numbers what the proposition states qualitatively. For instance, a proposition may predict "friendliness", "high participation", "strong identification" of a group of people under specific conditions; a hypothesis would then utilize the appropriate empirical indicators to allow measurement and thus empirical validation of the proposition. By employing a different indicator for the same variable of interest a different hypothesis will be derived from the same proposition (Dubin 1969, pp. 211 et seq.).

Most emphasis, however, is put on *Why*. While *What* and *How* describe the factors and the relationships among them, *Why* provides the explanation, i.e., *Why* addresses the inherent assumptions the theorist makes about the causal logic that lies within the relationships between the factors. If *Why* is overlooked and the theorists focuses on *What* and *How* only, then the supposed theory lacks the potential to make predictions about the future; if predictions about the future are derived from past empirical data, disregarding the logic that has led to a particular phenomenon in the past, i.e., without making explicit the inherent assumptions about causal relationships, then we are dealing with "brute empiricism" (Sutton & Staw 1995). The importance of the *Why* is underlined by Sutton & Staw (1995, pp. 375-376): "The key issue is why a particular set of variables are expected to be strong predictors."[4]

Clearly defined *boundary conditions* (*Who*, *When*, *Where*) "constitute the range of the theory" (Whetten 1989, p. 492) and are "[o]ne indication that

[4] It should be mentioned that the elements *What*, *How*, *Why*, and the boundary conditions which together constitute a theory, are treated differently by other researchers. In the context of social science, Dubin (1969, pp. 9 et seq.), for instance, maintains that there are two distinctive objectives of research which are "not often achieved together": understanding of interaction (which refers to "Why") and prediction of outcomes (which refers to "What" and "How"). In contrast to (Sutton & Staw 1995), Dubin (1969) claims that the notion that "if we are to make accurate predictions about social phenomena, we have to know the processes built into these phenomena and the characteristics of all possible outcomes toward which the processes move" is a "pious value position that bears little relation to the practice of social scientists" (pp. 9-10). Possibly, then, the constituting elements of a theory as proposed by (Sutton & Staw 1995) with (full) knowledge about the relationships between the factors of a model could be conceived of as an ideal situation that, in practice, is difficult to achieve. As with the definition of a system (cf. Section 2.5.4), a model should include those elements which are considered important for the understanding of reality and/or the creation of predictions. "Important" means the elements are useful (cf. Mintzberg (1979) as quoted on page 17) and are able to explain and determine the effect of interest to the largest extent. The creation of a model apparently cannot require full knowledge of all elements of a real world system and the relationships among them as otherwise there would be no necessity to examine it further. Hence, for this thesis work Dubin's (1969) contention is interpreted as a practical suggestion that it will not be worthwhile seeking full understanding of the system of interest in the early iterations of the theory-building process and instrad utilize empirical data gathered throughout this process to improve the model and develop it into a theory in the course of the project.

strong theory has been proposed" (Sutton & Staw 1995, p. 376). Stating the boundaries of a theory provides information about its generalizability. By relaxing the conditions (or reducing the criteria) that determine the boundary, the boundary will expand and the model will gain greater generality (Dubin 1969, pp. 141 et seq.). By the same token, several models with narrow boundaries can lead to one more general model. Dubin (1969, p. 142) provides an example of models of different types of relationships, such as mother-child relationship, doctor-patient relationship, teacher-student relationship, etc. Through identification and separation of *isomorphic* boundary-determining conditions of these different individual models it is possible to create one more general model of two-person relationships.

Also, testing the theory under different conditions – even when the testing is limited to thought experiments – can provide useful information that can be fed back to evaluate the *What*, *How*, and *Why* (Whetten 1989, p. 493). In addition to explicitly stated boundaries the theory might also be bounded by the researcher's implicit values (Bacharach 1989, p. 498).

The question of generalizability – or more generally: scope – is closely intertwined with the research method that leads to the theory's development. In deductive reasoning, the conclusion will always be true if the premisses of the inference are true; the premisses entail the conclusion. In contrast, in inductive reasoning, the premisses of the inference do not entail the conclusion, i.e., even if the premisses are true, the conclusion might still be false (Okasha 2002). In fact, inductive reasoning often means generalization from a limited set of observed units to the entire population of units of this kind. Wacker (1998) states that research (or science) is called formal or analytical when it is conducted according to deductive rules whereas it is called empirical when inductive methods are used.[5]

Mintzberg (1979, p. 584) maintains that deduction "is the less interesting, less challenging part" of science. Countering Popper (1968), he suggests that useful research often requires generalization. Generalization, however, may come on

[5] Wacker (1998) credits Sax (1968) for this statement. Unfortunately, he does not provide bibliographic data for this reference.

the expense of accuracy and it might be necessary to trade-off one for the other (Weick 1979, 1995). Such "[c]ontradictory demands for both strong theory and precise measurement" pose a major problem for researchers who submit their papers for publication in certain journals (Sutton & Staw 1995, p. 381). Emphasis on validation and internal consistency lead researchers to narrow the scope of their theories, sometimes rendering theories trivial (Weick 1989, van de Ven 1989).

Mintzberg (1979, p. 584) continues:

> "The fact is that there would be no interesting hypothesis to test if no one ever generalized beyond his or her data. Every theory requires that creative leap, however small, that breaking away from the expected to describe something new. There is no one-to-one correspondence between data and theory. The data do not generate the theory – only researchers do that – any more than the theory can be proved true in terms of the data. All theories are false, because all abstract from data and simplify the world they purport to describe. Our choice, then, is not between true and false theories so much as between more and less useful theories. And usefulness, to repeat, stems from detective work well done, followed by creative leaps in relevant directions."

Runkel & Runkel (1984) note that many authors in the social sciences in the titles of their publications modestly try to avoid the impression they aim to constitute a *theory* and thus understate their case. Because the term *theory* suggests uncertainty about its own validity by its very definition as well as by the way it is generally used, Runkel & Runkel (1984) encourage authors to "use theory whenever they are theorizing" (p. 129). Similarly, Weick (1995, p. 386) suggests that scientists should not confine themselves to the dichotomy of "theory" versus "not theory" but instead understand theory as a continuum.

Gillham (2005, p. 159) notes:

> Writing a research report is an act of reconstruction and of intellectual discovery. What can be left to be discovered? After all, you

> are familiar with all the elements, have checked and inspected them perhaps dozens of times.
>
> But in social research, particularly that of a qualitative character, the real discoveries are not of startling new facts (there aren't many of those) but *conceptual*: seeing familiar aspects of our social world differently, making sense of it in an original way" (emphasis in original).

Though Gillham (2005) refers to social research, the point he makes may apply to other branches of reseach, too. This dissertation revolves around areas of research which have received significant researcher attention for more than two decades and which thus are well-explored. The original element of this dissertation lies in the combination of such research areas (e.g., of Supply Chain Management, complexity science, network theory, and bottlenecks) and in the transfer of concepts from other research areas (e.g., from research on bottlenecks in factories to bottleneck management in supply networks). What is hoped to be discovered are valuable new insights into the problems of supply network management. More specifically, it is hoped that the creation of the foundation of a "formal" disciplin of bottleneck management that provides a new perspective on supply network management as well as a frame of reference for methods to manage bottlenecks will be achieved. That is, rather than *testing* theory this dissertation aims to *create* theory inductively.

1.4.2. Research Design

Yin (2009, p. 26) defines the research design as follows:

> "In the most elementary sense, the design is the logical sequence that connects the empirical data to a study's initial research questions and, ultimately, to its conclusions."

He emphasizes five components of the research design (ibid, pp. 27 et seq.):

1. "a study's questions;
2. its propositions, if any;

3. its unit(s) of analysis;

4. the logic linking the data to the propositions;

5. the criteria for interpreting the findings."

This study's questions will be defined later in this thesis (Section 4.7) after a review of the relevant literature will have been conducted. At this point, the general aims and objectives of the project have already been defined (cf. Section 1.2).

In Section 1.3, it was explained that critical realism aims to improve the ability to explain phenomena and it was said that explanation is indeed one of the goals of this study. Another defining characteristics of this project, however, is its exploratory nature. While the subject of this thesis is at the interface of several, generally well-researched, fields, it is centered on more specific under-researched aspects of these fields. A good share of the effort of the empirical data collection is dedicated towards the identification and exploration of actual organizational practices. There is no such formalized discipline as bottleneck management in supply networks yet, so that to a good extent the "topic is the subject of 'exploration'" (Yin 2009, p. 28).

That is, this study does not aim to refute or verify propositions or hypotheses. Instead, it tries to accrete the knowledge around the management of inbound material streams and of bottlenecks that affect such streams. It aims to explore existing practices, the reasoning behind and the limits to such practices, and it attempts to explain what it could explore.

The *unit of analysis* of the multiple-case study are the interviewed companies' strategies, measures, and limitations in the management of inbound material flow as well as the causes of bottleneck emergence. As indicated in Section 1.4.1, this element of theory is typically addressed with "*What* questions" (cf. Section 4.7 for the research questions). The companies in the study are referred to as *case companies*. There are many more aspects of the case companies that could be studied to create a more detailed account of the factors of the events and actions of interest, yet the boundaries have to be narrowed so as to be able to focus on a manageable amount of data within the given constraints of this project.

The “logic linking the data to the propositions” refers to the “analytic strategy” which Yin (2009) calls “one of the least developed and most difficult aspects of doing case studies” (p. 127). In order to be able to devise such a strategy, however, one would need to have a fairly precise expectation of how the actual data collected at the case companies will look like. Although semi-structured interviews were chosen early in the research process as primary mode of data collection, it remained unclear of what format the data would be until the interviews were conducted. It was unclear, for example, whether interviewees would allow audio recording of the interviews and possibly provide additional material such as archival records or data base extracts. Recorded interviews would allow subsequent transcription and coding – sparse handwritten notes would not or not to the same extent. The analytic strategy to be chosen thus remained undefined at the outset of the project. First attempts to make sense of the data collected were made early during the process of data collection. At that point, it became clear that transcription and coding with key words would likely yield the best results so that this method was chosen. The key words emerged from the review of literature which resulted in the conceptual model (cf. Chapter 4). The conceptual model provided the underlying structure and logic of the interview questionnaire which greatly facilitated the analysis and interpretation of data as it also provided the structure for the development of case descriptions for each individual case company and later enabled comparison across the case companies. Cross-case synthesis was chosen as an approach in Phase III of the data analysis. More information about the case analysis is provided in Chapter 5.

The fifth element Yin (2009) proposes should be part of the research design is a definition of the criteria for the interpretation of the case study data. As two examples he mentions statistical analysis and discussing rival explanations. Statistical analysis will not be conducted in this thesis as valuable information needed to address the research aims and objectives are likely to be qualitative in nature and context-sensitive. As to rival explanations, the partly exploratory nature of this project prevents the definition of rival explanations as it prevents the definition of propositions at the outset of the project. Rival explanations for the phenomena observed can therefore only be developed once the data analysis has been advanced. The existence of rival explanations is addressed in Section 6.5.3.

Edmondson & McManus (2007, p. 1156) provide a simpler account of the research design. They define four elements:

1. "Type of data to be collected
2. Data collection tools and procedures
3. Type of analysis planned
4. Finding/selection of sites for collecting data"

The authors discuss the methodological fit of the elements of research (e.g., research question, research design, goals of data analyses) and the maturity of the research field. As to the maturity of the research field, they distinguish between *nascent*, *intermediate*, and *mature* states of the field. Depending of the maturity, the research requires different approaches.

As previously indicated, the subject of interest is an under-researched aspect at the interface of several research fields. In other words, the research problem investigated in this project can be described as nascent or at most as being located at the boundary between nascent and intermediate. The research design needs to be defined accordingly. It was decided to treat the problem as nascent.

The type of data to be collected for a nascent research problem is mostly qualitative in nature. It is not clear from the beginning what information needs to be included in the study. Interviews represent an adequate tool for data collection for this type of problem. The fit between type of data and maturity of the research problem is depicted in Figure 1.4.2.

As to the data analysis, Edmondson & McManus (2007) suggest "thematic content analysis coding for evidence of constructs" for nascent problems. This advice was followed in the data analysis.

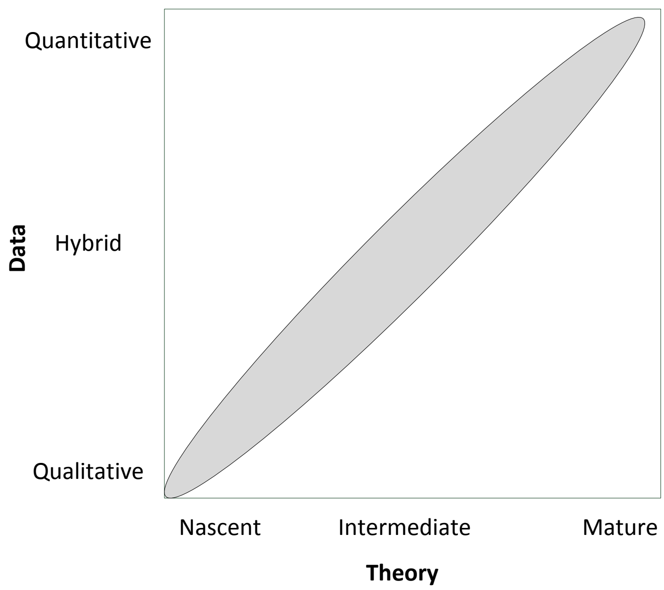

Figure 1.4.2. – Fit Between Type of Data and Maturity of Research Problem (Edmondson & McManus 2007, p. 1168)

As to the selection of sites for collecting data, it was tried to get access to case companies from different industries and of different size. Furthermore, the companies had to have a supply network necessary for their primary value-creation processes (i.e., they have to receive goods to use them as input to their production processes or to provide a service). The selection of case companies is described in greater detail in Section 5.4.

Summarizing, at the outset of the research project the research design could not be completely described based on the criteria proposed by Yin (2009) but it could be – and had been – defined based on the criteria proposed by Edmondson & McManus (2007).

1.4.3. Research Approach

As pointed out in Section 1.4.1, the central purpose of this thesis is to develop theory. In Section 1.1, it was argued that a research gap exists. This study aims to reduce or close the gap by providing complementary theory and thereby enhance the existing body of knowledge.

A multiple-case study has been chosen as the method to create the empirical data base from which theory will be developed inductively. According to Yin (2009) , the case study method is an appropriate mode of research if focus is set on the questions *How* and *Why* something occur or is as it is (cf. Section 1.4.1). The case study method thus represents a useful tool for building theory and appears to be an adequate tool within the realm of critical realism. The research process follows what Sayer (2000) calls an *intensive* research process which is "primarily concerned with what makes things happen in specific cases" (p. 20).

The case study method is employed to collect *qualitative* data. *Semi-structured interviews* are used as the primary data collection mode. The interviewer takes the role of the "disinterested scientist" (Guba & Lincoln 1994, p. 112) and neither provides advice nor actively participates in the business of the case companies. Semi-structured interviews are intuitively appealing a data collection mode in this project as they allow both to uncover new aspects in the research domain and to learn, for instance, about the reasoning behind the selection of certain measures for bottleneck management or more generally to follow up the themes identified in the first (theory) part of this thesis. That is, semi-structured interviews support both the exploratory and the explanatory aspects of this research. Structured interviews would limit the data collection for they do not support the exploratory component while unstructured interviews would do just this but are likely to render any structured cross-case analysis difficult. The exploratory element of the case study research will be judged successful if it can support the creation of a theory upon which organizations can build in order to stabilize inbound material flow in their supply network.

1.4.4. Structure of the Thesis

This thesis is structured as follows.

Chapter 1 – the present chapter – contains an introduction to the research topic, a statement of the research problem, and information about research philosophy, design, and approach.

Chapter 2 presents a review of relevant literature. The review taps relevant streams of literature adjacent to this topic. The introduction to this chapter includes explanations as to the selection of topics reviewed. The first topic (shortly) discussed is manufacturing systems. It was tried to extract relevant information that may have implications for the existence and the management of bottlenecks.

Bottlenecks are then discussed in greater detail in Section 2.3. A review of existing definitions of bottlenecks is followed by the proposal of a new and arguably better definition. It was then tried to classify types of bottlenecks and states of bottlenecks before the section ends with a discussion of the impact caused by bottlenecks.

Next, the topic of complexity is investigated in Section 2.4. Different authors have related complexity to the field of Supply Chain Management (SCM) and both the academic discourse as well as industrial practice suggest that the existene of complexity does have implications for the management of supply networks. The wider discussion of complexity leads to an introduction to systems theory and systems thinking.

The last part of Chapter 2 dives into a more general theory of networks and finally into supply networks. Definition and conceptualization of networks are discussed. Moreover, the popular field of Supply Chain Management is reviewed with respect to the validity of some of its claims and, maybe more importantly, with respect to the validity of its two most prominent underlying conceptions: supply chains and management. Some aspects of networks, such as power and dependency, are discussed before the section closes with a discussion of the classification of supply networks.

Chapter 3 continues with the review of literature on more specific concepts that are thematically related to bottleneck management or have the potential to provide useful concepts for the development of a theory of bottleneck management in supply networks. Some of the topics discussed are traditionally unrelated to supply networks but are focused on manufacturing and material flow within one factory. Some are part of the SCM canon or related to it. The chapter closes with a comparison of two types of material flow systems: the traditional factory and the supply networks.

Chapter 4 summarizes some points of the extensive review of literature and derives a conceptual model. Categories of bottleneck management activities are defined as well as categories of causes for bottleneck emergence. The chapter closes with a tentative conceptual model and with the research questions.

Chapter 5 introduces the multiple-case study as the method for collection of empirical data. It lays out the selection criteria for the case companies and explains the structure of the interview questionnaire.

Chapter 6 contains the findings of the empirical data collection. The findings are presented and discussed in three phases. Phase I includes case descriptions for each company. The case data is structured along the categories that was developed in the conceptual model and based on which the interview questionnaire was built. Phase II presents the cross-case comparison along the same categories. These first two phases of the data analysis are descriptive and exploratory in character. Phase III relates the case data to some important concepts identified in the literature review and attempts to provide explanations as to why the case companies do what has been found they do. This phase of the data analysis is explanatory in character.

Chapter 7 draws together the findings of the data analysis in Chapter 6 so as to provide an overview of all the important elements for a basic theory of bottleneck management in supply networks.

Chapter 8 concludes this research project.

Figure 1.4.3 illustrates structure and flow of the thesis.

1.5. Summary

The first chapter introduced the reader to the general problem of bottlenecks in supply networks and stated the research need. General aims for this project were defined and the selection of the philosophical research perspective was explained. Finally, research methodology and structure of the thesis were outlined. The purpose of this chapter is to provide transparency as to the approach and reasoning this researcher has followed.

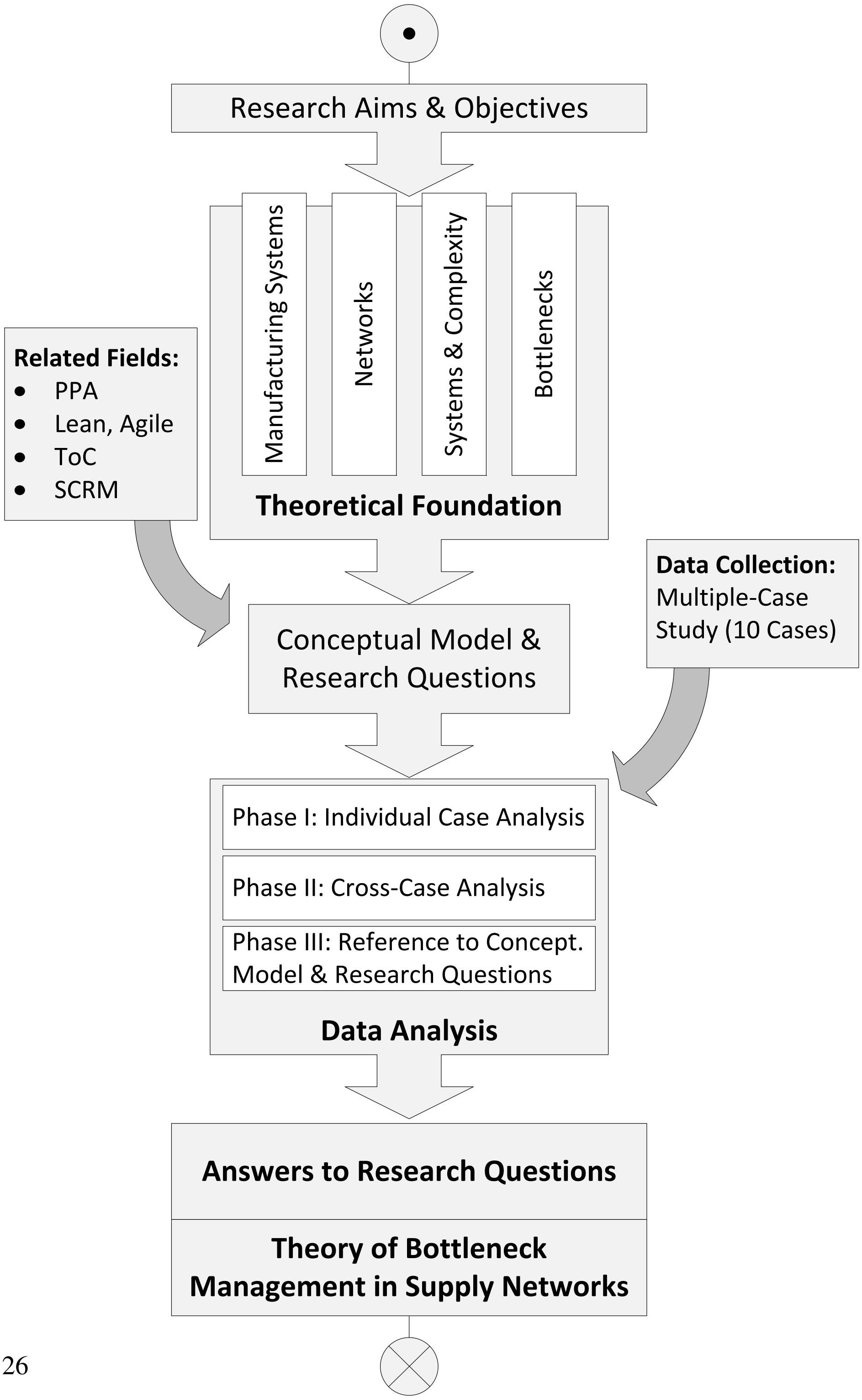

Figure 1.4.3. – Structure of the Thesis

2. Theoretical Foundation

2.1. Introduction

This is the first of two sections in this thesis where literature on various topics is reviewed. This section covers fundamental research topics whereas the second part of the literature review in Section 3 will cover more particular concepts that evolved out of industrial practice. The choice of topics selected for the review and the way the topics are presented may call for explanation.

Among all research fields in the broad vein of Operations Management (OM), it is probably in the field of *manufacturing* planning that the bottleneck concept has received most attention. The popularity of the concept in that particular field can be attributed to the Theory of Constraints which, in spite of attempts to "promote" it as a general approach for anything from marketing to project management , has been most influential in manufacturing. Manufacturing systems can be quite diverse, and so are the requirements on raw material supply to feed these systems. The short review of manufacturing systems thus serves these to identify important characteristics of and differences between manufacturing systems and to better understand the interface of manufacturing and supply. The review of manufacturing systems be conducted in Section 2.2.

The *bottleneck* concept itself requires a thorough review. Since it represents the backbone of this project, its conceptual clarification is a necessity. The metaphorical term bottleneck has been used in a wide variety of circumstances and arguably so without paying much attention to the value the concept could provide quite apart of its use as a synonym for drag force or a scarce resource. An in-depth investigation into the bottleneck concept shall be conducted in Section 2.3. For a clear understanding of the term and how it relates to the other theoretical subjects discussed the reader is referred to page 38 where a definition is provided before he proceeds.

Complexity is a term the researcher will almost definitely encounter when reading contemporary publications on anything related to the management of supply. Complex seems to be a characteristic often associated with supply networks and their management, probably not least due to growth of global trade and global production networks after the end of Cold War. The dimensions of such networks and the activities related to their functioning are difficult to grasp for laymen, and so the term complexity is slapped on them, as seemingly on anything that is complicated and thus difficult to understand (cf. Section 2.4.2). Its vagueness in everyday use notwithstanding, complexity as a fundamental concept has attracted many smart minds, and it seems worthwhile investigating in what these have to say about the concept and its possible implications on the management of supply networks. This will be done in Section 2.4.

Organizational networks provide the setting for the topic of interest. Supply networks are one type of organizational networks which bear many more interesting concepts than is apparent from their simplified treatment in the field of Supply Chain Management. Some elementary theory of networks shall be discussed before supply networks are introduced as one particular of networks. More specific aspect of networks shall be included, too, so as to enrich the theoretical base from which to draw. Organizational networks shall be discussed in Section 2.5.

The above short discussion explains the choice of topics selected for the literature review. As might have become apparent from the discussion, the selection seems almost natural. It will be noted that the topic of interest, bottleneck management in supply networks, is located at the interface of the research fields described above. Some of these research fields are partly overlapping or complementary whereas others exist mostly independently of each other. The selection of topics for the review was guided by the presumption that a synoptic investigation in adjacent yet independent fields of research is likely to yield a workable knowledge base for theorizing. Reframed as a question, it would have been asked what research fields were likely to provide insights in the topic of bottleneck management in supply networks, either by providing analogies, tools, ways of thinking, or practical application in industrial settings.

It remains unclear at this stage of the project to what extent a theory of bottleneck management in supply networks can benefit from each of the topics selected for the review, yet one can be hopeful that fruitful ideas can be identified eventually.

2.2. Manufacturing Systems

2.2.1. Introduction

Although this dissertation deals with bottlenecks in supply networks, it seems necessary to discuss some aspects of factory-internal manufacturing systems. The reason being that ultimately the supply network's role is to support the focal firm's manufacturing process. Characteristics of the internal material flow system thus arguably at least partly determine characteristics of the supply network. Furthermore, a discussion and classification of manufacturing systems will support field research as the characteristics of manufacturing systems will be used for the selection of case study firms and for the analysis of field data. Arguably, the emergence of bottlenecks in supply does not have the same impact on each type of manufacturing firm in each type of supply network. The wide spectrum of different manufacturing environments requires that for this dissertation an environment had to be selected to focus on; including all types of manufacturing environments seems infeasible. Nevertheless, when characteristics and implications are clearly defined, the discussion of one type of manufacturing system and supply network can inform management of other types. Thus, a thorough discussion of characteristics of manufacturing systems and supply networks will support the generalization of findings (McCarthy 1995).

2.2.2. Classification Criteria of Manufacturing Systems

There is a variety of criteria that have been used to distinguish and classify manufacturing systems. According to Carper & Snizek (1980), there are "virtually

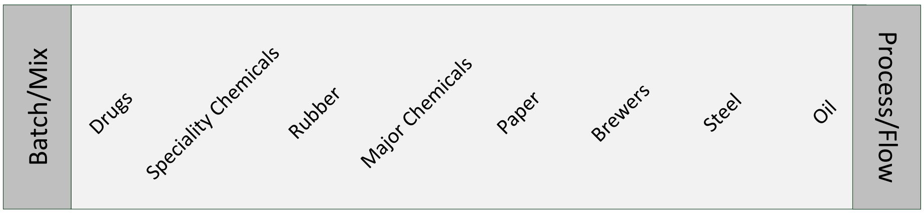

Figure 2.2.1. – Typology of Process Industries (Fransoo & Rutten 1994, p. 52)

as many different ways to classify organizations as there are people who want to classify them" (p. 70).

An early attempt to classify production systems was made by Woodward (1965). She identified three types of production systems and related each to one type of management structure (in terms of centralization and level fo bureaucracy). Her three types of production systems are

- small batch and unit production
- large batch and mass production
- Continuous process production.

The work by Woodward (1965) is frequently cited and has been updated by other scholars (e.g., Hull & Collins 1987).

Fransoo & Rutten (1994) elaborate on the differences within the *process industry*. They establish the two extreme poles *process/flow* production and *batch/mix production* between which there is a continuum of differences (cf. Figure 2.2.1). The authors thereby simplify some earlier typologies of production processes in which two dimensions – production process (ranging from "job shop" to "flow shop") and customization of the product (ranging from "custom" to "commodity") – are defined to only one dimension. Fransoo & Rutten (1994) justify this simplification by pointing out the strong correlation of the two axes (customized products tend to be produced in job shops whereas commodities tend to be produced in flow shops) with the values lieing on a curve with a slope of 45° (similar to Figure 2.2.3).

They describe seven predominant criteria along which the differences can be established. The criteria are

- throughput time (process/flow: low; batch/mix high),
- determination of capacity, routing options for products, and volume flexibility (process/flow: clear determination of capacity/one routing for all products, no volume flexibility; batch/mix: difficult determination of capacity, complex routing options, many configurations),
- product complexity (process/flow: low; batch/mix: higher),
- added value (process/flow: low; batch/mix: high),
- impact of changeover times (process/flow: high; batch/mix: low),
- number of production steps (process/flow: low; batch/mix: high), and
- number of products (process/flow: small; batch/mix: large).

Generally, process/flow production tends to require large and expensive production assets since large quantities of output are demanded, as the authors maintain, whereas lower output demanded suggests batch/mix production.

Another important point Fransoo & Rutten (1994) raise concerns the number of different inputs and outputs in process industries and in discrete manufacturing industries. They propose that in discrete manufacturing, the number of inputs tends to be high, whereas the number of outputs tends to be low. That is, several components make up one product at the end of the production process. In process industries, this ratio is reversed: the number of inputs is low whereas the number of different outputs is high. When products experience greater differentiation, then the number of different outputs increase in either case. The concept is illustrated in Figure 2.2.2.

A well-established classification was introduced by Hayes & Wheelwright (1979). They use the two criteria *process structure* and *product structure* to classify manufacturing systems (cf. Figure 2.2.3). Their underlying assumption is that a mismatch between product structure and process structure is likely to

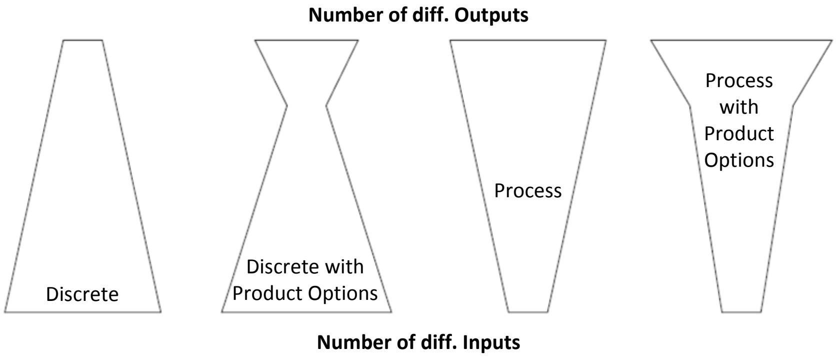

Figure 2.2.2. – Input to Output Ratio in Discrete Manufacturing and in Process Industries (Fransoo & Rutten 1994, p. 49)

cause inefficiencies. A position on the diagonal represents the "natural" choice (Hayes & Wheelwright 1979) for most manufacturing companies, and a position significantly above or below the diagonal may lead to unintended distortions, especially when chosen unconsciously.

The different characteristics of the two criteria reflect stages of product and process life cycle. Production starts off in a flexible way – Hayes & Wheelwright (1979) refer to this process stage as "fluid" – and develops into a standardized and automated stage as the product matures and volumes increase. Each stage of the life cycle is linked to different management foci. As product and process maturity increase, more attention is given to process efficiency while flexibility tends to decline. In that respect, companies closer to the lower right-hand corner of the diagram arguably are more sensitive to interruptions in supply. Increased awareness and the existence of strategies to prevent, as well as contingency plans to resolve, supply shortages thus are likely to be more important than for companies that are located closer to the upper left-hand corner.

McCarthy (1995, p. 45) suggests classifying production according to different types of complexity[1]:

- "Product complexity: An indicator of the degree of manufacturing difficulty associated with the product (number of parts, number of connec-

[1] Cf. Section 2.4 on page 48 for a more detailed discussion of complexity.

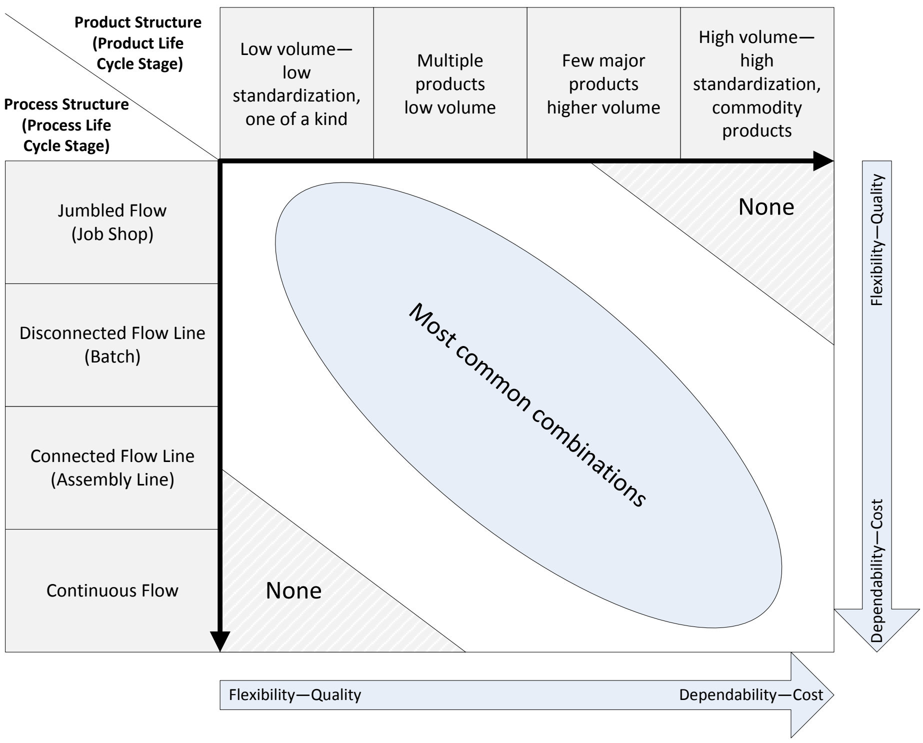

Figure 2.2.3. – Product-Process Matrix according to Hayes & Wheelwright (1979)

tions, product variety and volumes, etc.). A primary influence on structural and dynamic complexity.

- Open Complexity: The complexity of the environment that the manufacturing system must interact with (customers, suppliers, legislation, etc.). Also, a primary influence on structural and dynamic complexity.

- Structural Complexity: An internal complexity relating to the static/structural aspect of the manufacturing system. It is associated with hierarchy, size, flow structures, etc.

- Dynamic Complexity: Related to structural complexity, but deals with the activity and time aspects (operational) of the manufacturing system. Describes the interaction between resources (material, machines, labour)."

The description of these four types of complexity suggests that the first two types are independent variables of complexity whereas the latter two types are dependent variables as they are determined by the first two types. Indeed, product characteristics determine the number and type of operations that need to be applied in order to create the desired output. Product complexity, as described by McCarthy (1995) in terms of number of parts, connections, product variety, volumes, and other characteristics, determine (not fully, but to considerable extent) what organizational resources are needed and how they should be organized. Additionally, the environment poses certain requirements on the organization. Besides customers, suppliers, and legislation, competitors are a major stakeholder that may have influence on how the firm will organize itself. Likewise, dynamics of the production process depend on the type of product and its (complexity) characteristics as well as on the environment, e.g., customer demand and industry standards.

Melcher et al. (2002) classify production systems in a 5x5 matrix along the two dimensions

- "level of technology of production systems" as a technological variable and

- "workflow interdependence" as an organizational variable.

The result are 25 theoretical variations between the two extreme poles "low-tech job shop (residential construction)" and "CIMS[2]-dedicated focused automated factory (Saturn Auto Plant)".

2.2.3. Implications for Bottleneck Criticality

The variable Hayes & Wheelwright (1979) use to describe the maturing of processes – a continuum between flexibility and efficiency – is a rather common way to characterize processes. In their development of a taxonomy of supply networks, Harland et al. (2001) use a similar variable to describe supply networks between the two poles *dynamic* and *routinized* with the former tending "to compete primarily on innovation rather than cost" (p. 24) and the latter focusing on cost-efficient and reliable processes. The implications for bottleneck management are similar for manufacturing systems and supply networks: when efficiency is a primary success factor, then the emergence of material flow bottlenecks arguably has higher criticality than in flexible systems where asset utilization tends to be lower and also of lower importance.

Many products include components that come from firms which can be categorized as belonging to the process industries. Fransoo & Rutten (1994) suggest that in case of batch/mix production in process industries the identification of quality problems in production generally require that the entire production batch is scrapped whereas in discrete manufacturing processes the defective components often can be singled out. This implies that in process industries quality problems by tendency will lead to more capacity wasted for rework than in manufacturing of discrete parts. Hence, if production already runs at capacity, more delay is likely to be induced in process industries as compared to discrete manufacturing.

[2]CIMS stands for "Computer Integrated Manufacturing System" (Melcher et al. 2002)

2.3. Bottlenecks

2.3.1. Introduction

The following sections introduce the concept of bottlenecks. It is central to this thesis as several arguments will be build upon it.

This chapter begins with an introduction of the bottleneck metaphor and the definition of the term. In order to define the term (or maybe better: in order to avoid creating a new definition) a broad set of literature was reviewed that uses the bottleneck concept. It was found that many authors neglect to provide a definition, which is unfortunate since those authors who do provide a definition in many cases seem to be divided over an exact definition so that a lack of conceptual clarity results. Hence, a new definition was provided.

The text continues with a classification of different types of bottlenecks. There seems to be no comparably comprehensive classification in the current literature. It is hoped that the classification adds to clarity and understanding of the concept. For the most part, the empirical analysis later in this thesis does not explicitly draw on the classification, however, although several elements of the classification were implicitly incorporated. Examples are "location" and "origin" of bottlenecks, the first being a primary differentiator between bottlenecks that fall within the responsibility of supply management and those which do not, and the latter being incorporated into the definition of bottlenecks as well as into the categorization of causes of bottleneck emergence. The "Locus of Control" turns out be an important distinction as several bottlenecks the case companies have encountered are indeed outside their organizational reach and control. "Exploitation options" have influenced the conception of the bottleneck management activities that are introduced later.

The chapter ends with a short discussion of bottleneck states. The discussion is to add further clarity to the bottleneck concept. Again, these states were not explicitly used in the later analysis of company data. Nonetheless, this classification of bottleneck states can be related to the discussion of causes for bottleneck emergence and it can be used to "prime" bottleneck analysis in practice so as to select the most appropriate measures.

Overall, this chapter, while not extensive, represents an important part of the theoretical underpinning of this work. It will provide the reader with several important concepts required to understand and fully embrace the remainder of this thesis.

2.3.2. What are Bottlenecks?

The term bottleneck is frequently used both in everyday language and in science. Apparently, the bottleneck metaphor is perceived as useful circumscription for something (or someone) which (who) is responsible for a lower than possible outcome. Accordingly, Merriam-Webster Online Dictionary provides three definitions of bottleneck that fit to the given context: "*1 a*: a narrow route. *b*: a point of traffic congestion. *2 a*: someone or something that retards or halts free movement and progress" (Merriam Webster Online Dictionary 2013*a*). Whereas the first two definitions (1 a and b) are oriented towards traffic problems, the third definition is more general.

Bottlenecks are an important topic in a variety of scientific disciplines. Examples are disciplines as diverse as *traffic planning*, *computer network bandwith allocation*, *population bottlenecks and reduction in gene pool variation*, and *production planning and control*. One might assume that given the ubiquitous nature of the bottleneck theme a good understanding of what bottlenecks are (i.e., a common definition) has evolved. Surprisingly, though, a recurrent statement in the literature – at least in the discpline of production planning and control – is that a common definition of bottlenecks does *not* exist. Therefore, a review of literature on bottlenecks with respect to the definitions used – or more specifically: the definitions explicitly stated – seems necessary. A summary table containing multiple publications with and without proposed definitions of bottlenecks can be found in Appendix A.

Reviewing literature on bottleneck management and related fields, it seems that there is actually no strong disagreement on common elements of a definition. Rather than disagreeing on one definition of bottlenecks, it seems that many authors confuse the definition of bottlenecks with the methods to detect bottlenecks (e.g., Lawrence & Buss 1995, Wang et al. 2005, Jain et al. 2000).

Frequently one can find within the same publication statements such as "A bottleneck is (defined as) a machine that impedes system throughput", "There is no consensus as to how exactly a bottleneck can be defined", and "Bottleneck definitions can be based upon machine utilization and system throughput sensitivity", or similar, partially contradicting, combinations of statements. Lawrence & Buss (1995), for instance, based on a short survey of definitions found in the literature, propose "three principal definitions of bottleneck resources" (p. 342): short-term definition, inventory definition, and production definition. The "inventory definition" aims at the identification of bottlenecks based upon the queue waiting in front of a station whereas "short-term definition" and "production definition" are essentially the same and aim at high utilization as characteristic of a bottleneck. From the definitions it can be seen that the authors confuse what a bottleneck is with how it can be identified. According to Merriam-Webster Online Dictionary, a definition is "a statement expressing the essential nature of something" (Merriam Webster Online Dictionary 2013*b*). If the various bottleneck detection methods as hinted at by pointing out high utilization, long queue length, long waiting time etc. lead to different results while the actual bottleneck may possibly remain undiscovered, then such descriptions of possible bottleneck characteristic do not seem to be adequate definitions. Since it turns out not to be feasible to find one acceptable definition of bottlenecks on this level of details, the level of details incorporated into the definition may need to be reduced. The following definition is proposed:

Definition 1. The bottleneck of a system is the element (node or edge) that limits the system in attaining higher throughput beyond a certain threshold. This threshold is determined by the bottleneck's physical throughput capacity, organizational rules, or operational practices.

This definition avoids the use of any additional term of ambiguous meaning that would require immediate definition.[3] It is more general than, for instance,

[3] There has been extensive discussion about the term *system* for many years, yet a rather clear understanding of what constitutes a system has evolved. While details remain to be worth discussing, the common understanding of what a system is is reasonably precise and usable for scientific work.

the definition by Goldratt & Cox (2004) in that it does not limit the existence of bottlenecks to question of physical capacity.[4] In fact, the definition includes an anticipation of one parameter of the classification of bottlenecks that is going to be introduced in Section 2.3.3. The definition states that the threshold beyond which the bottleneck becomes *binding* is determined either by physical capacity, organizational rules, or operational practices. Put in manufacturing terms, this is to express that the constraining factor in attaining higher production throughput is not necessarily represented by a maching station's (or a worker's) physical limits; instead, the root cause of the system's inability to generate higher throughput might be found in the way the work at the bottleneck station is organized, in the way overall production is scheduled (e.g., work order releases or batch configuration), in the way breaks are scheduled, etc. The important implication for bottleneck management is that higher system throughput often does not necessarily require higher physical production capacity (Goldratt & Cox 2004).

Also, it is important to note that this definition of bottleneck does *not* equate the existence of a bottleneck with the existence with any type of mismatch between demand and supply of material, just like the existence of a weakest link in a chain does not imply the chain is going to crack. Yet, *if* it cracks, it will be the weakest link that cracks first; by the same token, *if* a material flow system experiences a mismatch between demand and supply, it will be the bottleneck that limits throughput. Accordingly, a bottleneck can exist and remain unnoticed until throughput reaches a threshold.

2.3.3. Classification of Bottlenecks

The review of literature with respect to definitions of "bottleneck" suggests that a common and unambiguous understanding has not evolved. Partly, this might

[4]Goldratt & Cox (2004) have chosen their wording very carefully. The reason why they chose to make the existence of bottlenecks a question of capacity lies in the fact that they distinguish bottlenecks from capacity constrained resources, the latter of which are delaying or disrupting material flow not necessarily due to their internal capacity restrictions but to any other possible reason. This distinction is not made in this document. A more elaborate discussion of types of bottlenecks will follow in Section 2.3.3.

be explained by the differences between the various domains where bottlenecks can play an important role. Nevertheless, the lack of a unifying taxonomy poses a problem for the researcher who attempts to make system level comparisons or tries to adopt useful concepts from one system for application in another. Possibly, a classification of bottlenecks might contribute to a common taxonomy and remove ambiguity. Below the development of a classification of bottlenecks is attempted. Such a classification will facilitate bottleneck management as it contributes to a more precise understanding of the nature of bottlenecks emerging as well as of possible remedies.

A first rough distinction between different types of bottlenecks can be found in the tangibility of bottlenecks: Bottlenecks can be intangible or tangible. *Intangible* bottlenecks are, for instance, processes that inhibit higher system throughput. Processes can impede the system from achieving higher throughput because they are badly designed or because the process is simply cumbersome and takes a lot of time (e.g., EPA approval for new drugs in the US). *Tangible* are those bottlenecks which impede higher system throughput due to physical limitations. Furthermore, system elements that are tangible bottlenecks can be either active or passive. *Active* tangible (physical) bottlenecks are those elements which can influence system throughput by their own actions and behaviour (either deliberately or unintentionally). Examples are workers of a production station (on a high level of detail) or an entire factory (on a lower level of detail). *Passive* tangible (physical) bottlenecks, on the contrary, are not able to change system throughput by themselves since they do not exhibit will or power to do so. Examples are machines of a production station reaching their physical limitations and streets that slow down transportation due to high traffic density.

Another way to categorize bottlenecks is by origin: organizational bottlenecks, physical bottlenecks, and operational bottlenecks. *Organizational* bottlenecks refer to situations where the root cause of constrained throughput can be found in processes, organizational directives, or established procedures. Examples of organizational bottlenecks in a factory setting are maintenance processes that require significant downtime of a machine, large buffers, order release rules that increase WIP, and ineffective quality assurance processes leading to delays or low yield. Put differently, organizational bottlenecks refer to the question "How things are planned". *Physical* bottlenecks refer to the physical capabilities or limitations of a system's element. Physical bottlenecks refer to the physical capability of a resource (e.g., a machine or a worker) or limitations due to the general physical setup of production facilities. Put in different terms, physical bottlenecks refer to the question "What can theoretically be done". So far, this categorization into organizational and physical bottlenecks at first sight appears equivalent to the previous categorization into intangible and tangible bottlenecks. The third category, operational bottlenecks, demonstrates the difference, though. *Operational* bottlenecks refer the actual handling of production assets and parts. Examples are careless use of tools and machines that reduces yield or requires frequent reworking, deviation from management directives, destruction of finished products due to careless transportation and badly scheduled breaks (e.g., lunch breaks) at resources with high utilization. Put differently, operational bottlenecks refer to the question "How things are being done". Hence, this classification addresses "how things are planned", what physical limitations are met, and how the work is being conducted. However, it is important to note that the root cause of a bottleneck in the material flow system is not necessarily so obvious that one could easiliy identify the bottleneck as, say, organizational bottleneck. The bottlenecks would materialize in some element of the system that passes on or processes material. The root cause of the problem, as in the case of organizational bottlenecks, may still lie somewhere else in the firm or even in another organization. Liu (2011, p. 39) proposes another classification of bottleneck origins: bottleneck resources and logical bottlenecks. By *bottleneck resources*, he refers to organizational and physical resources such as processes and facilities; by *logical bottlenecks*, he refers to schedules and functions.[5] It seems that these categories are well covered by the more sophisticated distinction between organizational, physical, and operational bottlenecks as proposed above.

For the management of bottlenecks, it is important to know whether effective measures lie within or beyond one's reach. Therefore, a distinction can

[5]Unfortunately, the examples given by Liu (2011) are rather vague.

be made between bottlenecks that lie inside and those that lie outside management's reach. Borrowing from psychology, this parameter will be referred to as *Locus of Control* (LoC, Rotter 1966) . If a bottleneck has an external LoC, which may be the case if the bottleneck has its root cause outside the boundaries of the organization, then management might be able to influence throughput at the bottleneck through negotiation and "politics", yet it is unable to directly apply technical or organizatiomal measures that elevate system throughput. In case of an internal LoC, the bottleneck lies within management's reach and effective measures can be directly applied. As an example, in 2010 and 2011 many car manufacturers suffered from a shortage of components from their suppliers that included microchips (cf. Beer 2011). The bottleneck were the production facilities of semiconductor producers. During the 2008/2009 crisis, semiconductor producers cut back production capacity which they were then unable to ramp up fast enough when some industries experienced resurgence in 2010. Furthermore, the production capacity available was largely used to supply important customers from industries such as consumer electronics: both margins and volumes there were considerably higher than in automotive. The reaction of automobile manufacturers was both individual and joint efforts in persuading semiconductor producers to dedicate more of their production capacity to chips that were needed for automobile industry supply. Because neither individual automobile OEMs nor the automotive sector altogether represent a major share of customers, they were unable to exert power over semiconductor producers. Instead, high-ranked managers of semiconductor producers were invited for negotiation and "event days" where automobile OEMs tried to influence capacity dedication of semiconductor producers in their favour.

Another fundamental difference is whether a bottleneck emerges "somewhere" or is *planned* by design. There are no material flow systems without bottleneck; if there were, system throughput would be unlimited. Engineers planning a material flow system can make deliberate decisions as to what element of the system shall be the bottleneck. In a factory setting, for instance, firms may choose the station as a bottleneck that involves the most expensive equipment and machinery for reasons of depreciation. In a rather static environment where little changes in the factory layout occur, firms may also choose the last process step as the bottleneck (Goldratt & Fox 1986). If a bottleneck is deliberately chosen, this will allow taking effective measures to protect throughput at the bottleneck. In contrast, if the bottleneck emerges in random, unforeseen places, then throughput may suffer since the bottleneck may not be identified as such (or only with some delay) and effective measures to protect throughput are thus difficult or impossible to apply. “Randomly” appearing (i.e., *floating*) bottlenecks are a typical phenomenon in multi-product manufacturing environments and are difficult to detect with certainty as the location changes with the product mix (Nakata et al. 1999, Hopp & Spearman 2008, p. 486). Firms may therefore choose to eliminate the possibility of bottlenecks in some stations where adding capacity is cheap, just to reduce the number of possible bottleneck locations if identification proves challenging. From the perspective of a powerful OEM, it might be beneficial for the OEM to design the supply network such that the OEM’s production facilities represent the bottleneck and thus enjoy high utilization whereas suppliers are required to provide some more excess capacity. Quite apart from these considerations, a material flow system can be purposely designed such that it will not be able to meet market demand because the production output is intended to be scarce and valuable and not widely available. This often concerns limited editions of luxury products, but more mundane products can be subject to such considerations, too. Oil production, for example, had been curbed in the past to establish higher price levels and similar measures were discussed by OPEC member states after a sharp drop of oil prices in the second half of 2014 (Lawler et al. 2014). While decisions to lower production output were made deliberately despite higher production capacity available, the same principle can be applied to factory design.

Another distinction can be made in terms of *necessity* – between avoidable and unavoidable bottlenecks. Bottlenecks appear to be unavoidable if they result from demand (that could not be reasonably anticipated) exceeding supply capacity, so that physical limitations become binding. If, however, the emergence of a bottleneck is due to sloppy preparation or other operational problems, or possibly even due to not well thought-through organizational policies, it seems to have been largely avoidable. Companies could make such a distinction in order to identify levers for improvement.

Bottlenecks differ in the duration of their existence. The duration of their existence can be determined by changes in product mix, by demand fluctuation, by changes in production capacity, by competitors entering or leaving the market, and by a variety of other incidents that affect the firm's ability to meet demand. Lawrence & Buss (1995) assert that long-term bottlenecks cannot exist: "either work will increase without bound or there will be sufficient loss of business to reduce demand rate below capacity" (p. 342).[6] Accordingly, they suggest bottlenecks can only exist in the short-run and these can be managed through the use of appropriate shop-floor control techniques. The authors ignore two important aspects, though. First, *every* material flow system is constrained by a bottleneck as otherwise throughput would be infinite. The bottleneck can be internal or external to the system, but it does exist and does limit the system's throughput. If we accept this premise, then the second point is that bottlenecks can exist *by design* and hence independently of short-term demand or supply fluctuations. Markets can experience long-term upswings and a factory system that is planned based upon (old) market might be unable to meet full demand. This would be an example of an *unintended* (or unplanned) bottleneck by design. Löffler et al. (2002)[7], for instance, discuss "static bottlenecks" that persist over a full time period as demand continues to exceed supply capability. As explained earlier, however, bottlenecks can also be purposely built-in by design. Therefore, bottlenecks can be distinguished between *short-term*, *medium-term*, and *long-term bottlenecks* provided these categories are useful in the context of the problem and they are assigned more specific time horizons.

In a similar fashion, Nakata et al. (1999) argue in terms of lead time until *appearance* ("appearance cycles") of bottlenecks and propose different management approaches, particularly in terms of time horizon, for long-cycled, mid-

[6]Probably, Lawrence & Buss (1995) refer to self-regulating market mechanisms that will, in the long-run, match demand and supply. In addition to the arguments that follow it shall be noted that markets often are imperfect and not regulate themselves but also depend on external control and steering mechanisms to maintain their functionality. Therefore, the authors are disagreed with unless further clarification is provided as to the exact meaning of "long-term".

[7]As cited in Schultheiss & Kreutzfeldt 2009

cycled, and short-cycled bottlenecks. *Long-cycled bottlenecks* according to the authors are those which emerge due to, for instance, planned changes in product mix or changes in process design, i.e., changes that are known long[8] before the consequences (i.e., the emergence of the bottleneck) occur. *Mid-cycled bottlenecks* emerge due to unplanned changes at short notice, such as changes in customer orders that arrive after the production process has already been started which leads to delays for the new order. *Short-cycled bottlenecks* are the third case the authors describe. This case refers to machine breakdowns and similar occurrences that will delay production.

Wandering or *shifting* bottlenecks are a problem widely discussed in the production planning and control literature (e.g., Roser et al. 2002, 2003, Hopp & Spearman 2008). Therefore, bottlenecks can be devided by their *steadiness*. In dynamic production environments with changing product mix and varying production processes, possibly not one particular station limits throughput but a variety of different stations depending on the specific situation. Such dynamically shifting bottlenecks pose problems for bottleneck detection methods (Roser et al. 2002). Static bottlenecks, on the other hand, are more likely to emerge in low-dynamic environments. Where production schedules don't change because of stable demand patterns, bottlenecks are less likely to shift in normal operation mode. Having said that, other stations can emerge as temporary bottlenecks due to process variability such as rework, low yield, or machine breakdowns. Static and shifting bottlenecks pose different challenges for bottleneck management. Generally, shifting bottlenecks are more difficult to identify, to resolve, and to protect than static bottlenecks unless the root cause (mostly variability) is resolved or mitigated.

Another rather practical distinction can be made based upon options that exist to resolve the bottleneck. Regarding the conception of bottlenecks as a mismatch between demand and supply, it seems straightforward that a bottleneck can be resolved by an increase in capacity. Goldratt & Cox (2004) suggest that an increase in capacity often is neither necessary nor sufficient since the root

[8] "Long" is a rather subjective term and its meaning depends on context and perception. In this context, "long" means about several days or a week in advance. The context of Nakata et al. (1999) is semiconductor production.

Parameters	Characteristics		
Location	Internal	External	
Origin	Organizational	Physical	Operational
Locus of Control	Internal	External	
Intention	Planned	Unplanned	
Necessity	Avoidable	Unavoidable	
Duration	Short-term	Medium-term	Long-term
Appearance	Short-cycled	Mid-cycled	Long-cycled
Steadiness	Static	Dynamic („wandering“)	
Exploitation Options	Only through capacity increase	Through various options	
Financial Implications	High	Medium	Low

Figure 2.3.1. – Morphological Classification of Bottlenecks

cause of the problem tends not to be a lack of capacity of the bottleneck station but rather how the capacity available is utilized. Nevertheless, it can be that an increase in capacity of the respective station is the only effective measure to increase throughput, especially when other options have already been explored. Therefore, it is suggest to classify bottlenecks further according to the options available for effective throughput improvement into bottlenecks that can be relaxed (i.e., throughput can be increased) by a combination of measures and bottlenecks that can be relaxed only by adding additional capacity.

Bottlenecks can lead to severe *financial consequences*. On the other hand, they could also be harmless. If, for instance, there is some slack between arrival time of supply and begin of production, or if inventory can buffer delayed arrival of supply, the bottleneck might not even invoke action on part of the focal firm. If the bottleneck starves the focal firm's production, however, leading to delayed order fulfillment for customers, and upon arrival of supply the bottleneck shifts to the focal firm which then has to catch up with production schedules, works overtime, stretches maintenance cycles (possibly leading to compromised quality), and frustrated customers turn to competitors, then the financial implications for the focal firm are intense. Many examples are conceivable where the existence of a supply bottleneck falls into either category.

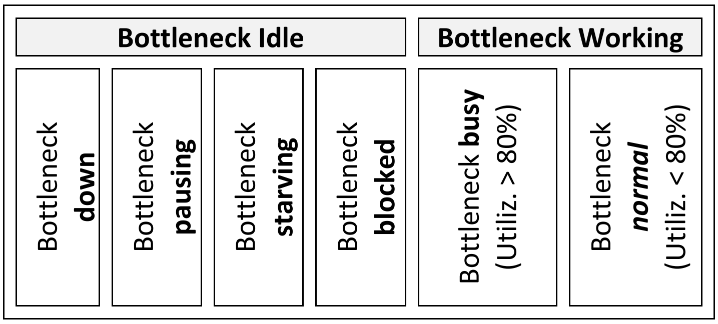

Figure 2.3.2. – Conceivable States of a Bottleneck

2.3.4. Bottleneck States

Bottlenecks can be in different states. Generally, the following states of a bottleneck are conceivable: A bottleneck can either be *working* or not working (i.e., *idle*). If the bottleneck is working, a meaningful distinction can be made between “normal” operations with “normal” utilization (say, less than 80%) and the bottleneck being fully engaged with extremely high utilization. The reason why such a distinction is important is that mathematically, throughput time increases in a highly non-linear fashion as of a certain utilization rate of the system whereas at low utlization rates throughput time behaves almost linear (Hopp & Spearman 2008). If the bottleneck is idle, it could idle due to a breakdown, it could be pausing (i.e., it has been consciously stopped by someone), it could be starving, and it could be blocked.

With the exception of “normal” operations, each of these states provides a starting point for a more detailed investigation as to why the state is so. Moreover, it can provide the basis for a typology of causes for the emergence of bottlenecks. It should be kept in mind that we are already dealing with a subset of bottlenecks, namely unplanned bottlenecks (as opposed to planned bottlenecks; cf. Section 2.3.3). That is, we are dealing with bottlenecks that emerge unintendedly and have not been planned into the system with full consciousness (and possibly good reasons).

2.4. Complexity

2.4.1. Introduction

Complexity has been part of several of the preceding sections. *Increased complexity* is a mantra in much of the management and economics literature.[9] In this dissertation, too, increased complexity has been repeatedly mentioned, e.g., as a result of economic development, technological advances, interaction of actors in a network, and system border porosity of supply networks. In fact, it seems like complexity is conceived of as one of the dominant challenges in the management of modern organizations and networks.

In this section, a contribution shall be made to a clarification of the term complexity in the context of supply networks and bottleneck management. It is not attempted to provide a complete account of complexity; rather, the ambiguity of the term complexity as commonly used shall be demonstrated, and its meaning shall be narrowed down so that eventually sense can be made of the term from a supply network management perspective.

2.4.2. Definition and Meaning

In everyday language, the noun *complexity* (or the adjective *complex*) is generally used to describe something that is not straighforward to grasp or to solve (e.g., a problem). This understanding is reflected in dictionaries' definition of "complex": "consisting of many different and connected parts" and "not easy to analyse or understand; complicated or intricate" (Oxford Dictionaries 2014*a*). This definition also shows that complex and complicated (or complexity and complicatedness, respectively) are used synonymously. Accordingly, the dictionary definition of "complicated" is very similar: "consisting of many interconnecting parts or elements; intricate" and "involving many different and confusing aspects" (Oxford Dictionaries 2014*b*). Dissecting the differences between

[9] Internet search engines are useful to illustrate the ubiquitous use of the expression: Google provides about 319.000 results for the expression "'increased complexity' + economy", about 543.000 results for "'increased complexity' + management" and about 527.000 results for "'increased complexity' + product".

complicatedness and complexity is far from straightforward and a great many controversies have evolved around this question. Furthermore, it is difficult to discuss and define complexity without reference to *complex systems* or even *Complex Adaptive Systems (CAS).* The term complexity shall be clarified first before it will be continued with a discussion of Complex Adaptive Systems in Section 2.5.4.

As to the difference between complex and complicated, Reitsma (2003) provides the following summary:

> "A system is *complicated* if it can be given a complete and accurate description in terms of its individual constituents, no matter how many, such as a computer or the process of programming a VCR (Cilliers 1998); 'a complication is a quantitative escalation of that which is theoretically reducible' (Chapman 1984, p. 370). A system is said to be *complex* when the whole cannot be fully understood by analyzing its components (Cilliers 1998)" (Reitsma 2003, p. 14).

Reitsma (2003) also emphasizes that complexity has gained a meaning beyond the dictionary definition. Throughout the 1980s and 1990s, researchers from different disciplines have attempted to find common ground among their fields by focusing on the characteristics and implications of complexity. Horgan (1995) provides a critical account of this new field of "complexity science" – as made popular by the Santa Fe Institute (Waldrop 1994) – and the hopes and claims associated with it. He points out that there is disagreement even among the key figures of this young branch of science with regard to the questions that can be answered with the help of thinking in terms of complexity. Moreover, it seems there is no unified understanding of what complexity is in the first place. The view that this new field of science has been "over-hyped" is shared by Edmonds (1999, p. 210). On the future of the discource on complexity he notes:

> "[T]he dangers are short-term and common to many other new trends and labels. Approaches associated with complexity will be subject to too much hype for a while and their usefulness will be

> both under- and over-estimated, depending on the age of those who judge them. While this stage lasts, there will continue to be much confusion caused by the word 'complexity', so much so that serious researchers will start to seek to avoid using it. On the other hand politicians will start to use it in speeches, demanding such as 'a complexity-led solution' to particular problems" (Edmonds 2010).

Some authors consider complexity as a subjective measure. Discussing problem complexity, Waxman (1996) asserts that the complexity of a system is reflected by a person's difficulty to identify the unknowns of the system. As Edmonds (1999) points out, this would mean that all complexity were only apparent and thus equal to ignorance (p. 81).

Complexity can be considered a world-view or *paradigm* (Kuhn 1970) that stands in contrast to a *Newtonian* (also referred to as *Newtonian-Cartesian* or *Cartesian-Newtonian* or *mechanistic* or *reductionist*, to list only some names commonly used) paradigm. According to the Newtonian perspective, we can explain phenomena (such as the behaviour of a system) if we deconstruct the system and look at its components. The rise of complexity as a science originates in the recognition that while this approach has been very fruitful in a great many instances it *cannot* explain *every* kind of system and thus not every phenomenon. The fact that certain problems – or more generally: systems – cannot be dissected without ceasing to exhibit the phenomenon in question gave rise to the attractiveness of complexity as a way to look at problems. That complexity has been called a paradigm here shall not suggest that the complex systems perspective and the reductionist perspective are mutually exclusive; in fact, it seems that they are *complementary* approaches to solve problems and to understand the world around us.

Weaver (1948) distinguishes *disorganized* and *organized complexity*. He introduces problems of disorganized complexity by contrasting it with problems of simplicity. Simple problems contain only a few variables which can be solved for easily. Weaver uses the example of the motion of a single billiard ball whose position at a certain point in time represents a problem of simplicity. The problem becomes manually unsolvable, however, when several billiard balls (like ten or 15) are involved and their motion is to be calculated as too many variables are involved. The calculation becomes manageable again when very large numbers of balls are involved since statistical methods can be applied. So it becomes easier to calculate the (average) motion of millions of billiard balls at once than of only 15 billiard balls; and the more balls (variables) involved, the more precise the statistical methods will work. Although individual balls cannot be traced, the "system as a whole possesses certain orderly and analyzable average properties". The "*middle region*" between simplicity with very few variables and disorganized complexity with very large numbers of variables is the region of organized complexity with "a sizable number of factors which are interrelated into an organic whole" (Weaver 1948). These are the problems that remain particularly difficult to solve.

Wood (1986) discusses three types of task complexity: *component complexity*, *coordinative complexity*, and *dynamic complexity*. Component complexity refers to the number of distinct acts required by a certain task. Coordinative complexity comprises "timing, frequency, intensity, and location requirements for performances of required acts" (p. 68), or put more simply: a measure of what needs to be done in what way to achieve the desired output. The first two types of complexity Wood (1986) refers to as static complexity in order to contrast it from dynamic complexity as the third type. Dynamic complexity exists when during performance of a certain task parameters change so that requirements to successfully achieve the desired end-state change. Accordingly, tasks that last longer are more prone to changes and thus more prone to exhibit dynamic complexity during performance than tasks that are performed within a short period of time.

Also in the context of task complexity, Campbell (1988) distinguishes four sources of complexity ("basic complexity attributes"):

1. presence of multiple paths to a desired end-state,
2. presence of multiple desired end-states,
3. presence of conflicting interdependence, and
4. presence of uncertainty or probabilistic linkages.

Generally, as Campbell (1988) states, "any objective task characteristic that implies an increase in information load, information diversity, or rate of information change can be considered a contributor to complexity" (p. 42). This statement reflects Naylor and Dickonson's (1969) definition of complexity of a task component which they define "in terms of its information-processing and/or memory-storage demand requirements" (p. 167). The presence of multiple paths increase information load and, thus complexity if only one of the multiple paths eventually is the correct one (although several may look correct) and if efficiency is one success factor (otherwise all paths could be tried until the correct one will be found). The presence of multiple desired end-states increases complexity (if the desired outcomes are not positively related) as they increase information load and information diversity. The presence of conflicting interdependence refers to the presence of several outcomes where each of which precludes the achievement of the others. The presence of uncertainty or probabilistic linkages increases complexity of information as they increase information load and information diversity. While the sources of complexity just mentioned result from the objective nature of the task, there are other, contextual, factors, such as imperfect communication of task requirements. Through different combinations, the four basic attributes can represent 16 different tasks of differing complexity.

Senge (2006) distinguishes *detail complexity* from *dynamic complexity*. Detail complexity exists when many variables are involved, e.g., many parts that need to be put together to build a house. Dynamic complexity exists where the links between cause and effect are not obvious:

> "When the same action has dramatically different effects in the short run and the long, there is dynamic complexity. When an action has one set of consequences locally and a very different set of consequences in another part of the system, there is dynamic complexity. When obvious interventions produce nonobvious consequences, there is dynamic complexity" (Senge 2006, p. 71).

That is, Senge's (2006) definition of dynamic complexity differs from Wood's (1986) definition of detail complexity. Senge suggests that dynamic complexity is a more urgent problem to tackle in many management situations. Senge's typology of complexity has been adopted by some other researchers, such as Bozarth et al. (2009).

One of the main determinants of complexity according to Senge are time delays. People have difficulties to see the connection between cause and effect when there is a delay. The relationship between cause and effect becomes even more difficult to see when feedback loops are involved. Senge proposes that most people are unable to fully understand the implications of actions in systems that contain several feedback loops and delays.

2.4.3. Complexity in the Context of Supply Networks

In this section, the term complexity shall be related to the context of supply networks.[10] It is in this branch of research where the term complexity enjoys particularly high popularity and with some certainty can be found in the majority of publications, often to underline the importance of the respective author's research. The tale usually is that complexity of the economy and of supply networks has increased or is *ever-increasing*. Globalization, shortened life-cycles and changing customer preferences among the customers are often associated with this development. As it has been pointed out in the previous section, meaning and understanding of the term complexity vary depending on context and author. When we narrow down the context to supply networks, we might expect to find greater alignment among different writers. Review of the literature indicates, however, that the term complexity is still too vague and needs further refinement. Writers in the research field of supply networks have responded to this problem by introducing different *types* and *categorizations of complexity*. They have discussed *drivers* that contribute to the different types of complexity. The goal of this section is to introduce the most important concepts of com-

[10]The reader may want to become familiar with the concept of networks before proceeding with this section. Networks, and supply networks as a more specific form of networks, are discussed in detail in Section 2.5. Because the concepts of networks, manufacturing systems, complexity, and bottlenecks are interdependent in the way they are dealt with in this work, any ordering of these topis in the structure of the thesis may require occasional interruptions of the reading flow.

plexity in the context of supply networks. It will not be attempted to discuss all the drivers of complexity in supply networks; rather, the understanding of complexity in supply networks shall be enhanced by pointing out different interpretations of complexity, thereby increasing sensitivity towards the various problems that may or may not emerge due to complexity.

Discussing complexity in supply chains and how it impacts on the pefor-mance of manufacturing plants, Bozarth et al. (2009) distinguish between *upstream complexity*, *downstream complexity*, and *internal manufacturing complexity*, thereby addressing different origins of complexity in a supply network a manufacturing plant has to cope with. On each of the three levels, complexity comprises detail complexity and dynamic complexity. In their study, they find that dynamic complexity poses greater challenges for the organization of manufacturing processes in a production plant than detail complexity. This finding confirms Senge's (2006) notion that dynamic complexity is more difficult to manage than detail complexity.

Wilding (1998) discusses the *supply chain complexity triangle*. The triangle consists of the three "interacting yet interdependent effects" (p. 599) *amplification*, *parallel interactions*, and *deterministic chaos*. The author considers each effect a source of uncertainty which in interaction "result in complex demand patterns" (p. 607).

With amplificiation, Wilding refers to the swings in inventory in combination with distorted ordering behaviour along a supply chain which is commonly referred to as *Forrester Effect* or *Bullwhip Effect* (Forrester 1958, Lee et al. 1997). It describes how relatively small changes on a downstream stage in the supply chain will be amplified as orders travel up the supply chain. In extreme cases this can lead to an alternation between significant over-supply and complete depletion of inventory. Some of the underlying reasons for the amplifying fluctuation upstream in the supply chain are uncertainty about actual demand, the time gap between end customer purchase and production of the product, the number of tiers (echelons) in the supply chain and the tendency of the actors involved to apply some safety factor to order size or to increase safety stock . The effect has been illustrated and made popular with the *beer game* in which

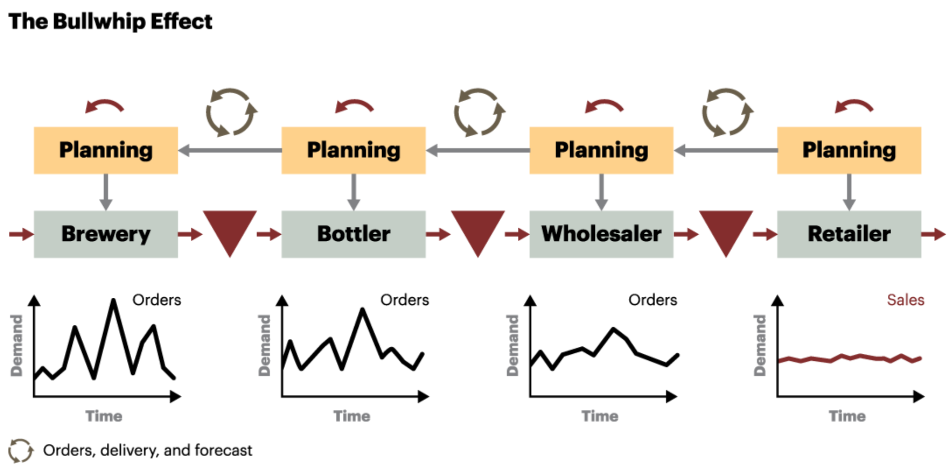

Figure 2.4.1. – Bullwhip Effect: Amplification of Demand as Orders Travel up the Supply Chain (ATKearney 2013)

a supply chain consisting of four tiers is simulated. Figure 2.4.1 illustrates the concept of the game. It shows the increasing amplification of order quantities as orders are passed through the supply chain.

The second effect of the triangle Wilding (1998) introduces is parallel interactions. He describes them as "interactions that occur between different channels of the same tier in a supply network". As an example, Wilding describes the situation that a a firm will not receive the input it needs from one supplier so that the customer has to reschedule its production which, in turn, affects the customer's other suppliers (p. 604). Another form of parallel interaction is often referred to as *indirect demand*. Indirect demand becomes a problem when one customer of a supplier occupies the supplier's production capacity to an extent that makes it diffult for the supplier to meet demand from another customer who then might run into inventory stockouts. Besides the supplier's production capacity it could also be other resources that are scarce, e.g., certain types of raw material which then have to be allocated among the various customers. Power of certain customers, for instance, might influence the allocation of resources in their favor and to the the disadvantage of less powerful customers. Parallel interactions are one of the reasons why the notion of supply *networks* in many instances is a better representation of reality than supply *chains*, as discussed in more detail in Section 2.5.4 and in Beer et al. (2012). Wilding (1998) points out that suppliers that normally show good performance can be adversely affected by such indirect impact so that they will be unable to meet their delivery targets. He points out that Just-in-Time suppliers in particular will suffer from such irregularities.

The third effect and source of uncertainty in Wilding's triangle is deterministic chaos. He characterizes determistic chaos as being governed by rules, as highly sensitive to initial conditions, as exhibiting non-linear behaviour, and as *theoretically predictable* – albeit practically unfeasible to predict (pp. 600 et seq.). Since Wilding refers to the beer game for purposes of demonstration deterministic chaos, the exact differences between amplification and deterministic chaos each of which he describes as a separate source of uncertainty remain unclear. Moreover, it remains unclear where Wilding draws the line between *chaos* and *complexity* in his paper, as well as their relation to uncertainty as uncertainty can be seen as another word for ignorance which, as indicated above, by some authors is considered the sole source or even a synonym for complexity. That Wilding (1998) uses these terms almost arbitrarily suggests that the paper's conclusion regarding implications of complexity need to be treated carefully. Regarding the differences between chaos and complexity, Reitsma (2003) states that "in Chaos Theory disorder arises from simple ordered states, in Complexity Theory large scale order arises from complex apparent disorder at the local scale". Cilliers (1998) points out that while chaotic systems are highly sensitive to initial conditions, complex systems are not, but are rather robust by their adaptive nature. Furthermore, chaotic behaviour can result from a small number of equations whereas complex systems normally comprise a huge number of components. Reitsma (2003) further adds that Chaos Theory is concerned with closed systems whereas Complexity Theory is concerned with open systems. Supply Networks, show characteristics of open systems (cf. Section 3.7). Hence, it will remain debatable as to what extent Wilding (1998) has carefully chosen his terminology and as to what extent valuable conclusions can be drawn from his use of the concepts of chaos and complexity. Besides that, regarding the properties of complex and chaotic systems, one might argue that the beer game is an adequate representation of the latter rather than of the first: it depends on a small set of differential equations, it is highly sensitive to changes, and it develops from a stable state into chaotic behaviour. Nevertheless, the beer game does include the elements that Senge (2006) considers essential for defining complex systems, such as delays and feedback loops. Hence, the beer game illustrates once more the difficulties in clearly separating widely used terms such as complexity and chaos.

Isik (2011) defines six "key dimensions" of complexity in supply networks:

- numerousness,
- diversity,
- interdependency,
- variability,
- variety, and
- uncertainty.

Each of the dimensions is positively correlated with supply network complexity, i.e., when any dimensions increases, then complexity will increase, too. *Numerousness* refers to what Senge (2006) calls detail complexity. The difference between *diversity* and *variety* is not apparent from Isik's definitions of the dimensions; one might assume that diversity refers to the existence of many different parts and that variety refers to the quantitative relations between such parts. *Interdependency* refers to the existence of systemic relationships between the entities of the system (e.g., products and actors). *Variability* refers to the amount of changes to system states inherent to the system or induced, e.g., by customers' volatile preferences. *Uncertainty* refers to ignorance about the system's future states. Isik (2011) furthermore distinguishes internal drivers of supply network complexity from external drivers. Internal drivers refer to, for instance, interruptions due to supply shortages and large product variety. External drivers refer to factors such as competition or volatile customer demand

		Technology	
		Process / Product (Structure)	Management Systems (Infrastructure)
Information Processing	Complicatedness	• Skills and know-how required to operate processes or to manufacture the product • Number of tasks and sub-processes • Number of components (e.g., vertical integration) • Level of interactions between parts/components • Level of decomposability of processes	• Product variety and customization • Extent of supply network • Extent of customer base • Geographical span of suppliers and customers • Number of echelons in the supply chain
	Uncertainty	• Process capability of the focal firm (quality failures) • Process capability of suppliers • Throughput time variation and stochastic set-up time	• Production scheduling changes • Late product delivery by supplier • Demand volatility

Figure 2.4.2. – Conceptual Model of Supply Chain Complexity as Proposed by Vachon & Klassen (2002)

(Isik 2011, p. 421). Similarly, Vachon & Klassen (2002) state that "[b]oth managerial action and the external business environment can amplify or attenuate any effects of supply chain complexity" (p. 218).

Vachon & Klassen (2002) suggest a conceptual model for supply chain complexity based on the two dimensions *technology* and *information processing*. They further divide technology into *structural* and *infrastructural* components. Structure refers to characteristics of products and processes whereas infrastructure refers to characteristics of the broader supply network (e.g., number of tiers involved or demand volatility). Information processing is further divided into *complicatedness* and *uncertainty*. Together, the sub-dimensions represent a two-by-two matrix. Figure 2.4.2 visualizes the model.

Based on a literature review, Serdar-Asan (2013) mentions two ways to categorize drivers of supply chain complexity and (implicitly) points to a third way. The first categorization she refers to is based "upon the way [complexity] is generated":

- physical situation (e.g., number of products),
- operational characteristics (e.g., process uncertainties), and

- dynamic behaviour (e.g., demand amplification).

The second classification she mentions is based on the origin of supply chain complexity:

- internal (e.g., product variety and technology),
- supply/demand interface (e.g., supply policy and number of suppliers), and
- external/environmental (e.g., regulatory framework and actions of competitors).

Figure 2.4.3 illustrates the categorization of drivers as proposed by Serdar-Asan.

Serdar-Asan (2013) indicates the relationship between the origin of supply chain complexity and the reach of organizational influence and control. While the focal firm may be able to influence internal drivers of complexity to the greatest extent, its reach decreases as one moves towards external/environmental drivers. Hence, the firm's level of influence and control can be seen as another way to classify drivers of supply chain complexity. Figure 2.4.4 illustrates the concept.

Hashemi et al. (2013), similar to Bozarth et al. (2009), distinguish between *upstream complexity* and *downstream complexity* in supply chains. Upstream complexity is mainly determined by design characterisics of the product whereas downstream complexity is mainly determined by characteristics of product demand. Characteristics that make product demand complex are, for instance, demand uncertainty, demand variability, product variety, product lifecycle, product range, demand volume, and delivery lead time. As characteristics of product design that influence supply chain complexity the authors mention the level of innovativeness, structure complexity, product modularity, structure compatibility, and lead time to produce. In their article, Hashemi et al. (2013) also propose that product design complexity is influenced by product demand complexity, suggesting that firms design more complex products as a response to the desires of end-customers. This relationship, however, is likely to be bidirectional instead of uni-directional as complex products often allow customers to choose

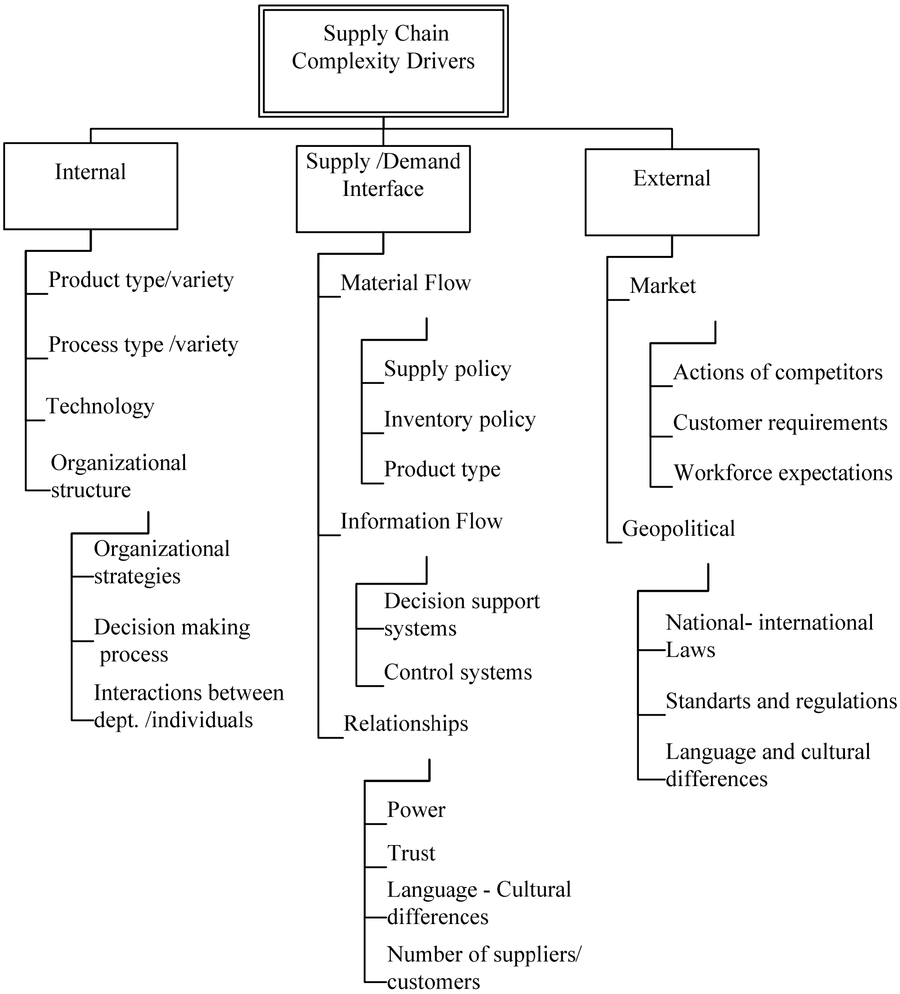

Figure 2.4.3. – Classification of Drivers of Supply Chain Complexity (Serdar-Asan 2013, p. 794)

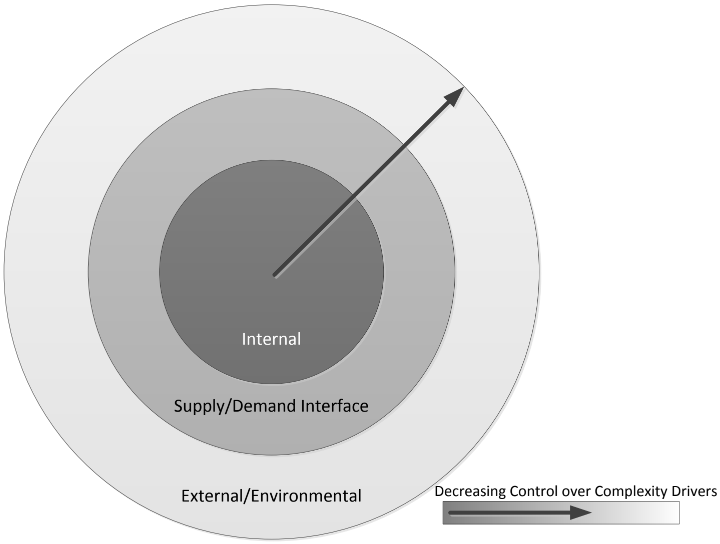

Figure 2.4.4. – Level of Control of Drivers of Supply Chain Complexity

among different product configurations (as with, for example, cars that can be ordered with or without certain extra options) which makes demand for certain product configurations difficult to predict and to plan for.

For a high-level differentiation, it is suggested to distinguish between *systemic complexity* and *induced complexity*. Systemic complexity is an inherent characteristic of the system. It results from the number of nodes in the system, the density of connections between nodes, the existence of feedback loops and delays in causal relationsips, the properties and requirements of the entities that flow through the system, the information requirements of and the information provided to the nodes involved, policies for information and material flow processing, as well as actual behavioural patterns of the nodes involved. In practical terms, systemic complexity depends (inter alia) on the number on suppliers involved for production and delivery of the components required *as well as* the suppliers' connection to customers and sub-suppliers outside the direct supply chain of the focal firm (cf. Section 2.5.4), on the number of products, on product properties, such as perishability, size, weight, and value, on delivery policies, transportation mode (air, sea, rail, road) and delivery mode (warehouse, consignment warehouse, Just-in-Time [JiT], Just-in-Sequence [JiS], Vendor Managed Inventory [VMI]), spatial disperson of the supply network, (technical) production process requirements, information transparency for suppliers (e.g., forecast horizon, actual order horizon, planned changes to products, new production introduction...), opportunism of suppliers or customers, contract design, qualification and reliability of suppliers and employees, and many more. When we understand the supply network as a system (see also Section 2.4.4 and Section 3.7), then systemic complexity is made up of all the elements – and their implications – that constitute the system.

Induced complexity, on the other hand, depends on events and behaviour that are not inherent to the system. What is inherent to the system and what is not does, of course, depend on how we delineate the system from its environment. For a model system to be useful we generally try to draw the system border in a way that lets us address the question of interest. The question of interest in a supply network is: what do we have to do so that

- the right product is
- in the right time
- in the right place
- in the right amount
- in the right quality
- to the right cost?

Through conscious design of the supply network, logistics planners aim to make all preparations necessary to ensure that the *6 Rights* will be satisfied. The system they plan contains many determinants for the success of this endeavour. There will, however, always be factors that lie outside the scope of the logistics planner and outside the system, and there is no point in integrating all possible determinants into the (model) system as the system would become too large and cumbersome for effective analysis. The global economy, for instance, often turns out to have implications for the functioning of supply networks. Nevertheless, it will not be useful to integrate the global economy into the model system of our supply network unless we want to have a model of the world. The same applies to natural desasters, political turmoil, unexpected rise of competitors or substitute products, unexpectedly changing customer preferences, traffic problems, strikes of labour or port workers, changing regulatory framework, unexpected quality problems of components delivered by a supplier, and so on. That is, there is a large amount of factors that *induce* complexity in our system in addition to the inherent complexity of the system.

Whether complexity is induced or systemic does not perfectly determine to what extent the factors causing complexity, as well as the complexity itself, can be controlled, although nodes, edges, entities and events within our system are more likely to be controllable than those that are external to it. A supplier of a specific component is selected (and supplier managers try to make sure the selection does not lead frequently to surprises such as frequent quality variation), but it cannot necessarily be controlled what is going on inside the boundaries of the supplier's facility. The differentiating question therefore is: what are built-in factors that lead to higher (systemic) complexity – and what share of the complexity the system exhibits is caused unintentionally and unconsciously and is caused by nodes, relationships, and events outside the supply network system. When a firm considers its forecast information confidential and does not share this information with suppliers, then order variations may come as a surprise to the supplier and may cause perturbation among suppliers and sub-suppliers. Such an information policy is inherent to the system. When a firm chooses to source its parts globally to inexperienced suppliers in low cost countries while insisting on short production and delivery lead time, the resulting complexity is inherent to that decision and thus systemic. When the global economy is roaring and consumer electronics producers such as Apple and Samsung celebrate record production of electronic gadgets so that microchip producers' production capacity becomes short which makes further expansion of automobile production difficult due to a lack of certain electric components that require microchips, then this complexity is not an inherent part of the system design but is induced from outside.

From the discussion in this section, it can be concluded that the most useful way to categorize and structure complexity depends on the question or problem of interest. If a company experiences difficulties in managing integration of all the different parts sourced to different suppliers, then it might be useful to think in terms of detail or component complexity. When a company frequently suffers from unexpected demand swings, availability of raw material on global markets, interruption of traffic, and changing regulatory framework, then it might be useful to think in terms of external/environmental or induced complexity. If quality problems are prevalent, a look at upstream complexity, component complexity or systemic complexity may be helpful to identify the source of the problem. That is, no categorization of complexity is better than another as such; the quality of the categorization depends on its usefulness to address the problem of interest. Figure 2.4.5 provides a summary of different types of (and ways to categorize) complexity in supply networks.

It is important to acknowledge that complexity in supply networks is not negative *per se*. In fact, it might be inextricably linked to certain desired product features that provide the company with a unique position in the market. Being able to manage the complexity resulting from a particular type of product, service, or business model, may secure a sustainable competitive advantage. Though the value lies not in the complexity as such, a certain amount of complexity will come with the choice of particular products or processes, the size of the organization, or specific behavioural characteristics of certain customer groups, and therefore may be unavoidable. The complexity of serving a particular market or market niche may in fact act as a barrier to entry for possibly emergent competitorst.[11] This, of course, is only true for complexity that is unavoidable or even desirable as in the case of products that provide unique value due to their complex features. There is no value attached to complexity that exists because of intransparent processes, outdated organizational policies, scatterbrained management, or unreliable labour.

[11] Remarkably, complexity seems forgotten in the economic literature on barriers to entry. None of the definitions McAfee et al. (2004), for instance, review mentions complexity. Most of the barriers to entry are commonly discussed in terms of costs and margins.

Categories of Complexity			**References**
Organized	Disorganized		Weaver (1948)
Static	Dynamic		Casti (1979), as qtd. in Geurs et al. (2012, p. 17)
Detail	Dynamic		Senge (2006), Bozart et al. (2009)
Internal	External		Isik (2011)
Component	Coordinative	Dynamic	Wood (1986)
Upstream	Downstream	Internal Manufacturing	Bozart et al. (2009)
Internal	Supply/Demand Interface	External/ Environmental	Serdar-Asan (2009), Mason-Jones & Towill (1998; referring to Uncertainty)
Static	Dynamic	Decision Making	Serdar-Asan (2009)
Structural	Operational		Hashemi, Butcher, and Chhetri 2013,
Upstream	Downstream		Hashemi, Butcher, and Chhetri 2013,
Systemic	Induced		Beer (this thesis)

Figure 2.4.5. – Types of Complexity in Supply Networks

Generally, negative connotations dominate when it comes to complexity in supply networks. There are several reasons for that. Complex systems are difficult to control and to manage as actions and their effect are separated in time and often in space. Feedback loops are often invisible, subtle, and non-obvious. Delay between cause and effect makes it hard to associate effect with cause, and the decision to associate a particular effect with a particular cause can be ambiguous or even arbitrary. Therefore, complex systems pose a major challenge to learning abilities of people and organizations (Senge 2006). The requirements complex systems impose on management stand in conflict with the fast-paced business environment of which many organizations are part. Complex systems require a long-term perspective and time to learn in order to understand the relationships of cause and effect. Ironically, it seems that factors associated with the often-cited "ever-increasing complexity" of business in general and of supply networks in particular, such as shorter product life-cycles and increasingly dense competition, at first sight demand *faster* and more ad-hoc decision-making. That is, increasingly complex systems require a long-term perspective and time to learn while at the same time increasing the pace of business, encouraging short-term and short-sighted decision-making, thus leading to even higher complexity. This hamster wheel, a reinforcing loop, increases the pressure on everyone involved. From that perspective, it seems natural that complexity tends to be considered a threat. Complexity inhibits the understanding of causal relationships and thus the control and management of a system.

Since complexity makes it difficult to oversee the implications of one's actions, people are likely to make mistakes without noticing it. Despite strict quality control, for instance, manufacturers of aircraft such as Boeing and Airbus face severe difficulties trying to eliminate all safety-relevant problems in new highly complex aircraft (Lavrinc 2014, The Telegraph 2013, Flightglobal 2009). It seems that the more complex a system becomes, the more difficult it will be to get it free of errors, which raises concern not only about the quality of products one can expect as a consumer but also about the manageability of supply networks that grow more complex to accommodate more complex products.

2.4.4. Supply Networks as Complex Adaptive Systems

Intuitively, many would agree if a network of organizations were suggested to be described as a system. And yet, modeling an organizational network as a system will come with a broad set of implications some of which are less intuitive. Indeed, a significant fraction of the research branch termed Supply Chain Management does ignore such implications. Conceiving of organizational networks as systems can help understand problems organizations deal with, actions organizations take, and consequences of such actions for the organization itself as well as for its environment. The consequences of the actions of one organization could be negligible for the organizational network and its environment, or they could pose significant changes. It is important to understand that one may not be able to know in advance what will happen and whether the effect that will be achieved will be desirable. Systems that produce unpredictable behavior due to the dynamic interaction of its constituents are the subject of the science of complexity, a branch of research that has been developed and formalized (predominantly) in the United States throughout the second half of the 20th century. Its formalization is inextricably linked with the foundation and work of the Santa Fe Institute (Waldrop 1994). Complexity science deals with a special sort of systems that have been termed *Complex Adaptive Systems* (CAS).

In fact, Choi et al. (2001) assert that supply networks should not be regarded as mere systems but as complex adaptive systems. Pathak et al. (2007) suggest it is a “natural step to identify supply networks as a CAS” since organizations adapt to complex environments (p. 550). Before this perspective can be adopted, a definition of CAS shall be provided. Then, properties of CAS will be compared to properties of supply networks. The understanding of *systems* is central to the understanding of complex adaptive *systems*. Therefore, this section will start by reviewing the concept of systems and their properties.

The conception of systems can be traced back more than two thousand years, with the Aristotelian wisdom from his *Metaphysics* that “the whole is more than the sum of its parts” certainly being one of the first concise statements that system properties cannot entirely be explained by properties of its constituents (Bertalanffy 1972). In spite of the general acceptance of thinking in terms of systems across a variety of disciplines it seems that an understanding of what *exactly* systems are has not evolved for a long time (Marchal 1975).[12] Von Bertalanffy has attempted to create an interdisciplinary theory of systems – General Systems Theory – to develop an understanding of systems that is generally applicable to various branches of research . One of the most important contributions of Systems Theory to science and research may be that due to its very nature it has stimulated interdisciplinary discussion. If objects being researched are understood as (open) systems which are connected to other systems in their environment and experience transition of states due to the exchange of inputs and outputs with those other systems, this emphasizes that concentration on one system while ignoring the environment may inhibit a comprehensive understanding of causes for and effects of transitions of states. Other systems within the environment of the focal system may be subject of very different branches of research and yet understanding of such systems may improve understanding of the focal system. In the context of this thesis, manufacturing organizations can be understood as open systems. What is happening within the boundaries of one manufacturing organization cannot be fully understood without reference to other systems such as another organization, e.g., a supplier. The relationship between the focal organization and its supplier is a system by itself. This dyadic relationship, in turn, cannot be fully understood without seeing the bigger picture of the supply chain involving not only the two organizations of the supplier-OEM relationship but the supplier's supplier(s) as well. As one extends the view to include other systems and their implications for the focal system, one may have to leave the boundaries of his academic discipline as well. The researcher in the discipline of, for instance, Operations Management may thus find answers in Exchange Theory, Transaction Cost Economics, Resource Based View, Resource-Dependence Theory, Supply Chain Management, Social Network Theory and Supply Chain Risk Management as he widens his perspective and attempts to better understand the behavior of an individual organization.

[12] Dubin (1969, p. 8), for instance, points out that System Theory uses the term system as a *synonym* of *model*. *Model*, in turn, is often used interchangably with *theory*. Therefore, all of the three terms are used interchangably by Dubin.

Although General Systems Theory has gained popularity throughout the second half of the 20th century and was able to provide reseachers in a variety disciplines with a new perspective on their problems, it has had its critics. Some of the criticism revolved around the applicability of a systems perspective, and critics pointed out that even Systems Theory adherents were adopting mechanistic views of their problems (Phillips 1972). Also, as Marchal (1975) reports, many researchers have raised concerns about and objections against such a general use of 'systems' as there is a danger of the term losing any rigorous meaning and common (non-trivial) properties. From a broad set of examples of definitions by various researchers, Marchal (1975) has distilled the minium commonalities across the various definitions down to "S is a system only if S is a set of related elements and relations between the elements" . Most definitions that include more attributes, he argues, define some more specific kind of system and thereby exclude others that should also be counted as system.

The system is distinct from its *environment*. Like the system, Hall & Fagen (1956) define the environment as a set of objects. The environment interacts with the system – if it is open (see below) – and can change attributes of the system just like the system can change attributes of its environment (pp. 19, 23). Because objects within the system interact and thus influence each other's attributes and the system as a whole interacts with its environment, there is no definite rule to identify which objects belong to the system and which do not but are part of the environment. Essentially, the definition of the system boundary depends on the question at issue; objects whose properties and interaction are of interest shall be considered part of the system whereas those which are not of interest and the interaction with whom does not have implications for the question at issue shall be considered part of the environment. Also, this response to arbitrary system boundary setting goes to the heart of some of the criticism of a general definition of systems which Marchal (1975) reviews in his paper, e.g., that anything can be related to anything and would thus constitute a system and the concept would thus be "vacuous". Even if it were possible to relate arbitrary entities, however, it would still make sense to refer to systems with significant (i.e., non-trivial) relationships to emphasize the interrelatedness of their components (as it is the case for supply networks).

There are *open systems* and *closed systems*. Open systems allow material or energy to enter and to leave and thus allow change of their constituents (Hall & Fagen 1956, Bertalanffy 1950). That is, open systems do not normally reach equilibria whereas processes in closed systems which do not exchange energy or material with the environment must eventually lead to equilibria, obeying the second law of thermodynamics (Bertalanffy 1972, Waldrop 1994).

As with systems, the understanding of what *exactly* constitutes a complex adaptive system varies among researchers (Gell-Mann 1999). There is some confusion as to the defining properties of *complex adaptive systems* – as opposed to merely *complex systems* or just *systems*. The main difference between complex systems and complex adaptive systems may be the existence of agency as the necessary condition for adaptation, i.e., CAS contain active *agents* as opposed to merely passive entities (Choi et al. 2001). In a talk at the Santa Fe Institute (and about the Santa Fe Institute), Gell-Mann (1990-01-09) raises the same question by comparing the complex behaviour in turbulent flows of liquids (a complex system) with complex *adaptive* systems. He suggests that it is "the way information about the environment is recorded". In CAS, the information recorded makes up a model. CAS follow certain *schemata* (Anderson 1999, Gell-Mann 1999), also referred to as *internal models* (Holland, as quoted in Gell-Mann 1999, Waldrop 1994). These schemata can be understood as a cognitive structure or, more abstractly, as a set of rules (Anderson 1999) and include the learning and adaption capability that Gell-Mann (1990-01-09) suggests as defining characteristic for CAS. Choi et al. (2001) compare schemata to Schein's (1990, 2009) concept of organizational culture as a set of shared beliefs, values, norms, and assumptions about reality and to Senge's (2006) concept of mental models.

As to complex systems, Simon (1962) suggests hierarchy and non-trivial system behavior ("the whole is more than the sum of its parts") emerging from many interactions among a large number of parts as defining properties for complex systems. At the same time, this type of emergent behavior that Simon assigns to complex system reflects "the basic system problem", i.e., is characteristic for systems in general (Bertalanffy 1972, p. 407). Anderson (1999, p. 219) argues that General Systems Theory, as put forth by Bertalanffy, addresses deterministic systems whereas CAS show emergent behavior resulting from interaction on the agents' level. But again, the distinction is not quite sharp. In her review of literature on complexity in supply networks, Serdar-Asan (2009, p. 18) provides an overview of systems characteristics but does not distinguish between the properties of complex systems and complex adaptive systems. Since the discussion that follows will focus on complex adaptive systems which are a subset of systems and complex systems and thus inherit their properties in addition to the properties only possessed by complex adaptive systems, an exact differentiation between these three concepts seems not to be of paramount importance, however.

Because agents in CAS are connected they do not act independently of each other. The level of connectedness of agents (i.e., the density of ties in terms of graph theory) in systems can differ; sparsely connected networks of agents may not develop complex behavior but tend to "freeze" whereas densely connected networks are unstable and show chaotic behavior without any recognizable patterns. Systems with an intermediate level of connectedness among agents can show complex behavior that is unpredictable on the one hand but may show certain patterns on the other. Such a system *at the edge of chaos* (Waldrop 1994) can be fairly stable and show patterns of regularity (Anderson 1999); the agents involved do not reach an equilibrium, however, but are in constant motion and change steadily in response to each other, i.e., they show *self-organizing* behavior (Kauffman 1995). Self-organization occurs when agents, even simple ones, interact according to their schemata in a *nonlinear way*. The nonlinearity of interaction among agents is a result of their being connected through both positive and negative feedback loops which lead to amplification and attenuation of behavioral patterns, respectively.

Early understanding of adaptation of systems referred to "some prearranged end" to which an adaptive system will be led by its behavior (Hall & Fagen 1956, p. 23). This notion can be described as a top-down approach to adaptation – one might even conceive of this notion as fatalistic or religious – and it stands in stark contrast to the understanding of adaptation as put forward by researchers in complexity science where adaptation is exhibited through a set of *local* rules which can, in fact, be quite simple and only a few in number (Waldrop 1994).

Whether a system is adaptive or not to some extent depends on the time horizon during which the system's behaviour is observed. Looking at the beer game (cf. Section 2.4.3) one can see amplification of demand, leading to starvation and oversupply at different points in time. There is a chance, however, that those involved in the beer supply chain begin to talk to each other at some point, thus mitigating one factor for the amplification (uncertainty and lack of information) and possibly introducing other counter measures (e.g., information transparency). Systems are sometimes adaptive in the long-term but experience tough times in the short-term. Managers of supply networks may experience teething trouble with their suppliers during production ramp-up but may resolve many of the early problems in course of the contract life cycle. Shortening product and thus supply contract life cycles then of course lead to frequent repetition of the adaption phase.

The properties commonly associated with CAS can be summarized as follows (Waldrop 1994, Kauffman 1995, Holland 1995, 2000, Gell-Mann 1999, 1990-01-09, Anderson 1999):

- Consist of (many) Agents
- Internal Models/Schemata/Local Rules
- Adaptation
- Interaction
- Nonlinearity
- Emergence
- Evolution
- Self-Organization
- Hierarchy

- “Edge of Chaos”
- Positive and Negative Feedback Loops

Based on the properties of CAS that have been identified, supply networks can be analyzed with respect to the existence of such properties. Simply put, supply networks consist of organizations and relationships between organizations which, in turn, consist of people and relationships between people. So in most supply networks, a fairly large number of individuals is involved who make decisions and act according to the decisions of others. Individuals and groups of individuals (organizations) react to incentives, pressure, orders, or observations according to different types of rules, such as legal and regulatory frameworks, company policies, their own models of the world, and their own ethical compass. Individuals in organizations get rewarded and punished, and they can – albeit not always and not completely – observe the effects of their actions based upon which they can adjust their behaviour and actions.

This short description already involves some of the properties that are associated with Complex Adaptive Systems. It addresses the existence and numerousness of agents that populate the system, their ability to adapt to changing circumstances based on rules, their interaction with each other, feedback loops, and the hiercharchy in which they are organized.

The notion of supply networks as CAS becomes more difficult to defend when it comes to the properties of emergence and self-organization. Emergence and self-organization result from adaptation and interconnectedness of agents. These properties presume that the overall behaviour of the system (its global pattern) is dependent on the behaviour and the decisions of individual agents in combination, leading to some type of stability and order that would not have been apparent nor explicable from the properties of the individual agents. As mentioned before, this phenomenon can be summarized with the dictum '*the whole is more than the sum of its parts*'. Stacey et al. (2000) remark that the claims attached to these properties – i.e., that system behaviour emerges from the interaction of individual agents who act according to local rules (= schemata, internal models, or mental models) – challenge the common understanding of the role of management. This role is commonly associated with policy-setting, commanding, controlling, motivating, and goal-setting. The reason why it is challenged is that management depends on the ability of individuals in authoritative functions to select among different possible options – such as strategic choices, candidates for a vacancy, suppliers for a sourcing decision – the one option that promises the most desirable outcome which inherently requires the ability to predict likely outcomes of the different options at hand. As Stacey et al. (2000) put it: "Question predictability and you question all of these management beliefs" (p. 18). Controlling and leading – two of the management functions Mintzberg (2011) defines – obviously are difficult to perform if the notion of emergence and self-organizations is accepted. While Stacey et al. (2000) relate to management of one organization, their point remains valid for the management of supply networks and questions the notion inherent to Supply Chain Management that a focal company can *manage* its supply network.[13] Choi et al. (2001) suggest that the focal firm merely *triggers* the creation of the supply network. Most focal firms focus on tier-1 suppliers who in turn select their suppliers, and so on. These authors maintain that often the focal firm does not really know how the supply network looks like and what is going on. This observation is in line with this researcher's own findings that focal firms in automotive supply networks predominantly focus on tier-1 stage and only rarely include higher tiers in their supply management efforts (Beer 2011).

On the other hand, one might argue that the focal firm does not merely trigger the creation of the supply network but sets the standards it requires which are then cascaded upstream as suppliers and sub-suppliers make their respective sourcing decisions. In this case, the focal company would define certain boundaries and reduce the total population of possible choices its tier-n suppliers can make. Provided, of course, that suppliers are commited to adhere to the standards their customers require or suggest, which is a function of the power relationships between the two organizations in the dyad (cf. Section 2.5.5.2).

Additionally, some focal firms do in fact begin to engage stronger in their

[13] See also Section 2.5.5.2 for a discussion of interdependency between organizations and the ability to manage or merely *cope*.

supply network beyond tier-1 stage than they used to do and stronger than their competitors do (Beer 2011). There are several criteria based upon which the decision is made as to whether the firm should engage in tier-n management. One criterion used is the existence of a powerful tier-n (sub-)supplier who supplies a less powerful tier-(n-1)[14] supplier. In this case, the focal firm may engage in price negotiations, may close the sourcing contract for delivery of the tier-(n-1) directly with the the tier-n supplier, may support audits of the tier-n supplier, and may chime in in case of conflicts between tier-n and tier-(n-1). That is, the *management* of Supply Chain *Management* is emphasized to a greater extent, which counters the assertation made by Choi et al. (2001) that “the actual structure of the SN is *probabilistic* rather than deterministic” (p. 359; emphasis in original) and weakens the role of the “invisible hand”.

Accordingly, it is debatable if and to what extent supply networks exhibit self-organization and emergence. Obviously, supply networks differ in their characteristics; some networks might be closer to the “ideal” CAS than others which exhibit rather deterministic and controlled patterns. The arguments put forth by Choi et al. (2001) remain valuable as they indicate the need to assess the network with respect to its ability to exhibit unexpected and possibly undesirable behaviour.

2.4.5. Implications of Complexity for Bottleneck Management

Different types of complexity can be traded-off against each other. For instance, a company (such as a car manufacturer) may choose to use as many equal parts as possible in all of its diverse models. Thereby, the company would reduce the total number of different parts, leading to a significant reduction of detail complexity. On the other hand, this measure increases the inderdependencies between the components and different models into which the component is built. Thus, the decrease in detail complexity comes at the price of higher dynamic complexity. A change to the component in order to improve its fit in one model

[14]Read: tier-(n minus 1). This notation relates to a supplier downstream of a tier-n supplier, with *n* being the stage of the supply chain.

may trigger a series of changes to other models, which, in turn, may again lead to the necessity to change other components, and so on. More importantly, a higher share of equal parts in different products will influence demand and capacity planning, the severity of supply shortages, and the effort and cost of product recalls if it turns out that a common component is prone to defects or even poses a threat to customer safety. In such a case, regular production would continue while spare part production for the product recall would be increased and thereby adds to capacity requirements. The recent case of Takata inflators described in Section 1.1.2 is a case in point.

Complexity appears to be somewhat difficult to find access to in empirical research. As indicated before, researchers have varying conceptions of what complexity is. Measuring complexity does require its clear definition, though. Attempts to measure complexity are likely to break down this multifaceted concept into simpler, more accessible parts which may allow measurement yet which may not fully represent the theoretical construct of complexity, as discussed on the preceding pages, any more. One instance is the (certainly worthwhile) exploratory attempt by Vachon & Klassen (2002) to link supply chain complexity to delivery performance (Section 2.4.3; see also Figure 2.4.2 on page 58 for their conceptual model of supply chain complexity). Due to a lack of sufficient data support their study did not involve second and third tier suppliers or customers, which, however, add to the complexity of the supply network for each additional node induces complexity through its interdependence with other nodes, including with those outside the observer's bounded vision. Arguably, the complexity of supply networks is partly due to the interrelatedness of the various echelons of suppliers as well as their connections to organizations outside the direct supply network of the focal firm and their openness to influence from organizations, markets, and environmental factors any single oberserver cannot oversee. The approximation and simplification – and thus generally the deconstruction and dissection – of complexity for the sake of accessibility to empirical investigation arguably lets the complexity disappear, gives way to a reductionist perspective, and lets the researcher focus his attention on aspects of a broader phenomenon which he fails to describe.

Therefore, identifying the impact of complexity on bottleneck management is a problem. It can be presumed, however, that complexity does impact in the ability to manage bottlenecks as it generally does impact on the ability to manage *anything*, as discussed in Section 2.4.4 on page 67. Complexity shall thus be part of a theory of bottleneck management while it must be acknowledged that its impact can neither be quantified nor otherwise be determined in any exact way.

2.4.6. Systems Thinking and System Archetypes in Supply Networks

Senge (2006) introduces a set of different system archetypes that describe commonly observable behaviour in a broad variety of everyday systems. As supply networks have been characterized as systems – even as complex adaptive systems – it might be worthwhile analyzing supply networks with respect to the existence of some of these archetypes. The relevance of this analysis lies in the facilitated recognition of certain behavioural patterns and related fixes that are intended to influence the behaviour of the system in a certain way – and often are either ineffective or even reinforce undesired system behaviour.

People tend to interpret incidents in everyday life in linear ways. Problems are perceived as events and can be resolved through the application of a fix. Writer in systems thinking (e.g., Gharajedaghi 1999, Senge 2006, Morecroft 2007) point out that many fixes we can see being applied to solve problems do not address the underlying causes of a particular incident but merely the symptoms. The symptoms may then disappear for a while and the problem fix may be considered a success. It may well be, however, that the symptoms will appear again and require ever-increasing resources to apply the same fix over and over; or the problem fix may lead to the appearance of entirely different symptoms that are caused by the same underlying reasons which have remained unaddressed. As Senge (2006) puts it: “Reality is made up of circles but we see straight lines” (p. 73). Systems thinking emphasizes the need to understand causes and events as connected through feedback loops: instead of seeing an incident as an independent event, it shall be seen as the outcome of one or several other events that have occurred before. The phenomenon of interest may invoke certain actions which, in turn, will influence the events that have led to the events that have caused the phenomenon of interest. In short, incidents more often than not are not isolated events but are part of cause-and-effect loops, often including a delay.

The notion that immediate and seemingly obvious fixes can be misleading and leave underlying problems unaddressed is of high relevance in industrial production and supply chains. Without explicitly mentioning systems thinking and causal loops, Theory of Constraints (Goldratt & Cox 2004) emphasize the importance of following up causal chains and addressing the true underlying problems: Instead of increasing capacity and the level of automation in a factory to resolve problems with long production lead times, the protagonist in "The Goal" is advised to focus, for instance, on production scheduling and misleading incentives for production workers. In the supply chain context, the beer game that illustrates the bullwhip effect suggest that the actors generally suffer from a lack of understanding of the broader implications of their actions. The significant delay between their actions (ordering beer) and the effect they can observe (beer is delivered) is one of the main hindrances to their understanding.

Senge (2006) identifies three essential building blocks of system archetypes: reinforcing processes, balancing processes, and delays. All other system archetypes than reinforcing processes and balancing processes (which are an archetype in themselves) are comprised of a combination of these three building blocks. Senge (2006, pp. 389 et seq.) lists 13 different archetypes.[15] The purpose of discussing system archetypes is to facilitate and improve recognition of archetypes in supply networks and ultimately to pave the way towards better (fundamental) solutions instead of symptomatic "solutions" (Senge 2006).

Not all system archetypes are relevant in the context of this thesis and archetypes shall not be discussed in detail. It was found important, however, to relate to this concept as it enriches the discussion of management of supply networks.[16]

[15] As Senge (2006) points out, a lot of different people have contributed to the development of the different archetypes and they have been discussed in a variety of publications.

[16] Some that are relevant and can be related to situations observed in the practice of management of supply networks are: Fixes that Backfire, Success to the Successful, Reinforcing Loops,

2.5. Organizational Networks and Supply Networks

2.5.1. Introduction

That the amount of literature on organizational networks is comprehensive is certainly an understatement. In this section, some of the most crucial points for the understanding of organizational networks shall be highlighted without raising claims to completeness.

Many authors observe and describe an increased level of networking among firms. The prescriptive stream of literature considers interorganizational relationships a solution for upcoming challenges such as increasing customer demands, competitive pressure, or product complexity. Concepts from popular management literature such as the focus on core competencies as proposed by Prahalad & Hamel (1990) will necessarily lead to an increased number of interorganizational relationships an organization has to deal with. Gulati & Kletter (2005) consider an increased level of networking necessary to retain a competitive edge. They suggest that firms focus on fewer activities and outsource larger parts of their business. Hence, the authors propose essentially the same concept that has been popularized by Prahalad & Hamel (1990) fifteen years earlier. If firms follow this advice, it will lead to an increased number of vertical relationships with firms that take over activities. The authors also argue for expanding the value proposition that can be offered to customers through involvement of firms that can offer complementary products or services, which would lead to an increased number of horizontal relationships.

The broad stream of descriptive literature observes an increased trend towards outsourcing and shifts in value-added. This trend has been discussed in great detail in some industries in particular, such as automotive (Waldraff 2007, Semmler & Mahler 2007, Roehrich 2008, Rennemann 2007) and electronics (Sturgeon 2002). While the shift of value-added is seen by some as a

and Accidental Adversaries. *Fixes that Backfire* in particular can be related to several contemporary events, including the recent case of defective Takata inflators (see Section 1.1.2) which some commentators trace back to cost saving attempts.

potential measure to offload risk of volatile demand on suppliers, it comes with different other risks, e.g., the risk that "that some control is relinquished to a party who may not perceive the same concern with serving the end customer" (Tsay 1999, p. 1340). Also, there might be performance trade-offs being involved in outsourcing. As Weigelt & Sarkar (2012) report, firms may suffer from lower adaptability to customer demands and requirements when outsourcing the development and maintenance of technologically innovative solutions for efficiency reasons.[17] Cook (1977, p. 64) contends that networks (or more general: exchange relations) form primarily due to two interrelated reasons: (1) Organizations perform specialized functions and thus are part of a value-chain and have to create ties to other organizations. (2) Resources are scarce and not readily available to all organizations. This leads organizations to perform a limited set of functions which, again, makes organizations represent only part of a value-chain and drives them into interorganizational exchange (cf. Levine & White 1961). Even for a limited set of functions it may be necessary to obtain additional resources from other organizations.

Thompson (1967) discusses the ability of individuals to maintain control within an organization (pp. 132 et seq.). He contends that the notion of "omnipotent individuals" (as supposedly embodied by high-ranked managers) having full control over all relevant actions within the organization is misleading unless the degree of complexity is not higher than modest. Otherwise, individuals have to seek cooperation. The arguments he makes for power and control within an organization appear to be transferable to a network context to explain network formation, i.e., relationships between organizations characterized by coalition behavior. Thompson's three arguments are (ibid, p. 133):

- "When complexity of the technology or technologies exceeds the comprehension of the individual"
- "When resources required exceed the capacity of the individual to acquire"

[17] Furthermore, the authors propose that outsourcing for the sake of higher efficiency might have diminishing returns with increasing levels of outsourcing, cf. Weigelt & Sarkar (2012, pp. 193-194).

- “When the organization faces contingencies on more fronts than the individual is able to keep under surveillance”

Arguments as to why organizations seek cooperation – just like individuals in Thompson’s examples seek cooperation – can be made analogously.

The focus of this thesis is on supply networks. Networks often do share, however, certain characteristics regardless of the type of networks. The description of networks in terms of nodes and ties, for instance, is universal whereas their interpretation depends very much on the context, i.e., the exact type of network.

2.5.2. Conceptual Description of Organizational Networks

If organizations are looked at through systems thinking lenses, then it is impossible to say that there are not at least trivial relationship between any two organizations as they can always be related, for instance, in terms of spatial proximity (Hall & Fagen 1956, p. 18). Organizational networks, however, represent a set of organizations within the universe of organizations among which relationships exist that are significant, “non-trivial”, and useful for the question at issue. In most cases of organizational networks there will be implicit or explicit agreements defining the type of relationships that exist between any two organizations. These can be helpful to delimit an organizational network from its environment. Since organizations from within the network will normally maintain relationships with organizations, institutional bodies, and other stakeholders outside the network, i.e., from the network’s environment, the definition of the organizational network’s boundary can be somewhat arbitrary. Thus, the practical extent and the question *who belongs* can differ depending on the dimensions of interest.

Networks of organizations can be represented through a combination of nodes and ties with nodes representing organizations and ties representing relationships between organizations. Nodes are also referred to as “points” or “vertices” and ties are referred to as “edges”. There are some fields of science making use of this terminology, such as Graph Theory, Systems Theory, and Social Network Analysis (SNA). In fact, these bodies of research provide a broad variety of concepts that can be applied to organizational networks and “Supply Chain Management”, as increasingly many scholars have been doing in recent years (e.g., Kim et al. 2011, Wagner & Neshat 2010, Borgatti & Li 2009, Choi & Kim 2008, Pathak et al. 2007).

For a conceptual description of organizational networks, a variety of properties is available for *node-level* description, for *network-level* description, and for *tie-level* description.

2.5.2.1. Node-level Properties

Centrality One of the most obvious properties an organization (or more general: an actor) has in a network is its level of centrality. The concept of centrality plays a particularly important role in the analysis of social networks (Freeman 1979) but has increasingly gained from scholars from various branches of organizational and network science (e.g., Rowley 1997, Gulati et al. 2002, Kim et al. 2011). Centrality is a node-level property and positional descriptor characterizing the relative position of an actor with respect to other actors. Depending on type of centrality, branch of science, and question of interest, assumptions can be made about the focal actor’s power, alternatives, and popularity or status relative to other actors in the network (Brass & Burkhardt 1993, Rowley 1997, Bonacich 1972). The crucial point here is that it is not the collective individual attributes of the focal actor that provides him with a powerful position but the structure of the network (Rowley 1997, p. 898) .

There are several distinct types of centrality, each of which can have different implications for the relationship between the focal actor and other actors in the network, among them degree centrality, eigenvector centrality, betweeness centrality, and closeness centrality (Freeman 1979, Brass & Burkhardt 1993, Borgatti & Li 2009).

Degree centrality is based upon the graph theoretical concept of *degree* of a node. The degree of a node is the number of other nodes to which the node of interest has direct ties (i.e., which are *adjacent*; Freeman 1979). That is, degree centrality measures centrality by the number of direct ties an actor has to other actors in the network (Jackson 2008); the more ties it has, the higher is its level of degree centrality. If directedness of ties is considered, a further distinction can be made between in-degree centrality and out-degree centrality.

In-degree centrality is a measure of the number of ties going into the focal node. A practical example are companies seeking cooperation with one particularly innovative organization (such as a research institution or high-tech company) whereby the innovative organization will show a high level of in-degree centrality. That is, in-degree centrality can be used as a proxy for perceived innovativeness or prestige – albeit with limitations as any attempt to interpret network characteristics is context-sensitive.

Out-degree centrality, in turn, measures the number of out-bound ties from the focal node. An illustrative example for high out-degree centrality would be a supplier with many customers. If firm with high out-degree centrality turns into a bottleneck, many customers may experience shortages at the same time.

Eigenvector centrality is conceptually related to degree centrality. It builds on the notion that adjacency to a node that itself is very central tends to be more important than adjacency to a peripheral node (Bonacich 1972, Wasserman & Faust 2009). The concept of eigenvector centrality appears to be of particular importance for questions of information flow. The concept of *partner profiles* is related to eigenvector centrality. The idea is that characteristics of an adjacent node affect performance of the focal node. Gulati et al. (2002, p. 292) associate the potential benefit of status transfer with partner profiles.

Betweenness centrality is based on the graph theoretical measure of betweenness which describes nodes lying on the shortest path (the *geodesic*) between two non-adjacent nodes (Freeman 1979). High betweenness centrality thus indicates that a node lies on many geodesics. Betweenness centrality can have a wide variety of practical implications depending on the context. A node with high betweeness centrality has increased potential to learn from, control, and influence information flow between other nodes and thus can occupy the role of a gatekeeper or broker (Kim et al. 2011). By the same token, such nodes represent hubs and are thus structurally important in networks of material flow (Borgatti & Li 2009). It would take increased effort to transfer material between two nodes bypassing the intermediary on the geodesic – if this is possible at all;

it might not if there is no other path between the two nodes representing origin and destination of the material flow.

Closeness centrality can be understood as an indication of independence of intermediaries when connecting to other nodes in the network; there are, however, different definitions of closeness centrality, some of which are of rather general character (Freeman 1979). Closeness measures the sum of distances to other nodes. Distance in this context means number of intermediary ties (or “steps”) between two nodes (Borgatti & Li 2009, Kim et al. 2011). From a practical point of view, closeness facilitates communication and spread of information (Gulati et al. 2002).

2.5.2.2. Tie-level Properties

Types of Ties Borgatti et al. (2009) and Borgatti & Li (2009) discuss a typology of ties in a social network. They divide ties into four types: similarities, social relations, interactions, and flows. These four types can be further divided into continuous and discrete types of ties (cf. Figure 2.5.1). *Continuous* ties are those that persist over the duration of the relationship, i.e., the tie is not represented by countable events, whereas this is the case for *discrete* ties which are comprised of countable events.

It is not difficult to identify real-life situations in supply networks that could be described in terms of continuous and discrete ties. Continuous ties exist where long-term supply contracts exist. The duration of such contract periods may cover several years, often as long as the product and maintenance life cycle of a product. Instead of “social relations”, as termed by Borgatti & Li (2009), such ties could be more specifically described as *economic relations*, however. Discrete ties, on the other hand, can describe the economic relationships between buyers and sellers on spot markets.

Moreover, it seems that the concept of ties allows for different types of ties to be nested: Within a continuous economic relationship, as formally established by a sourcing contract, there will be deliveries of goods which are discrete events. Depending on the manufacturing environment, the delivery of supply could be almost continuous, as, for instance, in cases of frequent JiT deliveries

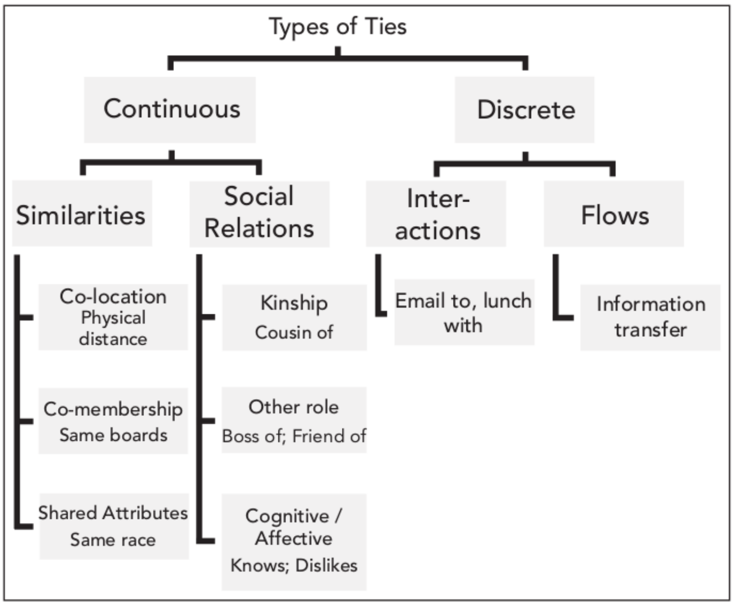

Figure 2.5.1. – Typology of Ties in Social Networks (Borgatti & Li 2009, p. 7)

or in supplier parks of automotive OEMs where supplier and OEM factories are located in close proximity and sometimes even are connected by conveyor belts between their factories. In more discontinuous, project-based production environments with lower frequency of deliveries which are formally specified and covered by an enduring supply contract, the supply relationships could be best described in terms of nested continuous and discrete ties.

Strong and Weak Ties The notion of strong and weak ties became popular with the seminal article "*The Strength of Weak Ties*" by Granovetter (1973). The strength of ties is a dyadic property (Gulati et al. 2002), i.e., they refer only to the characteristics of the link between two nodes, regardless of other connections each of the two nodes may have with other nodes. The concept seems to have been used mostly in the context of social networks. Granovetter (1973, p. 1361) defines the strength of ties as a "combination of the amount of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie". Furthermore, Granovetter hypothesizes that the existence of strong ties correlates with the proportion of nodes "to whom they will *both* be tied, that is, connected by a weak or strong tie" (ibid, p. 1362, emphasis in original). Drawing on various researchers' earlier studies, he infers that strong ties are "breeding local cohesion" and thus "lead to overall fragmentation" of communities (ibid, p. 1378). Weak ties, on the other hand, serve as important means towards integration into social communities. In other words: the central idea – which has become popular as „Strength of Weak Ties“ (SWT) Theory – is that weak ties between individuals, as in the case of an individual („Ego“) and her acquaintance (as opposed to a close friend in the case of strong ties), can function as a bridge between the group consisting of Ego and her close friends and the group consisting of Ego's acquaintance and his close friends, thereby providing Ego with access to information from the other group that it otherwise would not have been able to obtain. Accordingly, an individual without weak ties will remain limited to the information available in its own close group, separating it from the rest of society and leading to fragmentation. Thus, the value of weak ties lies in their ability to provide connectivity between an individual (and the group surrounding it) and another densely-knit group of individuals, bearing the chance of new information: „The closely-knit groups to which you belong, although they are filled with people eager to help, are also filled with people who know roughly the same things that you do“ (Easley & Kleinberg 2010, p. 47). Granovetter (1983) emphasizes that it is in their function of bridges between different social groups that weak ties are most valuable.

Structural Cohesion, Cohesive and Bridging Ties Structural cohesion is a measure that is often used in Social Network Analysis (SNA) to identify and describe subgroups. Different authors favour different formalizations of cohesion, e.g., mutuality of ties, closeness of subgroup members, frequency of ties among members, and relative frequency of ties among members compared to outsiders (Wasserman & Faust 2009, pp. 251-252). Structural cohesion can be seen as either a tie-level property (due to its being based on cohesive ties) or a network-level property (due to subgroups' being constituent parts of a network).

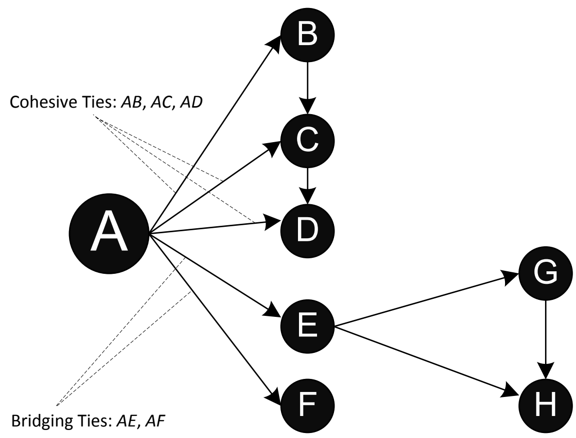

Figure 2.5.2. – Cohesive and Bridging Ties (Gulati et al. 2002, p. 290)

Gulati et al. (2002) contrast cohesive ties and bridging ties. They define cohesive ties as those that link the focal firm ("A") with a second firm ("B") which at the same time has ties with (at least) a third firm ("C") that maintains a connection with the focal firm ("A"). Cohesive ties are depicted in Figure 2.5.2 in the relations *AB*, *AC*, and *AD*. A large number of cohesive ties within one section of a network constitutes a subgroup. When all nodes are connected to all other nodes in the subgroup, i.e., when there is *complete mutuality*, the subgroup is called a clique (Wasserman & Faust 2009, pp. 253 et seq.).

A bridging tie connects one firm ("A") with another firm ("E") which has no other connection with the first firm ("A") in common. Bridging ties are depicted in Figure 2.5.2 in the relations *AE* and *AF*.

2.5.2.3. Network-level Properties

Density, Structural Holes and Structural Equivalence The *density* of a network is the ratio between all ties connecting nodes in the network and the maximum number of ties possible in the network (Rowley 1997), excluding loops and multiplexity. More formally and in terms of graph theory, "the density of a graph is the proportion of possible lines that are actually present in the graph" (Wasserman & Faust 2009, p. 101). Maximum density equals 1 and such a graph is called “complete”; if density equals 0, the graph is “empty” (ibid, p. 102).

Again, the ties can be of different nature – as can be the network in the first place. In a supply network, ties could be informal or formal communication ties, supply ties (i.e., actual supply relationships), or even spatial distance.

In a way, the converse concept to density are *structural holes*. Burt (1995, p. 18) defines structural holes as follows:

> ”I use the term structural hole for the separation between nonredundant contacts. Nonredundant contacts are connected by a structural hole. A structural hole is a relationship of nonredundancy between two contacts. The hole is a buffer, like an insulator in an electric circuit. As a result of the hole between them, the two contacts provide network benefits that are in some degree additive rather than overlapping.”

Dense networks have few structural holes whereas sparse networks have many.

Burt (1995) uses *structural equivalence* as one (imperfect) indicator for the non-existence of structural holes and thereby points to another concept that potentially has benefits for the analysis of supply networks. Structural equivalence exists when two nodes relate to every other node in exactly the same way (Lorrain & White 1971).[18] In the context of supply networks, two competing manufacturers are structurally equivalent if they are supplied by the same firms (and supply the same customers, but it is the supply side that is of interest here).

2.5.3. Network Configuration, Performance, and Bottlenecks

One area of interest for bottleneck management is the effect of the supply network structure on the likelihood and effect of the emergence of bottlenecks. As indicated earlier and explained in detail in Section 2.4.4 on page 67, examining the effect of the network’s structure requires the researcher to abandon the

[18] “Objects *a*,*b* of a category *C* are *structurally equivalent* if, for any morphism *M* and any object *x* of *C*, *aMx* if and only if *bMx*, and *xMa* if and only if *xMb*. In other words, *a* is structurally equivalent to *b* if *a* relates to every object *x* of *C* in exactly the same ways as *b* does” (Lorrain & White 1971, p. 63).

notion of a supply chain and to accept the premise that supply processes are organized in and dependent on networks of organizations that can, in fact, take the form of complex webs.

Whereas concepts from (social) network theory have been used in research branches such as sociology for a long time, researchers have begun to utilize the concepts for analysis of bottleneck management related topics only in recent years. Network research has recently experienced rising interest from the research community in various fields as indicated by the number of publications (Borgatti et al. 2009).

Different measures of networks and positional descriptors of actors in networks have been introduced in previous sections. In this section possible implications of some of these measures on bottleneck management shall be discussed. This is not a well-developed research field and literature that directly and explicitly discusses questions of network structure and its meaning for bottleneck management is rare. Since network analysis has become so popular and has been used in a great variety of research fields, there is plenty of literature that does create causal relationships between network structure and outcomes of some kind. In fact, as Borgatti et al. (2009) emphasize, it is „[p]erhaps the most fundamental axiom in social network research (..) that a node's position in a network determines in part the opportunities and constraints it encounters, and in this way plays an important role in a node's outcomes. This is the network thinking behind the popular concept of social capital (...)" (Borgatti et al. 2009, p. 894). Some of this work, especially the share dealing with social and economic networks, may be able to provide concepts and ideas that can be transferred to supply networks and be analyzed with respect to their implications for bottleneck emergence and management. Nevertheless, the interpretation of network configurations and their effect on the outcome both of individual organizations and of networks remains challenging. Contributions to this field often seem to be limited to theoretical reasoning rather than based on empirical evidence (e.g., Oliver 1991, Rowley 1997). One of the challenges is that cause and performance outcome are connected through rather indirect and often invisible links. Construct validity problems may easily arise (Kenis & Oerlemans 2008).

Provan & Sydow (2008) write:

> "It is difficult to determine with any precision what specific outcomes result from an IOR and what outcomes might have occurred in the absence of an IOR. The problem is compounded by the prevalence of different theoretical perspectives for explaining IORs. For instance, is the outcome financial as economists would claim, is it enhanced power and resource acquisition capability as resource dependence theorists would claim, or is it increased legitimacy as argued by those adopting an institutional theory perspective? Furthermore, the problem is complicated by questions about the appropriate level of analysis. Who generates and appropriates IOR outcomes? Is it the specific firm engaged in an IOR, the IOR dyad, a more complex network of IORs, or even the hub firm organizing a network of IORs?" (Provan & Sydow 2008, pp. 691-692)

Gulati et al. (2002) suggest that three characteristics of the networks and of the firm's position in the network are of importance for performance outcomes: centrality, structural configuration of ties, and partner profiles, with whom he associates various advantages for the focal firm.

Borgatti & Li (2009) point out that measures of social network theory can be applied to both "hard" and "soft" links in supply networks. Hard links refer to "technical" connections, such as material movement, whereas soft links refer to personal relationships, information flow, etc. In fact, both the "hard" and the "soft" dimension seem to be important for bottleneck management as organized material flow is generally accompanied – and preceded – by information flow.

2.5.3.1. Node-level Properties and Performance Implications

Leavitt (1951) has examined communication patterns and group performance in groups of individuals of different structure. His experiments show that while groups with decentralized structure (as in a circle; cf. first illustration from the left in Figure 2.5.3) provided higher satisfaction to its members such groups

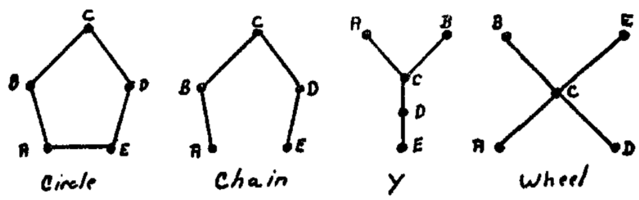

Figure 2.5.3. – Four Group Configurations (Leavitt 1951)

were outperformed in problem solving tasks by groups in which one actor obtained a high centrality position (as in a wheel structure; cf. fourth illustration from the left in Figure 2.5.3)[19].

The given structure of the „wheel group“ more or less imposes a certain way of organization with the central actor acting as a hub or leader – whereas in the „circle group“ where all members are equal in terms of centrality no specific form of organization is suggested. Leavitt (1951, p. 49) infers that „centrality determines behavior by limiting independence of action, thus producing differences in activity, accuracy, satisfaction, leadership, recognition of pattern, and other behavioral characteristics.“ While intuitive, however, this finding is incomplete as later experiments showed that there are more variables that will influence the outcome (Borgatti et al. 2009, endnote 7). The idea that the structure of a network and the centrality of its actors have implications for efficiency and accuracy of information processing as well as for communication patterns may be worthwhile discussing in the context of bottleneck management. Availability of information and its accuracy are important determinants for the success of supply network planning and maintenance. During the planning phase of the supply network, suppliers need information about projected sales from their customers so they can plan their production capacity. When the network has become operational, suppliers need updated information about sales forecast on a regular basis as well as accurate information about actual orders for their production planning. The customer, in turn, needs information about the supplier’s

[19]Leavitt (1951) summarizes his observation of the group with the wheel structure in this sentence: „the circle, one extreme, is active, leaderless, unorganized, erratic, and yet is enjoyed by its members.“ (p. 46)

ability to produce the quantities desired in the quality desired and to deliver it within the time frame desired. These different sets of information require the involvement of several organizational units. Involving the various information sources requires time and effort and is likely to lead to inefficiencies and delays. OEMs in some industries seem to have reacted by having created dedicated supplier management departments which can combine streams of information and information requirements from various sources and thereby enhance efficiency of communication with suppliers. Such departments obviously hold a central position both in terms of degree centrality and betweeness centrality and they can take a leadership role in case combined effort is necessary to complete a task or solve a problem. The interviews conducted in the course of the work on this dissertation as well as from an earlier study in the automobile industry (cf. Beer 2011) both suggest that the centralization of supplier management functions has been influenced by the need for coordinated action and information requirements.

Centrality is one of the characteristics which Gulati et al. (2002) attribute as decisive for individual firms' performance outcomes in networks, albeit supply networks are not specifically discussed. They associate degree centrality with higher cooperative experience and better capabilities to extract value from the network (ibid, p. 288). The authors do admit, however, that "empirical evidence on the linkage between degree centrality and firm performance is very limited and mixed" and they infer that degree centrality cannot stand alone but needs to be complemented by other centrality measures (Gulati et al. 2002, pp. 288-289). Closeness centrality is associated with information access as well as with accessibility for other firms that may approach the focal firm to jointly pursue opportunities. Betweeness is the third centrality measure discussed by the authors. Betweeness centrality is associated with control of information and resource flow, providing the firm with high betweeness centrality with a powerful strategic position in the network. Due to their generality, the advantages the authors attach to the three types of centrality do have implications for the management of bottlenecks in supply networks, too. Information access is crucial for the focal firm when appropriate measures are to be taken in the face of supply shortages. Control of network relations, e.g., the information exchange between suppliers and possible competitors, is desirable, as is power so as to be perceived by suppliers as important customer.

Mizgier et al. (2013) apply different measures from network theory in order to assess their ability to identify those nodes which possibly pose an increased risk of material flow interruption in a stylized supply network. Among the measures they use are out-degree centrality, betweeness centrality, weighted betweeness centrality, and radiality. Depending on the measure they apply, different nodes in the network are indicated to be „important“. Each measure has one or several advantages or disadvantages. Unfortunately, the analysis put forth by Mizgier et al. (2013) lacks interpretation. That is, the authors do not explain the implications of, for instance, a supplier being highly interconnected with other suppliers (in case of degree centrality). Network measures, however, have very different implications depending on the context in which they are used. Thus, the topological properties of networks are almost only of relevance if they are seen in the context of their practical meaning. A bank, for example, faces a very different situation when its network connections represent relationships to banks which it lent money and which own high-risk assets as compared to network connections representing relationships to other banks from which it borrows money. In each case, centrality may be high, yet the implications for the bank in the face of a recession may be completely different. The same is true for supply networks. Topological properties require further explanation if they are to be used as indication for the risk of unplanned bottlenecks. An OEM receiving material from a broad range of suppliers will likewise show a high level of in-degree centrality. In the latter case, however, in-degree centrality would not necessarily suggest any desirable characteristic on side of the OEM. In the context of material flow, it may have certain important implications, however, as the company has to integrate a variety of incoming material flows. If the company with high in-degree centrality is a supplier itself integrating incoming material flow from several second-tier suppliers, there may be an increased risk of the company becoming a bottleneck to its customer. One reason is that probabilities of failures multiply if several components are to be integrated into one piece; i.e., the more incoming material flows there are that need to be integrated, the higher is the probability that perturbations will arise. Therefore, "integrators" (Kim et al. 2011) deserve some increased attention from their customers. That being said, the type of inbound ties makes a difference: High in-degree centrality can suggest a critical point for material flow integration if most incoming ties are dedicated each to a distinct material flow – as opposed to several ties providing the same material as in case of dual- or multiple-sourcing strategies which obviously lower the probability of a bottleneck arising.

Of particular importance for questions of material flow is *betweeness centrality* (cf. Section 2.5.2.1 on page 83). Nodes with high betweeness centrality tend to be structurally important for the network. That is, if such a node fails, then increased effort is necessary to bypass the failing node and maintain operations. If the central node owns certain intangible assets that cannot easily be transferred – or the transfer of which is not in the interest of the node – then interruption of operations can be expected. This may be the case if the node in question holds a monopoly for the goods it supplies. A focal firm's dependency on sole supply from a node with high betweeness centrality can thus be considered risky.

2.5.3.2. Tie-level Properties and Performance Implications

Cohesive ties constitute cohesive subgroups. Generally speaking, cohesive subgroups are found where companies are particularly well embedded in a subset of nodes of a network. The implications for a focal firm depend on whether it is part of that group or not. If the focal firm is embedded in such a group (or even a *clique*), then it can possibly experience certain benefits for the management of its supply. Such benefits are, for instance, higher level of mutual trust, higher commitment of its suppliers, better information sharing, higher flexibility, and better resiliency (Uzzi 1997). Configurations that correspond with the concept of cohesive subgroups can be found in Japanese *Keiretsus*. Bhappu (2000) cites research according to which the way industrial organizations in Japan function must be explained by reference to the traditional Japanese family structure and the way it used to govern its family business. Successful large-scale family firms – called *Zaibatsu* – were broken up in the wake of Japan's defeat in World

War II. The parts into which the Zaibatsu were broken up were still linked by strong social ties which continued to coordinate their action despite the lack of common formal governance structure. Over time, this coordination has become increasingly institutionalized to build what today is referred to as Keiretsu (Bhappu 2000, pp. 410-413). In this context, Beer (2011) reports an example of a supply shortage that has been resolved through a mutually beneficial deal. In that case, a Japanese automotive firm was in short supply of glass panels. The (Japanese) manufacturer of these glass panels also is a manufacturer of laptop computers. The supply shortage could be resolved when the automotive firm agreed to equip a significant number of employees with new laptop computers from its glass panel supplier. Borgatti & Li (2009, p. 14) present an example of Toyota's supply network. The manufacturing facility of the sole supplier of one component was destroyed by a fire so that Toyota's production had to stop. Due to good relationships between the individual firms in Toyota's supply network, several suppliers collaborated to enable the continuation of production of the missing part within a short period of time. Borgatti & Li (2009) assert that it is the density of the Toyota ego network that accounts for this successful collaborative effort.

The situation is different if the focal firm is an outsider to the cohesive subgroup. In this case, the focal firm may under certain conditions experience a higher chance of supply irregularities. If a supplier faces capacity shortage and has to allocate its insufficient remaining capacity, the focal firm may become subject to lower prioritization as compared to members of the cohesive subgroup.

2.5.3.3. Network-level Properties and Performance Implications

As to *density* and *structural holes*, there are several advantages and disadvantages attached to having structural holes in one's network, many of which are related to the availability of non-redundant information. Individuals or organizations filling structural holes may be able to enjoy a power advantage as they serve as relay for information flow (Newman 2010). The advantages and disadvantages related to information flow are likely to be lower significance in the context of this study. Borgatti & Li (2009, pp. 13-14) theorize on the case that a lack of structural holes in a supply network leads to high interdependence between various suppliers so that the supply stream to the buying firm can become disrupted in spite of various simultaneous sources of supply.

Structural equivalence could represent a challenge for both supplying and buying firms in the network. If two manufacturers are structurally equivalent, the two buying firms may impose conflicting requirements on their suppliers, which would lead to inefficiencies and increased communication requirements, thereby increasing transaction costs. Also, the suppliers may have to set up "firewalls" between accounts so as to prevent the transmission of confidential information of one customer to the other. One customer may also be concerned that the competing firm will benefit from his joint R&D effort with the supplier. More importantly though, suppliers will have to make allocation decisions in case they do not have enough production capacity or enough parts from their suppliers to fulfill all orders from both customers on time, which can cause supply interruptions for either firm or even for both firms.

Such a situation does not require equivalence; similarity or even one common node in the supply network can already case perturbations. It is not uncommon that suppliers not only have multiple competing customers within the same industry but also have customers from other industries. With automobiles increasingly becoming mobile supercomputers, they share technology and parts with products from completely different industries, such as consumer electronics.

2.5.4. Supply Networks as one Type of Organizational Networks

Relationships can exist for a wide variety of purposes of which only a few are interesting in the context of this dissertation. In supply networks, these are information flow, material flow, and financial flow. As Harland et al. (2001) put it, the "primary purpose" of the organizations connected in supply networks is "the procurement, use, and transformation of resources to provide goods and services" (p. 22). Whereas information flow often occurs based upon merely implicit agreements, legally binding contracts are almost always the basis for exchange of material and financial means. Such contracts do not necessarily exist between the two parties directly involved in the exchange process but can also exist between a focal company (such as the OEM) and a second-tier supplier which has been selected by the OEM to supply its first-tier supplier (Kim et al. 2011). This concept wherein an OEM controls the sources of material of its direct suppliers is often referred to as "directed buying" or "directed sourcing".

Supply Chain Management (SCM) has become one of the dominant streams of research in logistics. This term as such, however, appears to be misleading as it has connotations of linear *chains* of organizations with *sequential* division of work and only *sequential* interdependencies, *managed* by an entity mighty enough to enforce rules and behavior comprehensive enough to be considered management. Some authors assign quite noble goals to supply chain management, such as the overall maximization of value (or 'supply chain surplus') generated (cf. Tan 2001, Chopra & Meindl 2010), and thereby generate a mental model of altruistic individual actors which are willing to sacrifice their own return for the sake of fair distribution of benefits among all supply chain partners (Beer et al. 2012). In reality, many interorganizational relationships are likely to be less romantic and more complex with a multitude of interdependencies not only within supply chains but also between several supply chains that share certain organizations (Dubois et al. 2004). Section 2.4.4 (pp. 67 et seq.) discusses supply networks from a Complex Adaptive Systems perspective; together with the discussion of dependencies and interdependencies among firms in networks (114 et seq.) it can be be conceived of supply networks as complex webs of firms that neither exist nor do business in isolation but instead are characterized by a multitude of different ties among them. Supply *chains* thus appear to be heavily simplified models which can't explain certain behavioral patterns of organizations. Extending the view to include lateral relationships to other suppliers and competitors then provides answers which cannot be found within the narrow perspective of the individual organization, the dyadic relationship, or the supply chain.

In addition to the simplified conception of supply structures as chains, there is reason to question the attitude assigned to organizations towards candid cooperation. Lonsdale (2001) remarks that the adoption of the expectations that organizations would happily cooperate and share information indicates “a lack of awareness of context” (p. 22) on side of lean management proponents who transferred a Japanese attitude towards business cooperation to the West and thus to a different behavioral context. Furthermore, it ignores opportunism (the existence of which is one of the fundamental assumptions of Transaction Cost Economics, cf. Williamson 1975, 1979, 1985). This is not to say that close cooperation does not exist; rather, it is suggested that a useful conception of supply networks should be consistent without reliance on altruistic behavior. A tension between overall optimization and local optimization exists in supply networks, as it does exist even within many factories (Skinner 1974).

Peck (2005) points out another aspect of the popular supply chain notion that does not correspond with reality. Optimization of information and material flow for close collaboration requires stability which is hardly a typical characteristic of many modern supply networks. In response to the“seamless supply chain model” (Geary et al. 2002), she notes that

> “It reinforces the notion of simplicity by promoting the vision of a stable, controllable, linear, self-transporting flow, hermetically sealed from disruptive environmental forces” (Peck 2005, p. 219).

In fact, an uncountable number of SCM publications begin with a vivid description of the ever-changing, complex market environment in a globalized and interconnected world. Hence, many authors negate the conditions for stable supply chains before they continue to discuss the advantages of closer cooperation, process integration, and other tenets of SCM. This tendency is fortified by the prescriptive character that is prevalent in much of the literature on SCM. Stebbings & Braganza (2009) suggest that theories “that assume alignment, equilibrium or harmony” between organizations may be “inadequate for the future” (p. 28). The authors emphasize the importance of adaptive network configurations as a means to deal with continuous change.

Johnsen et al. (2008) note about the origin of the term SCM:

> “The expression supply chains — and, consequently, supply chain management (SCM) — appears to have been invented in the early 1980s, principally as a simplistic method of describing the much more complex concept of a business network. It further appears to have been started as a means of selling management consultancy and early commentators do not offer much of a theoretical base. (...) Despite its weak provenance, ’supply chain’ has been welcomed into business parlance worldwide. (...) SCM does appear to have met success as an aid to selling management consultancy services and recently attracted theoretical discussion, albeit lacking consensus in its etymology.“ (pp. 71-72)

The “lack of consensus in etymology” of SCM becomes obvious when comparing the broad variety of definitions of SCM that have emerged over time (see, for instance, Tan 2001). This lack of precision makes the term arbitrarily usable in any situation where supply of goods, integration of processes, sourcing decisions, change of delivery mode, supplier base reduction, etc. are involved.

One might argue that if one piece of material is the object of interest, then it normally flows along a consecutive series of value-adding stages which could indeed be described as a “supply chain”. In fact, New (1997) contends that “supply chain” can be understood in three ways (of which the second one corresponds to the previous example):

1. “the supply chain from the perspective of an individual firm (as in ’ZipCo’s supply chain’);
2. a supply chain related to a particular product or item (such as the supply chain for beef, or cocaine, or oil); and
3. ’supply chain’ used as a handy synonym for purchasing, distribution and materials management” (p. 16).

It will be argue that the third meaning of supply chain as proposed by New (1997) is dominant, the first meaning is misleading, and the usefulness of the second meaning depends on the context.

2.5.4.1. The Notion of the Supply Chain from the Perspective of an Individual Firm

As to the first meaning of supply chain as proposed by New (1997), it is evident that firms do not normally deal with isolated and independent supply chains (Beer 2011, Beer et al. 2012), nor do many firms have only one single supply chain. Likewise, suppliers normally have more than one customer and supply performance can be affected by supply relationships with other customers. Indeed, buying firms sometimes compete for supplier capacity and use their negotiating power to push suppliers to allocate a greater share of scarce capacity in their favor. The automobile industry provides plenty of examples of powerful OEMs competing for parts in short supply, e.g., microchips and glass panels for GPS units.

Not only will most suppliers have several customers who can affect each other in their decisions towards the supplier, but customers can also be part of very different industries. The fact that firms compete across several industries can lead to surprising effects both, for suppliers and buying firms — but especially for the latter. Strong demand for Apple's iPhones and other popular consumer electronics gadgets, for instance, can lead to part shortages and increased lead times in the automotive sector as Apple (or Foxxconn, for that matter), Sony, and other major consumer electronics producers may be more attractive and lucrative customers for microchip producers than any automotive supplier (Beer 2011).

Apparently, it is not only the direct suppliers, or the suppliers of the direct suppliers, that can cause perturbation in material and information flow; unexpected situations of material shortage in the supply network can be caused by a variety of reasons, and many can be found outside the direct contractual relationships of a supply chain. Choi & Kim (2008) thus contend that more consideration should be given to the network the supplier which the focal firm wants to connect to is embedded in. It is not sufficient to examine the supplier in isolation if realistic conclusions are to be drawn prior to sourcing decisions about the supplier's performance and its potential as the supplier's own supply network can indirectly, through the supplier, affect the buying company. Thus, the supply network the supplier depends on for its incoming material flow deserves attention from the buying company.

The interest of the buying firm is to maintain an uninterrupted flow of all material and information necessary to be able to conduct its operations while maintaining or increasing operational efficiency. Many reasons for interruptions in supply, however, can be found outside the operational boundaries of the direct supplier which does emphasize the importance of a wider perspective on the management of supply beyond a notion of linear chains. Supply Chain Management arguably provides the methodological tool kit for a wider perspective that takes into account several value-adding stages since an inherent part of the SCM concept is to look beyond the first tier of supply and "integrate"[20] higher tiers into the supply management perspective. In fact, several definitions of SCM mention the entire chain of material and information flow from raw material supply through end customer as object of management's interest. Empirical evidence that such a perspective is adopted in reality is scarce, though; in particular, automotive (Beer 2011), apparel, and electronics industry seem to focus largely on their direct contractual partners with the latter two even being unable or unwilling to prevent frequent incidents of child labor and life-endangering working environments, as media reports reveal every other month.

Therefore, the notion of supply chains from the perspective of an individual firm is not an adequate description of reality.

2.5.4.2. The Notion of the Supply Chain of a Particular Product or Service

New (1997) suggests that "supply chain" can be understood as the physical flow of a particular product or service. This notion seems to be straightforward as the flow of one piece of material through several sequential value-adding stages can be adequately described as a supply chain. It remains to be seen whether this notion is useful, too.

Many non-trivial products in the manufacturing context consist of several components which are assembled in a series of value-adding stages and even-

[20] "Integration" appears to be one of the tenets of SCM

tually make up the final product. Many of the different components originate from different sources (i.e., suppliers). A tier-3 supplier may receive a variety of components which are then put together and delivered to the tier-2 supplier. The tier-2 supplier, in turn, will combine the components delivered by several tier-3 suppliers to a semi-finished good which will be delivered to a tier-1 supplier. The tier-1 supplier, again, integrates a variety of components received from various tier-2 suppliers before supplying the OEM for final assembly. The material flow of each individual component can be described as a supply chain; each individual supply chain will merge with another on the various tiers. For such a supply configuration, the supply chain model seems to be no particularly good representation of reality.

In contrast to the sequence of supply and assembly that has been described in the previous paragraph, there are products which are not combined with other products on the various value-adding stages. Some products are processed and thus are transformed while the "chunk" remains the same. Other products are delivered through a chain of carriers not for reasons of product transformation but for logistical purposes as in some complex international trade with a variety of different traders and distributors who take care of transportation, tariffs, and country specific legal obligations. Examples are some agricultural products and (illegal) drugs. The supply chain notion can be useful to describe the physical flow of such products the core or chunk of which remains the same through several value-adding stages.

In the manufacturing context where on many value-adding stages components are processed and integrated with other components before they are delivered to the next supplier, the supply chain notion captures only a peripheral part of the whole picture which would be more adequately described as a network. There is reason, however, to switch to a supply chain perspective if one particular components becomes the object of interest. Such a situation would emerge, for instance, in cases of part shortages where the bottleneck for the supply of one particular component is to be resolved. Part shortages often exist for one particular component and channeling an increased amount of attention to the part in short supply is prudent. For the sake of practicality one may want to talk about the supply chain for, e.g., glass panels, leather, or microchips to clarify where a part shortage has emerged.

Whereas the notion of supply chains for particular products or services seems to be well established in business parlance, it seems to be of no great use when identifying and eliminating bottlenecks. The reasons for the emergence of bottlenecks in supply can often be found outside the direct supply chain of the part in short supply. In fact, it may be difficult to understand the origin of the part shortage unless one adopts a network perspective as the following points shall demonstrate.[21]

Conflicting Requirements on Suppliers Suppliers normally have more than one customer. Each customer may expect a supplier to adopt specific processes, use certain software tools, employ and commit to standards. Also, customers may expect supplier to commit to certain capacity reserves and performance targets. In order to meet all requirements imposed by customers, suppliers sometimes have to dedicate significant resources. The resources dedicated to fulfill requirements from one customer may be missing when attempting to fulfill requirements from another customer. Also, certain rules imposed by one customer may conflict with rules imposed by another customer.

Competition for Supplier Capacity Depending on their product line, suppliers may have several customers from the same or similar market segments. That is, several customers may follow similar demand patterns as their market segment is growing or declining. Suppliers producing for BMW's 5-series may also supply Audi for the A6 and Mercedes-Benz for the E-Class. Accordingly, suppliers may face increasing capacity utilization when market demand for luxury sedans is growing and several customers simultaneously increase their orders. This tendency is fortified when several customers are supplied from the same tools or the same assembly line. Additionally, one or several customers may have market power that allows them to command guaranteed delivery —

[21] The following arguments have been published in Beer et al. (2012). The original paper draws on evidence from the automobile industry; the general implications, however, are likely to be valid in a variety of manufacturing industries.

on the expense of other customers. While suppliers would certainly hesitate to admit that this happens, some customers are certain about their being disadvantaged with delivery of parts in short supply due to other (competing) customers negotiation power (Beer 2011).

Cultural Influence and Loyalty Supply for many products is organized on a global basis. The reasons are diverse; cost pressure may play a role for global sourcing decisions, but sometimes specific production capabilities are only available in certain regions. Such regions may have a certain cultural code that differs from the cultural code of the customers. Much of the electronics industry, for instance, produces in Asian countries, predominantly China, Japan, and South Korea. Leading Western electronics firms focus on the invention, design, and marketing of products while outsourcing the entire production process (Sturgeon 2002). The relationships between firms in Asian countries like Korea and Japan are influenced by different cultural patterns than they are in Europe or the United States (Hofstede 1984, 1993, Bhappu 2000) and their organizational culture differs accordingly (Schein 1990, 2009). Interorganizational constructs like the Japanese *Keiretsu* have attracted much attention from researchers as the implications for business can be significant (Teece 1996). Trust, possibly fortified by institutional and societal sanctions, is one of the outstanding characteristics of relationships within these networks (Hagen & Choe 1998). There is reason to expect that firms embedded in such networks are not independent in their decisions but that they are constrained due to their interorganizational relationships (Granovetter 1985) which – measured by the standards of the Western observer – are often maintained for long periods of time. While this reduces uncertainty for partners within such networks, it does increase uncertainty for firms maintaining business relations with firms from within a Keiretsu while not being part of it themselves.[22] In cases of short supply, it can be expected that

[22] *Uncertainty* is an inherent characteristic of most transactions and is (essentially) due to incomplete information. It can be further divided into environmental uncertainty and behavioural uncertainty. *Environmental uncertainty* is caused by difficulties of predictability in general and by *bounded rationality* in particular (Rindfleisch & Heide 1997). Bounded rationality is one of the key concepts of Transaction Cost Economics (TCE) and refers to the assumption that actors do not have complete information and thus are limited in their rationality. The

firms embedded within an interorganizational network like a Keiretsu – or even just within the same cultural sphere – are more likely to find a solution for their supply problems if the producer of the scarce parts in demand is also part of the network.

Planning Horizon for Production Capacity In industries that produce on a large scale – such as automotive – sales forecasts provide valuable information for suppliers to plan production and adjust production capacity. Different customers, however, tend to provide forecasts for differing time horizons, and these differences can be significant. While some OEMs may provide forecasts for, e.g., nine months, others provide forecasts for, e.g., only three months. In addition to variances in time horizon, interviews with automotive suppliers have shown that there are also variances in forecast quality between different customers (Beer 2011).[23] The consequence is that suppliers can have difficulties planning their production capacity; accordingly, they may turn into bottlenecks and some customers may face part shortages in spite of their providing their suppliers with the necessary information on sales. The interviews showed that suppliers seem to generally try not to let any particular customer down even when their short planning horizon or unreliable data have led to perturbations,

TCE concept of bounded rationality thus contradicts the notion of rational decision-makers as proposed in neoclassical economic theory. Because actors are limited in their rationality they are unable to create and conclude contracts that provide for all contingencies, that is, there will always be a certain amount of uncertainty remaining which can lead to higher transaction costs. Looking at it the other way around, actors will have problems to create and conclude *complete contracts* because the environment is uncertain and may change which may make adaption of contractual agreements necessary and thus leads to increased transaction costs; Williamson (1979) asserts that "long-term contracts are necessarily incomplete (by reason of bounded rationality)" (p. 241). *Behavioural uncertainty* refers to the difficulty of predicting and assessing behaviour of other actors (Rindfleisch & Heide 1997 call this a "performance evaluation problem"). Part of the problem is *opportunistic behaviour* which TCE assumes to be a characteristic of human individuals and groups of individuals (organization). Williamson (1979) defines opportunism as "seeking advantage" or "self-interest in guile", which obviously implies incomplete information on the part of the contract partner if successful.

[23] Also, there are differences in forecast quality for the same customer for different components, which can create additional planning problems. In an earlier paper – Beer & Liyanage (2011) – adjustment of production capacity flexibility rates for supplied parts with certain characteristics was proposed.

so capacity problems may impact all customers, even the most reliable ones, if they arise (Beer 2011).

Indirect Demand from Competitors and Other Industries Many products share certain components although they may be from completely different industries as high-tech components become part of everyday life in a variety of ways. Cars, for instance, could be circumscribed as "computers on wheels" as no modern car would be functioning without real-time data processing for engine control and advanced driver assistance systems. Likewise, household appliances, air conditioning, security systems, and other devices and systems have computerized components that, in their core, often build on the same technology as cell phones or laptop computers. Accordingly, suppliers of microchips, glass panels, human interface devices, etc., have acquired customers that traditionally have not been part of their customer base; vice versa, OEMs have to manage suppliers that traditionally have not been part of their supplier base.

For suppliers, a broad variety of customers from different industries can make capacity planning even more challenging. For customers, unexpected part shortages may emerge when suppliers face capacity constraints and decide to focus their efforts on those customers that, for instance, pay the highest margins. While some industries demand cutting-edge technology with product life cycles shrunk to only some months, other industries demand relatively low-tech components for their products as product life cycle extends over several years. The first category of customers often pays high margins and constantly demands improvements in product performance whereas the second category of customers will be supplied with the same product for several years. An example for the first is consumer electronics, an example for the latter automotive. Accordingly, supplying automotive firms is less attractive for some electronics production firms than supplying consumer electronics firms such as Apple or Sony. Indirect demand from consumer electronics, for instance, could therefore lead to part shortages for automotive firms, especially when global production capacity is limited, as it has been the case for semiconductor production in the wake of the economic recovery after the 2007-2009 crisis.

Supplier Ownership In their search for capital, some firms open up to international capital markets. Additionally, large companies are looking to invest their their capital internationally. Increasingly many lucrative German SMEs, for instance, have been acquired by Chinese companies in recent years (Eisert 2013-04-13). In some industries such as automotive, strong consolidation among suppliers has taken place (Semmler & Mahler 2007). The ownership structure of suppliers may not always be obvious at first glance and OEMs may unwittingly source to suppliers owned by competing firms. Even if ownership structure is known suppliers may be contracted for good reasons such as cost competitiveness or unique quality promises. Conflicts of interest may arise if suppliers have to allocate resources while several customers – the company owner among them – are in short supply. The German automotive supplier Angell-Demmel, for instance, had faced capacity shortages due to internal production bottlenecks and was unable to meet the demand from several of its customers, among them some German OEMs such as Mercedes-Benz and Audi. Angel-Demell is owned by Faurecia, a large French automotive supplier, whose largest share is held by the Peugeot Société Anonyme (PSA), the producer of Peugeot and Citroën cars. With regards to complicated cross-ownership structures in some Japanese Keiretsus or multi-faceted industrial conglomerates in other Asian countries such as China or South Korea, disadvantages in capacity allocation are a possible threat to supply reliability, which may be fortified by cultural influence and loyalty as described above.

2.5.4.3. The Notion of Supply Chain as a Synonym for Purchasing, Distribution, and Materials Management

The third dominant interpretation of supply chain according to New (1997) is its understanding as a synonym for purchasing, distribution, and materials management. In fact, this seems to be the meaning that has been most widely adopted. Supply Chain Management has become so dominant a term that among professionals and researchers alike many seem to consider SCM the more encompassing term while *logistics*, for instance, represents only a subset of SCM tools and concepts. Other consider the two terms equivalent and use them interchangeably. Apparently, management parlance and associated media have, through the ubiquitous use of the term, helped it dominate the much older and classical term logistics in the perception of many. At least part of its success can be explained by the SCM field's lack of conceptual clarity: its vague character makes it easy to apply it to everything from transportation to integration of business processes. Researchers have acknowledged the lack of conceptual clarity long ago (cf. Cooper et al. 1997, New 1996, 1997), yet after about 30 years up to the present day there is still no consensus as to a precise definition of Supply Chain Management and "much writing in this area is based around a loose agreement on a general theme" (New 1996, p. 19). New (1997) suggests that Supply Chain Management is also characterized by a "'normative tension' between the *is* and the *ought*" (p. 16), i.e., the claims of what Supply Chain Management ought to be according to its various (and often somewhat pompous) definitions and what it actually is in practice indicate a gap that cannot be filled by academic explanations of inadequate implementations in real life industry environments. Given the handiness of a concept that is intuitively appealing for laymen and at the same time vague enough to make a smart impression in a broad variety of business situations, the success of the SCM concept is not surprising, its conceptual gaps and broken promises notwithstanding.

2.5.4.4. Proposition About the Adequacy of the Supply Chain Model

As it has become obvious from the preceding discussion, supply chain can be a valid and useful model under certain circumstances. Its use in great parts of the literature, however, does not distinguish between conditions where the supply *chain* model is a useful representation of reality and where supply *network* would be the more adequate representation.

Borrowing terminology from critical realism, it can be stated about supply networks that they contain both *necessary* and *contingent relations* between organizations. The relation between a buyer and a supplier is a necessary one. If the buyer did not buy from the supplier, it would not be a buyer; the existence of a buyer necessarily requires the existence of a supplier (seller), and vice versa. There may be additional relations in a network, however. A supplier may maintain additional relations and the existence of such relations may have implications for the focal buyer-supplier relation. On a *physical level,* the supplier might have obligations towards other buying firms, too. Other customers might be competing for the supplier's attention and capacity, and how successfully they compete can influence the focal buyer-supplier relationship. On a *social level*, the supplier – and more specifically, the entities nested within the supplier: the supplier's employees – may have relations to and be influenced by the culture of their home country to which they might adhere to varying degrees. It is mostly the physical level of contingent relations that indicates the usefulness of a network model as opposed to a chain model of interorganizational buyer-supplier relationships.

In the preceding paragraphs, three meanings of supply chain were explored that New (1997) considers dominant in the literature. It was argued that the notion of supply chains from the perspective of an individual firm is not useful as firms in most cases will not deal with isolated chains but networks of supplying firms. As to the second notion of supply chains of particular products or services, it was argued that this perspective can be useful in cases where the object of interest is a clearly distinct component whose main characteristics remain unchanged throughout the supply processes yet in many other situations will not be a useful model for actual supply processes. As to the third meaning, it was argued that the notion of supply chain as a synonym for purchasing, distribution, and materials management is wide-spread but imprecise and not scientific. Hence, not much seems to be won by adopting the popular notion of supply chains and Supply Chain Management and only very deliberately will these terms be used in this dissertation. The mental model conveyed by the terms supply chain and Supply Chain Management appears to be misleading.

As indicated earlier in this thesis (Section 1.3), the ontology adopted for this project is critical realism. A multiple-case study was selected as the method to gather and work with empirical information. As Easton (2010, p. 123) points out, "critical realist case approach is particularly well suited to relatively clearly bounded, but complex, phenomena such as organizations, interorganisational relationships or nets of connected organisations". He also notes that boundaries that were initially defined might need to be modified in the course of the research. After all that was said about the (in-)adequacy of the supply chain model, it seems apt to explicitly widen the boundaries of the research phenomena of interest to include not only linear or even merely dyadic interaction and effects but also the possibility of lateral effects so as to be able to explain and interpret phenomena (such as the unexpected emergence of bottlenecks that cannot be explained alone with incidents within a linear chain model) and actions in bottleneck management. Limiting the boundaries to the supply chain, important information – including relevant entities – would likely not be included in the investigation as they are pushed outside the researcher's too narrow window of attention.

This section addressed aspects of research question 7. Strong and to some extent certainly provocative statements were made in this section. The reasoning was based on a review of literature as well as on evidence from an earlier study in the automobile industry. The collection and analysis of empirical data in a later part of this project may provide further evidence that will put the claims made in this section to a test.

2.5.5. Aspects of Interorganizational Networks

2.5.5.1. Relationships between Organizations in Interorganizational Networks

Interorganizational networks can appear in a broad variety of forms, some of which can be close to what is often termed a supply chain while others can be very different. To some extent, it is a matter of the perspective that makes something appear to be a chain or a network (cf. previous chapter). If taking a material flow perspective, one discrete piece of material or one part always flows between the source organization and the destination and thus the product flow can be adequately represented through the notion of a supply chain. For products consisting of more than merely one piece of raw material that is processed on different stages of a supply chain, several different chains will supply one common destination (e.g., the OEM); however, the same principle holds true for different value-adding stages in the process, i.e., for tier-1 suppliers, tier-2 suppliers, etc.). The organization "managing" its supply thus deals with a variety of chains. Such chains are not always independent of each other but often have several links in common. Therefore, it may be more adequate to talk about *networks* instead of *chains* if the management of supply – as opposed to the material flow between two or more organizations in a linear setup – is the object of interest.

In manufacturing networks within industries operating close to the technological edge, i.e., industries dependent on R&D and aiming at innovative or high-tech products, it is more than the technical setup of material flow that is important to make an interorganizational relationship successful. Organizations engage in coordinated relationships for different reasons with different objectives. In the best case, objectives of all organizations within an interorganizational engagement are complementary or identical (or at least congruent to the greatest extent). In such a case, cooperative behavior can be expected so that transaction costs are low and the relationship is most beneficial. Identical objectives are also an underlying assumption of SCM as authors attribute an altruistic mindset to members of a supply chain. (cf. Chopra & Meindl 2010, p. 22 for an example). While it seems straightforward that all members of a supply chain are interested in making profits, it is debatable whether they are mainly or exclusively interested in their own financial results or in the financial results of the entire supply chain – or whether it is a matter of distribution of bargaining power (Crook & Combs 2007). Even within the relatively simple setup of supply-demand relationships, objectives can, however, be conflicting in spite of organizations agreeing on the broad setup of the relationship and having entered into the relationship by their own choice. Firms trying out different business models, for instance, may face resistance from their sometimes larger suppliers as the latter may have to cope with greater bureaucratic hurdles, lower flexibility, different governance structures, different intrinsic motivation, different organizational culture, different leadership mindset, etc. The case of Riversimple, a UK-based start-up, provides an example for possibly diverging objectives in supply-demand relationships.[24]

Riversimple wants to sell mobility – a concept based on a different business model than selling cars. In its pursuit of sustainable business, the company extends its responsibility beyond production and sale of cars; in fact, Riversimple does not sell cars to consumers but leases them out. While service and repairs are important business for most common car manufacturers, it is a financial burden for Riversimple. Instead of having the customer pay for service and repairs when they occur, Riversimple charges a monthly fee that covers all costs the customer would normally have to bear except for fuel (the cars run entirely on hydrogen). Hence, Riversimple is best of when all cars are working normally and no need for repairs arises. This creates strong incentives for Riversimple's engineers to develop high quality reliable products – as opposed to other car manufacturers that benefit from product failures after warranty is over and thus do not have similar incentives. Riversimple does face a challenge, though: If it maintains ownership of all cars and just leases them out, this would be going to inflate the company's assets. To avoid huge amounts of assets in its balance sheet, Riversimple tries to convince its suppliers to maintain ownership of certain components and lease them out to Riversimple. Apparently, not all suppliers embrace this concept as it threatens their traditional business model: selling stuff. As a small company, Riversimple does not represent a large share of sales for most suppliers and its bargaining power is limited. Therefore, Riversimple and some of its suppliers are likely to continue to face diverging objectives as important differences are rooted in conflicting business models.

Companies may enter interorganizational relationships for different reasons and engage in different activities. Supply-demand (or more general: logistics) is but one area where firms can engage, but even here there is a variety of different parameters that determine the quality of a relationship. Manufacturers purchasing off-the-shelve products from a perfectly competitive supplier market can maintain a more distant relationship to their suppliers than manufac-

[24] The information about the Riversimple case were gathered during the research project SustainValue over a period of three years. Data were provided verbally by two founders and one leading engineer on several occasions, both formal and informal. The case was not part of the multiple-case study conducted for this thesis and serves only as an illustrative example.

turers purchasing fully customized built-to-order products from a monopolistic technology pioneer. Even if organizations engage in a relationship in order to secure supply of raw material for its own production or assembly, the interorganizational relationship will never be limited to just one single aspect. The supply relationship represents but one tie among several. The existence of a variety of ties which exist in parallel between two organizations is called multiplexity (Borgatti & Li 2009). Even for a supposedly clearly delineated network category like supply network there are additional specifications to be made in order to be precise. Organizations can receive a variety of sorts of supply from water supply to office supplies to actual production input, each of which may have different requirements for management and are of different interest for the present examination. When being more precise and using the term supply network exclusively in the context of delivery of production input (raw materials), further distinction can be made between contractual relations and actual material flow as organizations may receive materials from other organizations with which they do not have any contractual relationship on their own but which are appointed through directed sourcing agreements (Kim et al. 2011). In such a case, a tier-1 supplier can receive material from one or several tier-2 suppliers which have been appointed by the OEM and which are contractually bound to the OEM. This type of tier-n management has generally been avoided in some industries (such as automotive) as it contributes to higher complexity and higher transaction cost (the OEM may be regularly involved when problems between tier-1 supplier and tier-2 supplier need to be resolved) but has gained more attention in the past couple of years (Beer 2011). Since the focus of this thesis lies on problems of material flow tier-n aspects such as directed sourcing are not discussed in detail.

Definition 2. In the context of this thesis, a supply relationship as the basic dyadic module of a supply network is defined as a relationship established through contractual agreement and aiming at the directional transfer of material intended as production input from a supplying company to a demanding company in exchange for money or other means of payment, other potential ties leading to multiplexity notwithstanding.

2.5.5.2. Dependencies, Interdependencies, Power, and Governance Mechanisms

When organizations work together and maintain relationships that go beyond market-based ad hoc relationships, i.e., relationships that are sustained for the medium or long term, they may develop embeddedness (Granovetter 1985) and interdependencies on one another (Provan 1993). Such interdependencies develop directly among organizations that have some type of regular exchange of information or goods, i.e., within what is often referred to as supply chains, and they can indirectly affect organizations that do not have a direct contractual or transactional relationship with each other but are related through common partner organizations or, more generally, common interest or fate. That is, interdependencies exist not only within but among different chains of relationships (Dubois et al. 2004, Provan 1993). Where interdependencies exist, some type of coordination – or more specifically: governance of this interdependence (Grandori & Soda 1995, p. 187) – is required so effort of either organization can be directed towards the right goals.

In his well-cited book, Thompson (1967, pp. 54-55) distinguishes between three types of interdependence[25]: pooled interdependence, sequential interdependence, and reciprocal interdependence.

Pooled interdependence refers to a situation in which "each part renders a discrete contribution to the whole and each is supported by the whole" (ibid, p. 54) and thus is indirect by nature, which can apply to the case, for instance,

[25]While Thompson (1967) is mainly concerned with interdependence of parts within an organization, his concept of interdependence can be applied well to interdependence of different organizations or groups of organizations. On the one hand, his three types of interdependence describe logical connections that can be understood independent of the context of organizational theory; on the other hand, the generation of value-added in many industries is distributed vertically and horizontally to a greater extent, i.e., the value-adding functions that used to be represented by one organizations are represented by a group (or *network*) of organizations, hence making the application of Thompon's concept of interdependence appropriate for application. Lazzarini et al. (2001) propose that sequential interdependencies have been subject to what is often referred to as Supply Chain Management, i.e., the analysis and management of sequential vertical relationships, whereas pooled and reciprocal interdependence are dealt with in network analysis, by which the authors understand the analysis of firms among which there are mainly horizontal relationships.

of a supplier network where parts of low quality supplied to the OEM by one supplier lead to poor reputation of the product, and, eventually, lower sales and thereby adversely affect business of other suppliers that may not even know the supplier responsible for this effect.

Sequential interdependence is asymmetrical and refers to a situation where one part is directly dependent on another part, normally coupled with a temporal delay, as it is the case when the work output of one organization serves as the work input of another organization.

Reciprocal interdependence refers to a more circular situation in which "the outputs of each become inputs for the others" (ibid, p. 55). These three types of interdependence are not mutually exclusive, as Thompson emphasizes, but can be represented on a Guttman scale (Guttman 1944):

> "[A]ll organizations have pooled interdependence; more complicated organizations have sequential as well as pooled; and the most complex have reciprocal, sequential, and pooled. Knowing that an organization contains reciprocal interdependence automatically tells us that it also contains sequential and pooled interdependence. Knowing that an organization contains sequential interdependence tells us that is also contains the pooled type. Knowing that an organization contains pooled interdependence, however, does not tell us whether it has the others" (Thompson 1967, p. 55).

Where interdependence exists, action needs to be coordinated when unintended (and potentially adverse) effects are to be avoided. Coordination can be difficult within an organization consisting of several interdependent parts; but as opposed to networks of organizations where there normally is no governing organization that can freely impose rules on other organizations in the network and can expect obedience, the governance of individual organizations with internal hierarchy can make coordination *relative* easier compared to networks of legally independent organizations. Indeed, Williamson (1992) emphasizes fiat as an important characteristic of hierarchies (i.e., governance forms of individual organizations). The term Supply Chain *Management* suggests that focal firms can, to a certain extent, “manage” their sources of supply. As indicated earlier, however, supply chains do rarely exist but are, in fact, networks, which again leads to even more difficult management due to the various interdependencies that can exist – even between organizations that do not sustain or have ever had a direct relationship. The question arises how networks can be managed at all and what exactly can be understood by “managing a network”. Ritter et al. (2004) suggest that single organizations do not normally control networks and that networks rather are self-organizing systems. Organizations do, however, “confront different types of relationship and network management situations, including those when they are in a powerful and controlling position, those when they are subject of others [sic] control, and those in which multiple parties have strong influence over each other” (Ritter et al. 2004, p. 177). This argument is broadly in line with Harland & Knight (2001) who point out that the dichotomy between the two extreme positions on network management often referred to in the literature – organizations either merely “cope” with the network according to one stream of literature, or they control the network according to the other stream – is not necessarily reflected in practice and that organizations can employ “different types and varying degrees of intervention that [represent] more or less proactive forms of network management (...)” (p. 486). Harland et al. (2001) suggest that it depends on the value the focal firm adds to the network through volume and/or innovativeness whether the firm will merely cope with or actively influence its network.

As for coordination of interdependent parts, Thompson (1967) suggests three different types of coordination which refer to the three types of interdependence he introduces (cf. p. 114): coordination by standardization, coordination by plan, and coordination by mutual adjustment.[26] The different types of interdependence and the related types of coordination are displayed in Table 2.5.1 on the facing page.

Thompson also suggests that the cost of coordination differs among the different coordination approaches and is increasing from coordination by standard-

[26]Thompson credits March et al. (1958) for the three types of coordination of which he modified the names.

Table 2.5.1. – Types of Interdependence with Types of Coordination and Cost Incurred (based on Thompson 1967, pp. 54-57)

Context	Type of Coordination	Type of Interdependence	"Burden on Communication and Decision"	Cost of Coordination
"Situations that are relatively stable, repetitive, and few enough to permit matching with appropriate rules"	Coordination by Standardization	Pooled Interdependence	Low: Infrequent decisions and low communication activity	Lower relative to coordination by plan and coordination by mutual adjustment
"For more dynamic situations"	Coordination by Plan	Sequential Interdependence	Medium	Higher relative to coordination by standardization; lower relative to coordination by mutual adjustment
"For more variable and unpredictable situations"	Coordination by Mutual Adjustment	Reciprocal Interdependence	High: Frequent decisions and high communication activity	Higher relative to coordination by standardization and coordination by plan

ization (lowest cost due to lower amount of communication necessary and less frequent decisions) to coordination by plan (more frequent communication and decisions necessary than for coordination by standardization yet less frequent than for coordination by mutual adjustment) to coordination by mutual adjustment. Mutual adjustment is the most dynamic and difficult to manage form of coordination and requires a high degree of managerial involvement and hence cost. Such coordination cost can be seen as part of transaction cost. The reason is that coordination attempts are not ends in themselves but are embedded in a broader context, or simply put: *something* will be coordinated for *some purpose*. That is, coordination is necessary if, for instance, products and services are exchanged or produced, when resources are shared or distributed, or when common strategic plans are devised (Williamson 1979, pp. 239 et seq.,1981, p. 563). Williamson (1979, 1981) assigns three attributes to transactions: frequency, uncertainty, and asset specificity. As indicated by Thompson (1967) (cf. Table 2.5.1), reciprocal interdependence requires the highest frequency in decision-making and communication and thus involves higher cost. Furthermore, uncertainty is higher in situations of complex interdependencies which makes successful coordination less likely and can lead to higher transaction cost. With respect to the determinants of adequate coordination mechanism for interdependence among different organizations, Alexander (1995) considers what Thompson (1967) proposes for interdependence among work units within one organization too simplified. Alexander (1995) contends that in interorganizational relationships it is not only the type of interdependence that determines the appropriate form of coordination, but rather a combination of the specific characteristics of the transactions between the two organizations and the type of interdependence in combination (p. 33). Thus, Alexander's argumentation is in line with the Transaction Cost Economics (TCE) view proposed by Williamson: Williamson (1992) suggests, for instance, that vertical integration without high degree of interdependency between two organizations should be avoided (p. 344). That is, transaction cost does not suffice all information requirements when the most economical form of governance is to be selected and it is necessary instead to consider interdependencies.

Where transaction cost is high, different forms of governance may be efficient than when transaction cost is low (Williamson 1991). Organizations affected by high transaction cost due to complex interdependent relationships may therefore consider resolving some of their dependencies through vertical integration – or a different form of governance in the network. A wide-spread assertion from proponents of Transaction Cost Economics is that any form of network governance can be seen as an intermediate (or hybrid) form between the two poles *market* and *hierarchy* (Williamson 1991). While hierarchy refers to a fully integrated organization that is not dependent on transactions with other organizations to produce its desired output, market refers to a form of governance where firms interact on ad hoc basis and receive all information necessary for their (non-repetitive) transactions from market prices. The dichotomy between markets and hierarchies can be traced back to Coase (1937).[27] Some researchers disagree with the assertion that markets and hierarchies are the poles between which there is a continuum on which all other forms of governance lie. In particular, Williamson's "rule" – "try markets, try hybrids, and revert to vertical integration only for compelling cause" (1985, 1992) – is questioned. Powell (1990) calls this notion a "distortion of historical and anthropological evidence" (p. 298). Grandori & Soda (1995), too, disagree with Williamson and maintain that neither coordination processes nor structures of networks have to lie between the two poles.[28]

Provan & Kenis (2007) have analyzed different modes of network governance with respect to their effectiveness in different settings. The settings vary in (i.e., the independent variables are) (1) the level of trust distribution among network participants[29], (2) the number of participants, and (3) goal consensus among

[27] Coase (1937) has approached the question as to why firms (i.e., coordination as "the work of the entrepreneur") have emerged in some cases whereas markets (i.e., coordination as "the work of the price mechanism") have remained the dominant governance form in other cases by reference to the cost of exchange transactions.

[28] Grandori & Soda (1995) appear to disagree not only with Williamson's notion of networks as hybrid forms but also with Powell's conception of networks as a third form: "Both approaches stress, in an unnecessary way, some interesting properties of networks at the expenses of others" (p. 184).

[29] Level of trust distribution refers to the question whether trust is rather widely and equally distributed among network participants or rather to be found in subsets of the network such

network participants. Combination of these variables can serve as a proxy for certain levels of complexity in decision-making and requirements on communication, and hence for coordination cost.[30] Conclusions to be drawn for the appropriate form of network governance can thus be assumed to be comparable. Provan & Kenis use one additional output variable besides the proposed form of network governance: the need for network-level competencies for network participants which itself can be understood as a proxy for coordination requirements. The three forms of governance Provan & Kenis (2007) propose are

1. “shared governance”,
2. “lead organization”, and
3. “network administrative organization”

which, in this order, are considered to match increasing levels of network complexity. Shared governance refers to a governance form where no participant in the network carries higher responsibility for the effectiveness of the network than other participants. Lead organization refers to the situation that one organization in the network accepts (or actively claims) higher responsibility for the network outcome. The automobile industry can serve as an example since in many cases the auto manufacturer “manages” its suppliers and takes extended responsibility for the entire network’s success. The third form, governance with a network administrative organization, refers to a situation where one external organization is dedicated to network organization and coordination. Such a form of governance can be found in public-private partnerships and is related to the idea of fourth-party logistics providers. There are certainly other mixed forms that might be in place in practice, such as governance with a division of

as dyads. The other input variables are self-explanatory.

[30]The parameters cannot necessarily serve as a proxy for high interdependence, however, since this would require information about the nature of the ties between the different organizations in the network (Provan 1993). Until this point, it has been assumed there is interdependency among organizations in the network but it has not been discussed what the reasons for this interdependency might be. Provan & Kenis (2007) do, however, mention different levels of interdependence that require different levels of network-level competencies (pp. 12 et seq.). Hence, it seems that complexity and interdependence are assumed to be positively correlated which underlines the conclusions drawn here.

responsibility between an internal and an external lead organization. For their analysis, the authors focus on selected extreme cases, however. They assert that each governance model has its distinct strength and weaknesses and should find application in different situations. Table 2.5.2 displays the forms of network governance they propose for different configurations of input variables.

Gereffi et al. (2005) introduce a different typology of governance forms for networks. They use the combination of three independent (input) variables –

1. complexity of information and knowledge transfer,
2. codifiability of information and knowledge to be transmitted, and
3. capabilities of actual and potential suppliers

– to identify five distinct forms of governance for "global value chains". These forms are

1. markets,
2. modular value chains,
3. relational value chains,
4. captive value chains, and
5. hierarchy,

i.e., three forms of governance are conceptually located between markets as one pole and hierarchy as the other. Besides the form of governance that is likely to emerge, they define two additional dependent (output) variables:

1. level of explicit coordination and
2. power asymmetry.

While markets and hierarchy have been described above, the three remaining forms of governance require explanation.

In a modular value chain, a supplier in tier-1 position is responsible for the production and delivery of modules consisting of several parts which in earlier

Table 2.5.2. – Forms of Networks Governance as Proposed by Provan & Kenis (2007, p. 237)

Governance Form	Level of Trust Distribution	Number of Participants	Objective Alignment	Required Network-level Competencies
Shared governance	High	Few	High	Low
Lead organization	Low	Moderate	Moderately low	Moderate
Network administrative organization (NAO)	Moderate; monitored by NAO	Moderate – many	Moderately high	High

times might have been supplied to the OEM separately by several individual suppliers. This form of governance can be found in automotive production networks where tier-1 suppliers can be responsible to deliver an entire dashboard or fully assembled seats. With reference to Sturgeon (2002) who describes the same pattern for the electronics industry, the authors label such modular suppliers *turn-key suppliers*. Relational value chains is a description for networks of suppliers and customers with high levels of interdependence, asset-specificity, and switching costs. The last form of network governance is called captive value chain and describes a network relationship where the supplier experiences high degree of dependence on his customer as well as high switching costs. The customer plays the leading role in this type of relationship and imposes clear rules and requirements on its supplier. The forms of network governance as proposed by Gereffi et al. (2005) are summarized in Table 2.5.3.

Another aspect of interdependence that has been brought into discussion by Casciaro & Piskorski (2005) is the distinction between power imbalance and interdependence, where power imbalance refers to a predominantly one-way dependence relationships. According to the authors, significant power imbalance in a dyadic relationships suggests that no structural (governance) changes in the relationships between the two actors are likely to happen since the powerful actors will deny attempts of the dependent actor to reduce his uncertainty and dependence. Conversely, if the relationships is characterized by mutual dependence, i.e., *interdependence*, governance changes are likely to happen since both actors strive to reduce uncertainty.

Gulati & Sytch (2007) build on the dichotomy introduced by Emerson (1962) and further elaborated within the Resource Dependence Theory (RDT) context by Casciaro & Piskorski (2005).[31] They bring together the concept of interde-

[31] In its formal version, Resource Dependence Theory (RDT) originates in Pfeffer and Salancik's 1978 book "The External Control of Organizations" (reprinted as Pfeffer & Salancik 2003). Similar to the Resource-Based View (RBV), RDT deals with resources and the dependency on the organization's environment due to unequal distribution of resources; and similar to Transaction Cost Economics (TCE), RDT suggests that organizations attempt to reduce uncertainty through changes in organizational structure and coordination mechanism.

The focus of RDT is set on the organization's environment and the behaviour of organizations in the RDT framework is explained by reference to power and dependency over or on the environment, respectively:

Table 2.5.3. – Forms of Network Governance as Proposed by Gereffi et al. (2005, p. 87)

Governance Form	Complexity of Transaction	Codifiability of Knowledge and Information	Supplier Capabilities	Degree of Explicit Coordination and Power Asymmetry
Market	Low	High	High	Low
Modular Value Chain	High	High	High	
Relational Value Chain	High	Low	High	
Captive Value Chain	High	High	Low	
Hierarchy	High	Low	Low	High

pendence and embeddedness and argue that interdependence between two organizations will improve their performance through the logic of specific elements of embeddedness – joint action, trust, and improved information exchange. Hence, interdependent organizations achieve a stable and mutually beneficial relationship.

This perspective is broadly in line with Cook (1977) who argues that "actors prefer exchange with equally powerful actors because there are fewer costs attached to the exchange process" (p. 67). By power Cook (1977) refers to bargaining power as the converse of resource dependence. Equally powerful organizations thus would be mutually dependent.[32] This notion, however, is countered by Casciaro & Piskorski (2005) with their proposition that interdependence will let the organizations of the dyad face conflict and increased transaction costs in response to which they will intensify cooperation to improve their situation.

Grandori & Soda (1995) describe ten coordination mechanisms that networks of organizations can employ:

- communication, decision, and negotiation mechanisms,
- social coordination and control ("(...) in the sense of deep and stable

> "A good deal of organizational behavior, the actions taken by organizations, can be understood only by knowing something about the organization's environment and the problems it creates for obtaining resources. What happens in an organization is not only a function of the organization, its structure, its leadership, its procedures, or its goals. What happens is also a consequence of the environment and the particular contingencies and constraints deriving from that environment" (Pfeffer & Salancik 2003, p. 3).

Pfeffer & Salancik (2003, p. 3) further emphasize that dependence on the environment is not problematic as such:

> "Problems arise not merely because organizations are dependent on their environment, but because this environment is not dependable".

In this respect, RDT is very similar to TCE as dependency and uncertainty are important concepts in both theories (Nienhüser 2008, p. 12). RDT can also be considered a complement to RBV as Medcof (2001) suggests (p. 1002). The important characteristics of resources that create sustainable competitive advantage and constitute the core of the RBV tenet make an organization powerful with respect to other organizations which depend on such resources.

[32]In fact, they could also be completely independent to become equally powerful in terms of resource dependence.

relationships based on group norms, reputation and peer control (Ouchi 1979, 1980)" (Grandori & Soda 1995, p. 194)),

- integration and linking-pin roles and units (e.g., consortia for complex projects, interlocking directorates),
- common staff (e.g., "resident engineers" of automotive suppliers in OEM facilities),
- hierarchy and authority relations (organizations in networks may to some extent exert authority over one another, e.g., in franchise relationships and also in some supplier-buyer relationships),
- planning and control systems (e.g., audits),
- incentive systems (e.g., profit sharing schemes, property rights agreements),
- selection systems (e.g., sourcing criteria[33]),
- information systems (e.g., EDI and shared forecasting data), and
- public support and infrastructure (e.g., to control the use of shared resources; the authors refer to the "tragedy of the commons" problem, cf. Hardin 1968).

Grandori & Soda (1995) suggest that in different networks (and in different types of networks) these coordination mechanisms vary in their combinations, their degree, and the degree to which they are formalized, e.g., in contracts. They analyze different types of networks with respect to these two dimensions, distribution of coordination and degree of formalization. As to coordination, the authors distinguish central, asymmetric forms of coordination and parity-based, or symmetric, forms of coordination. In their analysis, central forms of

[33]"Even on the basis of casual observation of networking behaviour among firms, we can formulate the testable hypothesis that the broader the scope of cooperation, the stricter the rules of access will be" (Grandori & Soda 1995, p. 196).

coordination seem to be deliberately chosen by powerful actors who thereby are better able to exert and extend their influence and will.

A notion widely adopted in literature on dependence and interdependence between organization is that power represents the converse of dependence and that dependence of one organization on another thus equals power disadvantage of the first relative to the latter. Some researchers propose that having power advantage (over a dependent organization) therefore provides means of better performance. Starting from this hypotheses, Gulati & Sytch (2007) found in their study of relationships among suppliers and car manufacturers with different dependency profiles that this does not need to be so. For car manufacturers being dependent on suppliers, the authors could not find empirical evidence for improved performance of suppliers whereas for car manufacturers having power advantage over suppliers the performance effect was even negative. Yet again, there is some disagreement in the literature about the connection of possession of power and its use; some authors propose that possession of power will lead to use of power (Cook 1977, p. 67). These findings underline the need for a more elaborate discussion of power in interorganizational relationships. Kumar (2005) points out that talking about power as a generic construct is meaningless because there are different forms of power with different implications for interorganizational relationships. He distinguishes between dependence-based power and power based on punitive capability. Dependence-based power can result from the possession of important resources the other organization needs for value creation. Resource Dependence Theory, Exchange Theory, and Resource-Based View provide frameworks for analysis of this type of power. Power based on punitive capability can – but does not necessarily need – result from dependence-based power advantages. It describes one organization's "ability to inflict negative consequences on the partner" (ibid, p. 864). Cook (1977) discusses the converse relationships between power (by which she means bargaining power) and (resource) dependence in the context of Exchange Theory (Emerson 1962). In absence of other sources of necessary resources, an organization is dependent on the organization in possession of the resource. If alternative sources are available, the dependent organization can reduce its dependence and increase its bargaining power.[34]

However, dependence does not need to be absolute in order create power. Even in a monopoly or monopsony market situation a customer or supplier, respectively, may the have the ability to escape by changing technology, approaching new markets, changing his business model, or to obtain legal correction of the market situation. Hence, in many cases dependence can be represented by a certain amount of switching costs. This has implications for the use of power on part of the supposedly powerful party. Excessive exploitation of power advantage can lead the disadvantaged organization to opt for escape and accept switching costs. Therefore, the organization exercising power may experience a trade-off between value appropriation and value creation (Gulati & Sytch 2007, p. 59), i.e., the attempt to obtain a larger share of value will conflict with decreasing overall value generated. Organizations aware of this potential conflict may exercise power carefully in spite of the possession of potentially significant structural power advantages. Another hindrance to exploitation of power advantages due to one-sided dependence results from uncertainty with respect to future developments. Power advantages due to resource dependence, for instance, can be rendered useless if the hitherto important resource loses value due to innovation, can be substituted, obtained from additional sources, or otherwise becomes obsolete. Therefore, it is wrong to equate the possession of power with economical advantage.

2.5.5.3. Flow of Agents and Entities and Degree of Freedom

The design and setup of networks – or more generally: systems – not only depends on the objective that is to be achieved and on the means available, but also on restrictions or limitations that can be imposed on the planner or on the planning process from outside. Such restrictions can relate to the regulatory framework with which an organization has to comply and it can relate to actions from competing organizations. Generally, planning of a system – be it a supply network, a hospital, or a ski resort – can be described with a set of parameters

[34] Unless indicated otherwise, the use of the term power in the discussion of network relationships refers to dependence-based power.

Parameters	Planning		Operations	
Agents	Variable	Constant	Variable	Constant
Resources	Variable	Constant	Variable	Constant
Entities	Variable	Constant	Variable	Constant

Figure 2.5.4. – Parameters in Planning and Operational Stage

that may or may not be variable. Parameters that are not variable represent restrictions to the planning process.

A particular set of parameters that are part of the systems planning and execution process include the *agents* of the system, the *entities* of the system, and the *resources* of the system. The agents represent the subjects that perform operations with the entities – the objects – under utilization of the resources at their disposal. The resources required are determined by the activities that are to be performed. Activities also represent a parameter for planning and operations. They are no physical objects, however, and thus not of relevance at this point in time.

Systems differ with respect to the variability of these three parameters. Furthermore, such parameters may be variable during the planning process but may become constant once the planning phase is over and the system becomes operational. In the planning process of a factory, for instance, the location may be variable; once the factory building has been constructed, the location becomes a constant. Figure 2.5.4 illustrates the concept. In this figure, agents, resources, and entities can be understood as arrays, i.e., collections of elements that could be indexed. Accordingly, some agents, for instance, could be variable during operations while others are constant.

Up to this point, the description has been rather general. In the given context we can narrow the scope by focusing on the *physical flow* of agents, resources, and entities. The difference becomes obvious when different types of systems are compared, for instance a supply network and a hospital. In a supply network, the relevant physical flow is limited to entities, i.e., to the material that is processed and turned into a final product. In a hospital, on the other hand, physical flow consists of entities (patients), agents (doctors and nurses), as well as

Parameters	Supply Network	Hospital
Agents	Constant	Variable
Resources	Constant	Variable
Entities	Variable	Variable

Figure 2.5.5. – Parameters of Physical Flow in Operational Stage in a Supply Network and in a Hospital

resources (beds and technical equipment), and sometimes resources and entities are "grouped" and moved together, as in the case when patients are moved to a different room or part of the hospital while staying in their bed. The comparison is illustrated in Figure 2.5.5. That is, the *degree of freedom* for system configuration is much higher, which makes an optimal configuration a much more difficult objective to achieve as the number of different possible combinations increases.

2.5.6. Classification & Match of Supply Networks

2.5.6.1. Introduction

Supply networks can have a large variety of different characteristics that make them suitable for different market requirements. Obviously, the supply network behind a large automobile producer looks different than the supply network behind a retail store. In this section, common characteristics of supply networks are going to be explained. Moreover, a link will be established between the characteristics of a manufacturing system (as discussed in Section 2.2.2) and characteristics of supply networks that serve manufacturing systems. Finally, implications for bottleneck management will be outlined.

2.5.6.2. Types of Supply Networks and Strategies

It is debatable whether the majority of firms actually consciously elects and adopts a supply network strategy. Possibly, many networks have simply emerged as suppliers happened to be able to deliver a component which a manufacturing firm needed. When both firms were happy with such a relationship, it might have persisted over an extended period of time. On a low level, a conscious decision might well concern the priority a manufacturing firm assigns to certain characteristics of its supply operations. For instance, firms may put emphasis on *reliable* supply, on *quick* supply, on *responsive* supply, or on *cheap* supply, or on a combination of several of such priorities – with obvious trade-offs. When rather modern supply strategies like Lean are compared to the "classic" approach, the dichotomy stressed is often that between mostly cost-based approaches, with intense competition between several multiple sources, and the more efficient and better performing new approach, such as Lean. Such a dichotomy is often illustrated by case examples, with General Motors representing the retarded, cost-based strategy of the old world and Toyota representing the new approach, outperforming GM by far. Most likely, these popular case examples are no perfect representation of this dichotomy any longer, as industry analysts suggest (Cable 2009). Nevertheless, the point was made clear: different companies employ different sourcing and supply concepts, and some are more successful than others. Because product, demand, and production characteristics can differ significantly, firms are well-advised to choose their supply strategy accordingly.

Grandori & Soda (1995) characterize different forms of networks based upon their *mix of coordination mechanisms*. The dimensions they use are (1) the *degree of formalization* of the network exchange and (2) the *symmetry of coordination*. Network exchange can be rather *formalized*, as in case of bureaucratic networks such as trade associations, or rather *informal*, as in case of social networks such as personal social relationships. Moreover, networks can be *asymmetric*, as in the case when a central, often powerful, agent acts as an coordinator, or they can be more symmetric, when power and coordination is distributed more evenly (albeit not necessarily completely evenly). The symmetry of coordination, often correlated with power, is likely to influence the shape and content of supply relationships.

Fisher (1997) distinguishes between *functional* and *innovative* products on the one hand and between *responsive* and *efficient* supply networks on the other hand. He suggests that there must be a match between the demand character-

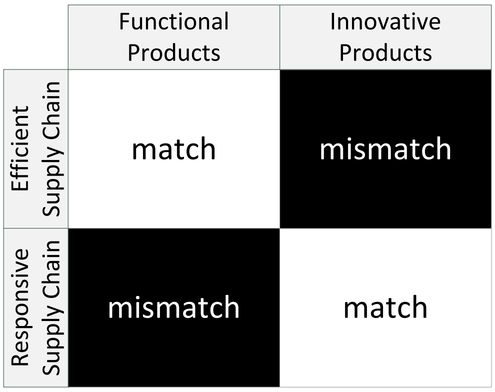

Figure 2.5.6. – Match Between Demand and Supply Characteristics (Fisher 1997)

istics for a product and the characteristics of its supply chain in order for the company to be successful. The demand characteristics of the product, he maintains, are influenced by many factors, but are primarily determined by the degree of its innovativeness (p. 106). Because demand for innovative products implies higher uncertainty than for functional products whose demand can be forecast with fair accuracy, supply networks need to be responsive when they serve manufacturers of innovative products and can be optimized towards efficiency when they serve producers of functional products. The principle is illustrated in Figure 2.5.6.

Lamming et al. (2000) extend Fisher's (1997) concept by adding requirements for *unique* products. They are building on the Resource-based View (RBV) notion of uniqueness and define unique products as those which are valuable, rare, non-imitable, and non-substitutable.[35] Moreover, the authors suggest that in-

[35]The Resource-based View puts emphasis on the importance of resources – as opposed to the market environment which has been emphasized by concepts such as Porter's (1980) Five Forces – for gaining competitive advantage or even *sustained* competitive advantage if the firm "is implementing a value creating strategy not simultaneously being implemented by any current or potential competitors *and* when these other firms are unable to duplicate the benefits of this strategy" (Barney 1991, p. 102).

The basic assumptions that sets RBV apart from much of the earlier research in strategic management (Priem & Butler 2001) are the existence of heterogeneous resource distribution and imperfect mobility of resources (Barney 1991, pp. 104-105). Several arguments concerning the quality attributes of resources and its implications for firms' (sustained) competitive advantage are based on these assumptions (Barney calls the different quality attributes renovative products and unique products are not generally the same; however, "it may be difficult in practice to differentiate between the two" (p. 681). Accordingly, they propose a distinction between supply networks for *functional* products and supply networks between *innovative-unique* products, closely resembling Fisher's (1997) dichotomy. In addition to the characteristic "competitive priority" which refers to the foci on flexibility or efficiency, respectively, Lamming et al. (2000) also mention "sharing of resources" as a characteristic in which the two types of supply networks differ. Whereas sharing of resources (such as staff, product information, cost information) tends to be unproblematic for supply networks of functional products, it may be problematic for supply networks of innovative-unique products. The reason lies in the uniqueness of the products whose characteristics firms may fear could be replicated by other actors in the network, the focal firm thereby losing its sustained competitive advantage. In addition to the distinction between supply networks for innovative-unique products and for functional products, the authors introduce *product complexity* as a second dimension with two characteristics (high and low complexity), thereby creating a 2x2 matrix in which they describe implications for competitive priority and options for resource and information sharing. The difference between networks for products of high and low complexity mainly lies in the need for more or less sophisticated information technology, respectively . Furthermore, their survey indicates that information sharing is inhibited when firms are marketing unique products (ibid, p. 688). Their resulting classification is

sources need to have for sustained competitive advantage "indicators of how heterogeneous and immobile a firm's resources are" (1991, p. 106)). To generate sustained competitive advantage, resources must be valuable, rare, imperfectly imitable and not substitutable (Barney 1991, pp. 105-106). Priem & Butler (2001, p. 31) point out that the former two attributes generate the competitive advantage whereas the latter two attributes make the competitive advantage sustainable.

Wernerfelt (1984) defines resources generally as "anything which could be thought of as a strength or weakness of a given firm" (p. 172). Among his examples are in-house knowledge of technology as well as skilled staff and trade contacts. The latter also indicates that interorganizational relationships may well count as a resource that can provide competitive advantage. Whether such a competitive advantage can be sustained depends on the specific relationship. Among the attributes of the relationship that are important for this question may be, for instance, contractual details (e.g., exclusive rights) as well as information about the market environment (e.g., relationships with a supplier holding a monopolistic position or being a monopsonistic buyer).

displayed in Table 2.5.4.[36]

Harland et al. (2001) assert that existing classifications of networks "offer limited operational assistance for focal companies trying to manage their networks effectively" (p. 22). Furthermore, the authors contend, existing classifications tend to be conceptual rather than empirically grounded. Based on empirical studies, Harland et al. (2001) offer a prescriptive framework based on two decision variables: degree of supply network dynamics and degree of focal firm influence. Network dynamics are based on internal factors such as operations characteristics as well as on external factors leading to uncertain demand conditions. Low degree of focal firm influence may be caused, for instance, by low purchasing and production volumes, or the focal firm being low on innovation, so that the firm adds little value to the network. Based thereon they define four archetypes of supply networks. In this framework, firms with low degree influence on the network appear to be *coping* with the network rather than being able to *manage* it whereas firms with high degree of influence tend to be able to make deliberate decisions rather than merely accept given conditions. At the same time, the optimization goals for dynamic and routinized supply networks differ. The focus in routinized networks lies on process innovation, operational improvement and reduction of inventory. In dynamic networks, the focus lies on product and technological innovation and the management of unstable and uncertain demand conditions, requiring inventory buffer. Accordingly, the means by which the focal firms in each type of network can operate vary. Network activities Harland and co-authors describe for firms with low degree of influence on their network are "motivating" and "risk and benefit sharing", whereas firms with high degree of influence in the network can select partners and make other deliberate decisions. Moreover, dynamic networks for either degree of influence on network call for "human resource integration" and "knowledge capture" whereas routinized networks are more apt for "equipment integration" and improvements in "information processing". The characteristics are displayed in Figure 2.5.7.

[36] The original table provided by Lamming et al. (2000) includes comments on the criticality of IT for information exchange which were omitted here for the perception of IT requirements is likely to have changed in the course of the years after the publication of the paper.

Table 2.5.4. – Classification of Supply Networks According to Lamming et al. (2000)

Characteristics	Supply Networks of Competitive-Unique Products	Supply Networks of Functional Products
High Complexity	*Competitive Priority:* speed and flexibility, innovation, quality supremacy *Sharing of Resources and Information:* large amounts of non-strategic information; problematic when involving sensitive information and knowledge *Examples from Survey:* not included in survey	*Competitive Priority:* cost reduction, quality sustainability, service *Sharing of Resources and Information:* large amounts of non-strategic information – generally unproblematic: may include cost breakdowns and strategic knowledge *Examples from Survey:* off-road car
Low Complexity	*Competitive Priority:* speed and flexibility, innovation, quality supremacy *Sharing of Resources and Information:* problematic exchange of sensitive information and knowledge *Examples from Survey:* drugs, LED semi-conductor, communications technology	*Competitive Priority:* cost (by high volume production), service *Sharing of Resources and Information:* generally unproblematic – may include cost and strategic knowledge *Examples from Survey:* canned soft drinks, beer cans, wheel cylinders, windows wipers

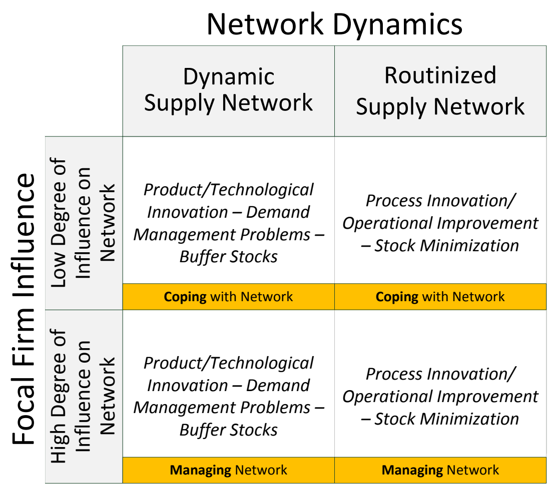

Figure 2.5.7. – Classification of Supply Networks by Harland et al. (2001)

Lee (2002) extends Fisher's (1997) framework by adding supply uncertainty as a second dimension to demand uncertainty (as implied in innovative vs. functional products in Fisher's framework). The resulting matrix displays four combinations, each of which is suitable for a type of products (e.g., fashion apparel vs. basic apparel) and a different supply network strategy (see Figure 2.5.8).

Trent & Monczka (2002) differentiate international purchasing from "true" global sourcing. They provide a five-stage framework that illustrates the path from solely domestic purchasing activities (level 1) via international purchasing (levels 2 and 3) to "integrated global sourcing" (levels 4 and 5), the latter of which, they claim, is rarely understood and adopted by industrial firms. Figure 2.5.9 shows their framework. The primary benefit the authors associate with global sourcing are cost savings which, the authors say, are higher the more integrated and global the purchasing process is.

Hull (2005) distinguishes between *make-to-order* (MTO) supply chains, *make-to-stock* (MTS) supply chains, and *supply driven chains*. The distinguishing characteristic is the event that triggers material flow. In MTO supply chains, actual customer orders trigger production while the information flow goes upstream to ensure that supply will follow. Similarly, in MTS supply chains, demand forecasts trigger material flow with the same implications for information

	Low Demand Uncertainty	High Demand Uncertainty
Low Supply Uncertainty	***Efficient Supply Chains***	***Responsive Supply Chains***
High Supply Uncertainty	***Risk-hedging Supply Chains***	***Agile Supply Chains***

Figure 2.5.8. – Supply Network Strategies for Demand and Supply Uncertainty (Lee 2002)

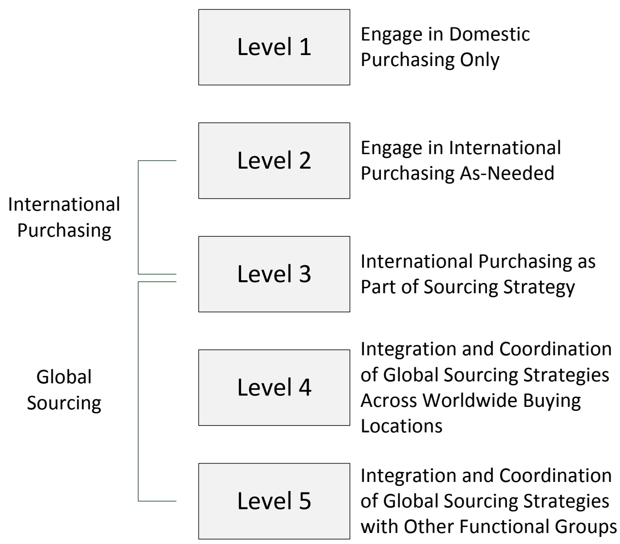

Figure 2.5.9. – Five-Stage Framework Illustrating the Development From Domestic Sourcing to Integrated Global Sourcing (Trent & Monczka 2002)

flow. In contrast, in supply driven chains, products are *pushed* downstream the supply network, and so is information.

Meyr & Stadtler (2005) identify functional attributes and structural attributes of supply networks. The functional attributes comprise the categories

- procurement type,
- production type,
- distribution type, and
- sales type.

The structural attributes comprise the categories

- topography of a supply network and
- integration and coordination.

The categories and attributes proposed by Meyr & Stadtler (2005) represent a comprehensive typology of supply networks. Tables 2.5.5 and 2.5.6 provide an overview.

Table 2.5.5. – Functional Attributes as Proposed by Meyr & Stadtler (2005)

Category	Attribute
procurement type	number and type of products procured
	sourcing type
	flexibility of suppliers
	supplier lead time and reliability
	materials' life cycle
production type	organization of production process
	repetition of operations (mass, batch, one-of-a-kind)
	changeover characteristics
	working time flexibility (overtime, additional shifts)
distribution type	distribution structure (stages)
	pattern of delivery (cyclic, dynamic [order-based])
	deployment of transportation means (standard routes vs. custom routes)

	loading restrictions (e.g., FTL)
sales type	relation to customers (B2B/B2C, transaction-based or agreement)
	availability of future demands (contract, forecast)
	demand curve (shape; e.g., seasonal, static, random)
	(stage in) product life cycle
	number of product types
	degree of customization (standard product off the shelf vs. highly customized)
	BOM structure (convergent, divergent, serial)
	portion of service operations

Table 2.5.6. – Structural Attributes as Proposed by Meyr & Stadtler (2005)

Category	Attribute
topography of supply network	network structure (convergent, divergent, serial)
	degree of globalization
	location(s) of decoupling point(s)
	major constraints (e.g., limited capacity of one supplier
integration and coordination	legal position (inter-organizational vs. intra-organizational supply chains)
	balance of power
	direction of coordination
	type of information exchanged (e.g., only capacity, also cost. . .)

In their discussion of product complexity and supply chain integration, Novak & Eppinger (2001) point out that there are more aspects to a sourcing relationship than the binary choice between make and buy. They refer to what Meyr & Stadtler (2005) have called *integration and coordination*, specifically the *legal position*. They mention

- *Keiretsu* relationships in which the OEM often partially owns the supplier,
- joint ownership agreements in which both supplier and OEM own (and possibly operate) the assets used to produce the part in question,
- equipment loans (in fact, in some industries such as automotive and agricultural machinery it is rather common that OEMs own the tools which

suppliers use to produce for the OEM),

- and arm-length subsidiaries[37].

Chopra & Meindl (2010) discuss the *strategic fit* between a supply network and a company's competitive strategy. They define two dimensions that have to be matched in order to achieve strategic fit: *responsiveness of the supply network* and *implied uncertainty* (cf. Figure 2.5.10). Responsiveness refers to the supply network's ability to react to variance in demand or supply. Implied uncertainty comprises implied demand uncertainty and uncertainty regarding reliability of the supply network (Chopra & Meindl 2010). In this respect, the framework presented by Chopra & Meindl (2010) is based upon the same dimensions as the framework presented by Lee (2002). *Implied* demand uncertainty, however, is different from "just" demand uncertainty in that it does not capture the entire market demand but only the specific portion that is served by the supply network of interest. Chopra & Meindl (2010, p. 41) illustrate the difference by contrasting the requirements imposed on a supply network that fulfills emergency orders with those imposed on a supply networks that fulfills orders for a construction site with long lead time and well-planned demands. The portion of market demand that is represented by emergency orders implies much higher demand uncertainty on the supply network in terms of quantities needed, response time tolerated, product variety demanded, and service level required.

Similarly, Christopher (2011) uses the two criteria *lead time* (supply characteristics) and *predictability of demand* (demand characteristics) to match generic supply chain strategies. Because lead time can be seen as just another way to express the responsiveness of the supply network, and predictability of demand can be seen as a function of product innovativeness, the parameters are essentially the same as in the models from Fisher (1997) and Chopra & Meindl (2010). The difference lies in the way Christopher (2011) frames the matching. He attempts to answer the question where a *Lean* configuration would yield the greatest benefits, where *Agile* configuration is preferable and where a hybrid

[37] Unfortunately, it is not clear what exactly the authors mean by arm-length subsidiaries. Possibly, they refer to fully owned suppliers that operate independently and have to compete with other ("external") suppliers for sourcing contracts.

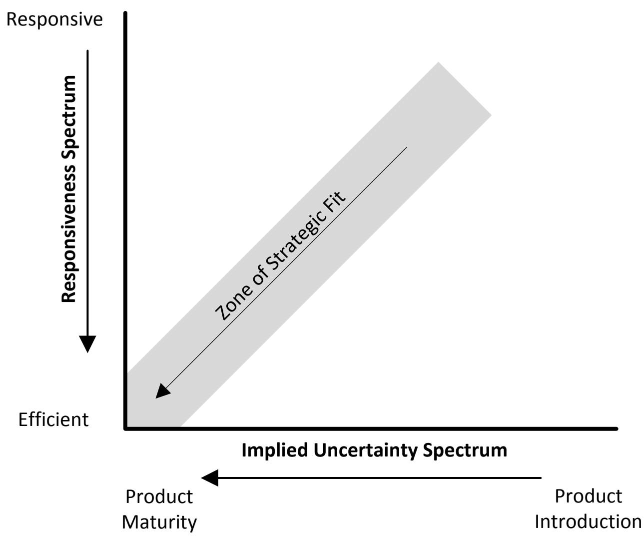

Figure 2.5.10. – Strategic Fit of the Supply Network (Chopra & Meindl 2010)

strategy should be adopted (cf. Figure 2.5.11, description of Lean in Section 3.3 on page 157 and of Agile in Section 3.5 on page 168).

Due to its inherent lack of flexibility (Hopp & Spearman 2008), a Lean strategy would suit networks which have to cope with rather predictable and stable demand whereas Agile is suited for networks which pose higher flexibility requirements. A parallel hybrid strategy can be adopted when each concept is suitable for different products with different demand and supply patterns (*Pareto curve approach*, Christopher & Towill 2001) or for *base* and *surge demand* (Gattorna & Walters 1996). A parallel hybrid strategy depending on product characteristics, similar to the Pareto curve approach, resembles Fisher's (1997) matrix (cf. Figure 2.5.6 on page 132). A consecutive hybrid strategy would use the order decoupling point where Lean would be adopted upstream whereas Agile would be adopted downstream (Christopher & Towill 2001).

Pagh & Cooper (1998) discuss postponement and speculation strategies. The idea of *postponement* is to be able to maintain a generic product as long as possible in the supply chain and only customize it to a specific customer or market when there is an actual order for the product, thereby reducing the number of

	Predictable Demand	Unpredictable Demand
Long Supply Lead Times	***Lean*** Plan and Optimize	***Hybrid*** De-couple Through Postponement
Short Supply Lead Times	***Kanban*** Continuous Replenishment	***Agile*** Quick Response

Figure 2.5.11. – Generic Supply Network Strategies (Christopher 2011)

variants that have to be kept on stock along the chain. Besides reducing capital expenditures, lower total inventory enables quicker reaction to possible market changes. *Speculation* represents the “converse concept” of postponement and thus suggests that the final destination and thus the final form of the product should be fixated as early as possible. The advantages Pagh & Cooper (1998) attach to this concept are scale economies and fewer stock out issues. Based on a 2x2 matrix with both concepts applied to each logistics and manufacturing, the authors define four generic postponement and speculation strategies for supply chains (cf. Figure 2.5.12).

Furthermore, the authors examine decision parameters based upon which the right strategy is to be chosen. They discuss “product life cycle, monetary density[38], value profile[39], product design characteristics, delivery time, frequency of delivery, demand uncertainty, economies of scale, and special knowledge” (ibid, p. 21).

[38]By *monetary density*, the authors mean the ratio between weight and value of the product (cf. Pagh & Cooper 1998, p. 22).

[39]By *value profile*, the authors refer to the allocation of value at each echelon of the supply network (cf. Pagh & Cooper 1998, p. 22).

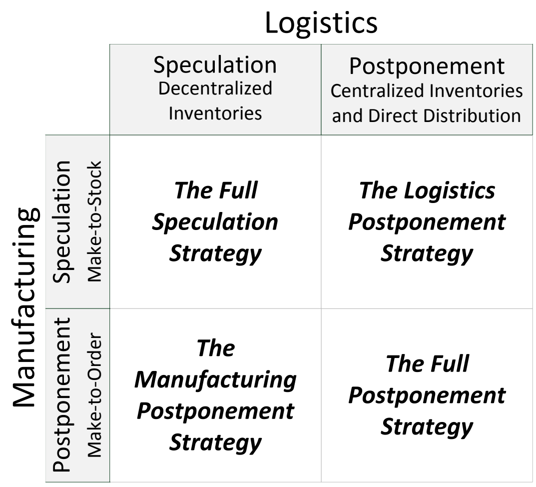

Figure 2.5.12. – Generic Postponement and Speculation Strategies (Pagh & Cooper 1998)

2.5.6.3. Summary & Implications for Bottleneck Management

As this section has demonstrated, supply networks can be very heterogenous. How they look like and how they behave to a large extent depends on a vast amount of factors. The attributes worked out by Meyr & Stadtler (2005) (Tables 2.5.5 and 2.5.6) provide good insight into the various variables. It has been pointed out that strategic fit is necessary in order to make the supply network both effective and efficient. Most authors reviewed above rely on two dimenions for their analysis of strategic fit. The various versions of two-dimensional analyses, as well as the more elaborate discussion by Meyr & Stadtler (2005) cited before, suggest that more than two factors need to be accounted for at the same time to create strategic fit.

It seems likely that different types of supply networks would require different reactions to the emergence of bottlenecks. Part of the reason is that the severity of bottlenecks is different. Supply networks which are particularly lean and where inventory buffers are mostly absent run a greater likelihood of interruptions. Where irregularities cannot be buffered by inventory, more emphasis on prevention of irregularities might seem appropriate. In competitive markets with little differentiaton between products or for products with switching cost, the existence of a bottleneck in supply may force customers to switch to competing products, switching cost notwithstanding. If satisfied with the new product they had to try out, customers might consider not switching back, which translates into loss of future business. Accordingly, the consequences of a bottleneck in supply may be negligible if the firm holds a monopoly position. High severity may be implied, however, when supply is insufficient for the production of innovative products with short life-cycles that have to reach the market fast or will become obsolete.

The implications just mentioned are merely examples. A more elaborate analysis is beyond the scope of this work but may yield very interesting insights. The take-away lesson from the discussion of different types of supply networks and supply strategies is that such differences and their implications should be taken into account when developing a strategy for the management of supply in general and for bottleneck management in particular.

2.6. Summary

The second chapter contains the first part of the literature review and introduced the reader to a variety of topics representing the theoretical foundation of this thesis.

A review of literature on manufacturing systems included a discussion of different types of manufacturing systems and how they have been classified by different authors. An introduction to bottlenecks followed, including the definition of the term, a classification of types of bottlenecks, and a short discussion of different states a bottleneck can have.

The third section of this chapter introduced the concept of complexity and involved a discussion of system in general.

Lastly, literature on organizational networks was reviewed. The discussion touched upon conceptual description of networks and on how different network setups relate to organizational performance.

Supply networks as one specific type of organizational networks were introduced, involving a discussion of the wide-spread notion of supply chains and the term Supply Chain Management. Different aspects of organizational networks were referred to in the following section. A short general discussion of objectives and relationships between organizations was followed by a more thorough investigation into power, dependence, and governance. The last aspect touched upon involved a short discourse on degrees of freedom in system configuration.

The chapter ends with an inquiry into different types of supply networks and how they can be categorized.

The topics reviewed the core of bottleneck management in supply networks but also adjacent fields that might provide useful concepts and ideas to build upon. Several concepts and ideas discussed in this chapter will surface again later on when the data collected in the multiple-case study are analyzed.

3. Analysis of Related Research Fields

3.1. Introduction

This is the second of two sections containing a review of related literature. This section covers more specific topics from industrial application which have their conceptual roots in more fundamental theory (as reviewed in the previous chapter) yet have evolved into largely independent subjects with high applicability and relevance in the industrial context. The topics selected for the review in this section tackle problems that are related to questions of stable and reliable supply.

The first topic covered is *purchasing portfolio analysis* (PPA; Section 3.2). It represents an early attempt to integrate the analysis of both purchased material and market characteristics so as to devise strategy for the management of supply. If dissected, the criteria suggested for the analysis can be traced back to insights from various research fields, such as manufacturing, power and dependence in networks, and systems theory. Hence, PPA is also a great example as to how the topics reviewed in this section relate to the topics reviewed in the previous section: the topics covered here combine insights from the more general, basic theory of the previous section and represent handy devices with catchy names for their industrial application.

Lean/Just-in-Time (Section 3.3) and *Agile* (Section 3.5) represent antagonistic yet complementary approaches to the configuration of both manufacturing systems and supply networks. When applied complementarily, the setup goes by the name of Leagile. Lean in particular seems to have received much attention since the 1980. The essential ideas of these concepts are identified and shortly discussed; their review is closed with a short discussion as to how they relate to supply-related problems.

Theory of Constraints (ToC), too, had received much attention since the 1980. It introduces a way of thinking about material flow problems in factories in terms of bottlenecks and thus is essential to consider for the conception of bottleneck management in supply networks. It will be reviewed in Section 3.4.

Supply Chain Risk Management (SCRM) is introduced in Section 3.6. The review is also used to introduce and define the term risk – which one would presume to be of relevance in the context of supply-related problems. Indeed, the emergence of bottlenecks can be seen as a risk in the management of supply networks, and it is this risk Supply Chain Risk Management is mostly concerned about. Hence the short review.

Apparently, there are concepts such as ToC that deal with problems similar as the one selected for this project in the context of manufacturing; some, like Lean and Agile, even span over and influence both settings, manufacturing systems and supply networks. This suggests there are conceptual similarities between these settings. After all, both are material flow systems. Therefore, the review closes with a *systematic comparison* between manufacturing systems and supply network systems in Section 3.7. The objective was to better understand the similarities, the differences, and the relation of the two systems.

As with the previous review of more fundamental topics, the selection of topics covered in this section comes rather naturally. It does not require an intellectual stretch to see the relevance of the topics reviewed for the topic of this thesis. Each of the topics were repeatedly encountered during the early widespread "cross-border" review of literature at the outset of the study and were saved for a more in-depth investigation at a later point in time. Each of the topics grapples with problems or aspect of problems encountered when thinking about and reframing supply-related problem in terms of bottlenecks.

3.2. Purchasing Portfolio Analysis

3.2.1. Short Description

The classical purchasing portfolio analysis (PPA) is an attempt to add some "strategic spin" to the corporate purchasing function. Kraljic (1983) defines a four-stage approach to identify suitable strategic action in purchasing. In the first stage, the purchased material is classified according to supply risk and profit impact, each of which is assessed according a set of criteria. Criteria the author suggests for profit impact are purchasing volume, percentage of total purchase cost, impact on product quality, and impact on business growth. Criteria for supply risk are, for instance, availability, number of suppliers, competitive demand, make-or-buy opportunities, storage risks, and substitution possibilities (Kraljic 1983, p. 112). The four resulting categories and their labels are depicted in Figure 3.2.1.[1] The strategic implications for each of these categories may be very different, as the author points out. It is the material identified as "strategic" in this first stage of analysis that deserves most attention.

Figure 3.2.1. – Categorization of Purchased Material as Suggested by Kraljic (1983)

		Profit Impact	
		Low	High
Supply Risk	High	***"Bottleneck"***	***"Strategic"***
	Low	***"Noncritical"***	***"Leverage"***

The analysis of purchased material is followed by a market analysis in the

[1]Note that how Kraljic uses the label "bottleneck" does not correspond to the use of the same term in this thesis.

second stage of Kraljic's approach. In the market analysis, specific criteria that mark strengths or weaknesses of the buying firm are compared to the corresponding items of the suppliers. The purpose of this analysis is to get an impression of the company's bargaining position as compared to its suppliers'. In a third step, the result of this analysis for each supplier of strategic material is plotted in the "purchasing portfolio matrix" (cf. Figure 3.2.2).

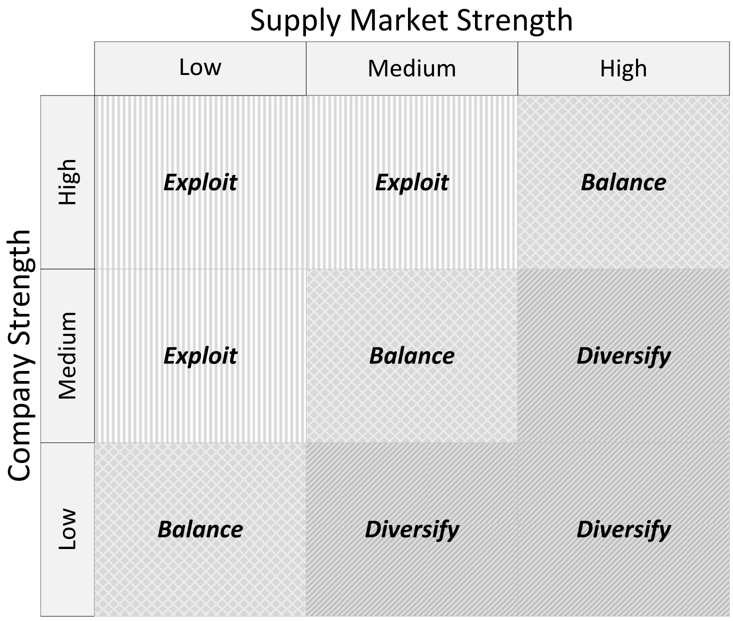

Figure 3.2.2. – Purchasing Portfolio Matrix (Kraljic 1983)

Wildemann (2001) uses the same concept but presents it in a slightly different manner. Just like Kraljic (1983), he combines the individual analyses of purchased materials (leading to the same categories with similar labels as in Kraljic's article) and supplier markets (leading to the four categories of suppliers or supplier archetypes with labels corresponding to the categories of materials: strategic suppliers, bottleneck suppliers, standard suppliers, and core suppliers) to deduce suitable purchasing strategies. The two matrices are then combined to one 16-field purchasing portfolio matrix that plots the four classes of material against the four classes of suppliers previously identified.

The purchasing portfolio matrix in Wildemann (2001) points at four archetypal purchasing strategies. These are: Purchase efficiently (standard material, standard suppliers), secure access (bottleneck material, bottleneck suppliers), use market potential, then cooperation (core material, core suppliers or strategic suppliers), and value-adding partnership (strategic material, core suppliers or strategic suppliers). The four strategies are described in greater detail along (and with implications for) items such as contractual terms, quality assurance, research and development, organization, and electronic supply markets.

The notable difference between Kraljic (1983) and Wildemann (2001) seems to be that Kraljic focuses exclusively on strategic material and plots supplier strength against buyer strength in the purchasing portfolio matrix to deduce three different strategic imperatives (exploit, balance, diversify) whereas Wildemann includes all four categories of material in the analysis and plots them against supplier archetypes which he identifies by combining supply risk and supplier development potential.

Power and dependence were discussed in Section 2.5.5.2. It thus appears to be worthwhile looking at how the analysis of power configurations in the supply network is approached in the purchasing portfolio analysis. Kraljic (1983, pp. 113 et seq.) suggests ten (exemplary) sets of criteria for the comparative analysis of supplier and buyer strength which are listed in Table 3.2.1. The criteria shall be shortly explained.

The first criteria compare the production capacity of an individual supplier with the overall supply market capacity for the specific material under consideration as well as the allocation of the purchasing volume of the buying firm to the supplier and its overall purchasing volume. The comparison of market size and supplier capacity gives an indication of the market share of the supplier for the specific material or component. At the same time, the purchasing volume of the buying firm gives an indication of the buying firm's importance for the supplier's business. Hence, the first set of criteria compares the buying firm's dependence on the supplier with the supplier's dependence on the buying firm in terms of purchasing volume.

The second set of criteria does essentially the same but looks at how this relation changes over time. It compares supply market growth with capacity

Table 3.2.1. – Criteria for the Comparative Analysis of Supplier and Buyer Power (Kraljic 1983, p. 114)

	Supplier Strength	Company Strength
1	Market size vs. supplier capacity	Purchasing volume vs. capacity of main units
2	Market growth vs. capacity growth	Demand growth vs. capacity growth
3	Capacity utilization or bottleneck risk	Capacity utilization (variation) of main units
4	Competitive structure	Market share vis-à-vis main competition
5	ROI and/or ROC	Profitability of main end products
6	Cost and price structure	Cost and price structure
7	Break-even stability	Cost of nondelivery
8	Uniqueness of product and technological stability	Own production capability or integration depth
9	Entry barrier (capital and know-how requirements)	Entry cost for new sources vs. cost for own production
10	Logistics situation	Logistic

growth of the supplier and buyers' market growth with the capacity growth of the buying firm and thus indicates how the dependence relations may change in the future.

While the first two sets of criteria focused on the market structure, the third set of criteria is more operational. Throughput time in a factory can behave highly non-linear so that congestion can be expected at very high utilization rates. Mathematically, throughput time becomes infinite at 100% utilization (Hopp & Spearman 2008). The supplier's capacity utilization thus plays an important role for the reliability of supply. At the same time, high utilization of suppliers' production capacity may hint at efficient use of assets and economies of scale. The implications for the power relationship between buyer and supplier – and thus why the Kraljic (1983) includes this item into the analysis – are not quite clear, however. For the assessment of capacity utilization at the demand (buying firm) side, the case is clearer. High variation in demand requires that suppliers maintain a capacity surplus so as to be able to meet peak demand. Maintaining extra capacity is expensive for the supplier and the buying firm may have to seek compromise with the supplier or pay a premium.

Next, Kraljic (1983) look at the competitive situation both of supplier and buying firm. This point is related to the first point (market size vs. supplier capacity), to the eighth point (uniqueness of product), and to the ninth point (entry barriers). Strong competition for sourcing contract lowers the supplier's bargaining power. By the same token, the buying firm's market share can provide a bargaining advantage if it is high and a disadvantage if it is low.

The next point, ROI/ROC, again is related to other items which are break-even stability and cost and price structure. In fact, the differences do not become apparent in Kraljic (1983). If the ROI/ROC can be achieved easily and early, the supplier is not urged to accept deals "at any cost" but can choose to seek a more favorable agreement with another customer, even at a later point in time. Likewise, break-even stability at low capacity utilization levels provide the supplier with more freedom to deny unfavorable conditions and thus increases its bargaining power. Similarly, the profitability of the buying firm's end products can provide a bargaining advantage or disadvantage to the buying firm. If profitability of end products is high, the buying firm does not have to seek compromise with suppliers in order to get the best price but can reject unfavorable conditions and look for other suppliers, even for those that would charge higher prices. On the other hand, low profitability of the end products may force the buying firm to accept unfavorable conditions (such as mediocre supply reliability) in order to achieve low purchasing cost per part.

The cost of nondelivery at the buying firm – although it remains unclear why this criterion is paired by Kraljic with break-even stability at the supplier – has important implications for the effort the buying firm should make in order to prevent supply shortages. If no or little cost is attached to nondelivery, expensive prevention and contingency measures are inadequate; also it provides a bargaining advantage for the buying firm. If, on the other hand, the cost of nondelivery is high, the buying firm would put more emphasis on reliable supply and thus is more dependent on the supplier's performance.

The uniqueness of the product or material delivered by the supplier was mentioned before in the context of the supplier's competitive situation. In the eighth set, the author pairs it with the buying firm's ability to produce in-house (or ability to integrate vertically so as to create options for in-house production). Obviously, if the supplier holds a monopoly position, this contributes to bargaining power. On the other hand, if the buying firm can produce the same component in-house, the buying firm improves its bargaining position by reducing its dependency on the supplier.

Entry barriers in the supply market are compared to entry (or switching) cost for new sources on the demand side. Entry barriers in the supply market can influence the supplier's competitive situation; if entry barriers are considerably high, new competition is less likely to emerge and suppliers can maintain their competitive position. By the same token, if the buying firm can easily switch to other existing sources or create new sources at little or no cost, it gains bargaining power as compared to its suppliers.[2]

[2] What exactly Kraljic (1983) means by logistics situation and logistic in the tenth set of criteria could not be determined from his article and thus remains unclear.

3.2.2. Ramifications for Bottleneck Management

The PPA goes to the heart of bottleneck management. It uses both product and market characteristics to assess the status quo of the purchasing portfolio in terms of bottleneck risk so that suitable strategies can be deduced that will help prevent supply shortages. It thereby provides a pragmatic approach to bottleneck management in supply networks. The focus on PPA is clearly on *prevention* which is merely one aspect of bottleneck management, however. The greatest value PPA provides lies in its being a framework to combine both market and product aspects in a consistent way, both of which include a broad variety of more detailed aspects and criteria.

By putting emphasis on power in the supply market analysis, PPA includes factors that tend to be neglected by the canon of SCM teachings (whereas emphasis is put on cooperation in the latter). Among the criteria PPA analyzes are lateral relationships in the supply network which seem to be mostly ignored in SCM yet can have important implications for the reliability of supply (Beer et al. 2012).

3.3. Lean Production and Just-in-Time

3.3.1. Short Description

Lean and *Just-in-Time* (JiT) have been extensively covered by researchers and practitioners alike throughout the past thirty years and it is not this researcher's intention to provide a complete account here. Instead, a concise overview of the central tenets that have ramifications for the management of bottlenecks is sought to be provided.

Lean and *Just-in-Time* (JiT) are mostly synonymous terms that surfaced at different points in time, however (Hopp & Spearman 2008). An early account of the production methodology and management paradigm that later have been associated with the term Lean has been provided by Hayes (1981) who did not use this term, however, in his vivid description of the Japanese manufacturing environment. As Holweg (2007) discusses, there has been extensive coverage of JiT methodology in the research literature throughout the 1980s before the term Lean has been established through the publication and tremendous success of the book *The Machine that Changed the World* (Womack et al. 1990). Lean and JiT will be used interchangeably when referring to the production and management paradigm. When JiT is used to refer to the actual delivery process, it will be obvious from the context.

Hayes (1981) describes his observations and impressions from visiting several Japanese factories. His article captures many of the features and particularities of the Japanese production system (most often referred to as the Toyota Production System, TPS) that later have been formalized as a comprehensive science of production and management – which we refer to as Lean or JiT. The increasing success of Japanese firms in the US at that time by many had been attributed to particular Japanese habits, Japanese governmental support, cheap labor, and other idiosyncratic factors unavailable to US firms (Holweg 2007). Others expected high automation, superior equipment, or some type of special techniques the Japanese were using to be responsible for the growing productivity and cost gap between Japanese and Western manufacturers. What Hayes (1981) saw and described, however, was largely the same equipment as used in the US (or even simpler), no hidden secrets or special techniques, but simply prudent and diligent Operations Management combined with the strive for perfection and the absence of compartmental thinking. Hayes' paper thus provides an early documentation of the ideological attachment of JiT – as opposed to a set of tools or techniques. A quote from his article brings this to the point:

> "The modern Japanese factory is not, as many Americans believe, a prototype of the factory of the future. If it were, it might be, curiously, far less of a threat. We in the United States, with our technical ability and resources, ought then to be able to duplicate it. Instead, it is something much more difficult for us to copy; it is the factory of *today* running as it should" (Hayes 1981, p. 57, emphasis in original).

The quote suggests that the key to productivity and quality as sought by "the Japanese" is predominantly a matter of mindset and organization. Nevertheless, JiT includes a variety of tenets that are derived from the broader philosophy and put into practice through standard operating procedures.

Reduction is one of the most important activities in JiT. Reduction of waste (*muda*) lies at the core of the concept (Bicheno & Holweg 2009). This includes reduction of inventory. In fact, Hayes (1981) quotes a Japanese senior manager on the problems attached to inventory:

> "We feel that inventory is the root of all evil. You would be surprised how much you simplify problems and reduce costs when there are no inventories. For example, you don't need any inventory managers or inventory control systems. Nor do you need expediters, because you can't expedite. And, finally, when something goes wrong, the system stops. Immediately the whole organization becomes aware of the problem an works quickly to resolve it. If you have buffer inventories, these potential problems stay hidden and may never get corrected" (Japanese senior manager, as quoted in Hayes 1981, p. 59).

Figuratively, inventory is sometimes compared with the water level in a river. As the water level – representing inventory – is decreased, rocks – representing problems – will surface that previously remained covered. As the rocks are removed and the water level is further decreased, new rocks will keep surfacing, and so on (Hopp & Spearman 2008, p. 165).

Reduction of complexity is a central tenet of JiT (Klaus & Krieger 2008, p. 308). Since the reduction of inventory will reveal problems (which is expected and intended), they are less likely to surface unexpectedly and can be resolved as they are found. This reduces the time gap that is to be bridged by the feedback loop, which is an important factor for complexity reduction (Senge 2006). Lower variety of products and processes reduces the chance of unexpected incidents and thereby further lowers the level of complexity. Process irregularities have a designated term in the JiT terminology – *mura* – and are continuously tried to reduce. *Standardize* (*Seiketsu*) is one of the *5S* – five methods for workplace organization (Bicheno & Holweg 2009).

Reduction of batch size is intended to reduce the average throughput time of parts. To make this possible, changeover time of tools likewise has to be reduced and thus is one of the core core operational objectives in JiT. Moreover, continuous reduction of changeover time is part of a broader set of activities to continuously *improve*. In fact, continuous improvement (*kaizen*) is another key activity which is reflected in a steady effort to improve product and process quality.

3.3.2. Ramifications for Bottleneck Management

JiT operationalizes the flow principle. That is, it employs a holistic view on the entire system and attempts to reduce measures that inhibit the unhindered flow of products (Klaus & Krieger 2008). Part of the *waste* that JiT aims to reduce is non-value-adding time of parts spent in the system. Non-value-adding time is, for example, waiting time in queues (Christopher 2011). Waiting time in queues is reduced via the reduction of work-in-progress (WiP) inventory. A means to this end is the reduction of process and transfer batches. The idealized goal is *zero inventory* and a batch size of one, that is *one-piece flow*. In this case, parts would flow through the system and no time would be wasted waiting in queues for processing (process batches) or for completion of transfer batches.

Although continuous flow of parts is desired in a Lean/JiT setting, workers are empowered to stop the production process if they encounter quality problems (or problems of other kind, respectively) so the problem can be resolved. That is, production interruptions will be frequent until a certain quality level is reached. Accordingly, JiT does not only foster stable processes but also requires a stable environment (Christopher 2011). Put differently, “JiT is inherently inflexible” (Hopp & Spearman 2008, p. 173). Flexibility, however, is needed to cope with variability. Generally, there are three types of buffers in systems: inventory, capacity, and time (Hopp & Spearman 2008) Each buffer comes at a cost and it depends on the specific situation in which combination and to what extent they should be used. As previously discussed, *inventory* is tried to be reduced to the greatest extent in JiT systems as it is considered waste or even “the root of all evil” (cf. p. 159). Accordingly, inventory is not the predominant way in which JiT systems buffer against variability. *Time* is the buffer to which systems fall back when they fail to deal with variability and find better solutions; in most cases, it may be the most undesirable type of buffer. Using time as a buffer simply means that throughput time extends so that customers would need to wait longer for delivery. Although there may be situations when this is acceptable, activities within supply management generally seek to avoid having customers wait for the product. *Capacity* is the third type of buffer against variability, and it is one type frequently utilized. Both ToC (see below) and JiT accept low utilization of process steps (e.g., machines or workers), in which case excess capacity is available to cope with demand peaks. In sourcing audits in the automobile industry, suppliers have to indicate the number of work shifts per week they will need to achieve the requested production output so that the customer (e.g., the OEM) knows that additional work shifts will be available in case demand will be higher than forecasted (Beer 2011). Capacity seems to be the buffer most favored in JiT systems. Foremost priority remains, however, the reduction of variability in the first place.

As inventory buffers are removed, there is the danger that interruptions occur more often. Bretzke (2010, p. 3) remarks:

> "We have to realize that the combination of rigid process interfacing and strong time compression has made our supply chains unnecessarily vulnerable and thus has lead to unnecessarily high shares of special express deliveries. It is no indicator of great logistical intelligence to configure hyper-lean process chains, creating an unanticipated amount of disruptions, to later use our whole mental concentration to create 'Supply Chain Event Management' in order to mitigate these disruptions subsequently."[3]

[3] Translated by the author. Original in German: "Auch werden wir zur Kenntnis nehmen müssen, dass die Kombination von rigiden Prozesskopplungen und starker Zeitkompression unsere Lieferketten unnötig verletzlich gemacht und damit unnötig hohe Expressfrachtanteile produziert hat. Es ist kein Zeichen von großer logistischer Intelligenz, erst hyperschlanke Prozessketten zu konfigurieren, die in einem ungeplanten Ausmaß Störungen produzieren, um dann mit unserer vollen geistigen Konzentration ein 'Supply Chain Event Management' zu kreieren, dass diese Störungen nachträglich entschärfen soll."

In an interview, the Director of Supply Chain Management at a major car maker indicated that supply interruptions had to be dealt with more often after suppliers adopted JiT delivery (Beer 2011). In factory environments, where the origin of JiT lies, interruptions were embraced as they served to reveal problems that ought to be solved (Hopp & Spearman 2008). Used in relatively stable environments, the cost of (relatively rare) interruption may be acceptable as they come with quality improvements. Supply networks, however, are relatively open systems, prone to induced variability from a variety of external sources. While the reduction of waste in general remains a valuable goal in either way, it must be evaluated with care for each particular case whether lean supply processes will generate benefits that exceed cost due to interruption.

3.4. Theory of Constraints

3.4.1. Short Description

The Theory of Constraints (ToC) started out as a scheduling logic for production systems and developed into what ToC followers say is a full-fledged management philosophy that favors continuous improvement and focus on a system's constraints (Raman 1998). ToC became popular after Goldratt released his business novel *The Goal* in 1984 (Goldratt & Cox 1984). While ToC has its root in manufacturing and continues to be most influential in this field, its concepts and ideas have been adapted to fit other management topics as diverse as project management (Goldratt 1997) or marketing (Goldratt 1994).

ToC is centered around few concepts which are repeated and applied throughout the various business novels and other publications, such as

- the distinction between constraints and non-constraints,
- a clear statement of a company's goal: "make more money now and in the future",
- criticism of common cost accounting logic and the introduction of a performance measurement system based on throughput, inventory, and operating expense,

- a five step thinking process to improve a system's performance ((1) identify constraint, (2) decide how to exploit it and exploit it, (3) subordinate everything else, (4) elevate constraint, (5) repeat)
- the *Current Reality Tree* to help illustrate likely causes and effects leading to the current state of the system,
- the *Evaporating Clouds Diagram* to help visualize conflicting demands on a system, and
- the *Drum-Buffer-Rope* logic for production scheduling.

ToC is not founded on entirely new concepts, although it's best-known publication, Goldratt's *The Goal*, does not give credit or refer to any previous concept. Goldratt met this criticism in Goldratt (2009) and explained the root of some of the core ideas of ToC.

It should be noted that while ToC certainly has gained a foothold in academia it seems not as much discussed both in wideness and in depth as related concepts such as Lean or Total Quality Management. The reasons are not entirely clear. One possible factor might be that ToC literature and organizations create the impression of a cult focused on their prominent founding father Goldratt. Also, while many authors have attempted comparisons between ToC and related or competing philosophies (Raman 1998 provides a – not quite up-to-date – overview), publications by authors from ToC's inner circle exhibit the tendency to create the impression of a ToC-centered universe, which might possibly conflict with the more objective stance academia is supposed to take.

Surprisingly little has been written about the application of the Theory of Constraints (ToC) on SCM despite some authors indicating the contrary (e.g., Childerhouse 2002).

Lockamy III & Draman (1998) discuss the application of the *Drum-Buffer-Rope* (DBR) concept, buffer management (BM), and the *5 Focusing Steps* of ToC on supply chains. The authors, however, do not do much more than putting forth high-level claims, such as that "members of a supply chain must recognize and embrace the global perspective" (p. 350), i.e., that they are part of a larger system that should be optimized, and that the tools of ToC "must" be adopted. That is, the authors do not discuss how members of a supply chain should introduce such measures or what could be the reasons that they have not done so already.

Simatupang et al. (2004) apply the Evaporating Cloud Diagram of ToC to investigate (1) impediments to collaboration in supply chains and (2) the application of ToC problems and solutions on supply chains. With the Evaporating Cloud Diagram, the authors illustrate the conflict between the altruistic idea of maximization of the entire supply chain's profit and companies striving after optimization for themselves, and they support the existence of this conflict by reference to literature. The authors then suggest the introduction of the ToC accounting system based on Throughput (T), Investment (I), and Operating Expense (OE) (Goldratt & Cox 2004) on a supply chain system level as a solution to the apparent dilemma. The weak point of this proposal is that the premises are weak. The underlying assumption of Simatupang et al. (2004) is that "[t]he supply chain can be viewed as a system established for the purpose of accomplishing a system's goal" (p. 61). The validity of this assumption, however, is debatable. One important difference between a firm and a supply chain (network) is that in a firm all members of the system belong to one legal entity and are legally obliged to obey orders from their superiors, i.e., all the entities by definition follow one overall goal which in a profit-oriented firm tends to be to make money (cf. Section 3.7 on page 175 for a more detailed discussion on the similarities and differences). The supply chain, on the other hand, consists of individual firms which in most cases do not belong to the same legal organization. That is, although the supply chain represents a system, this system has not been established for the purpose of accomplishing an identical or at least fully congruent goal. Cases of strongly idealistic organizations notwithstanding, members of a supply chain have not chosen to become part of a supply chain in order to join other members in their pursuit of the higher ideal of accomplishing a common "system's goal" but out of mere necessity because they need raw material to produce what they want to sell their customers in order to earn money which is their goal. That is, there is no common goal of a supply chain system but many individual goals companies pursue. Moreover, systems in general tend not to have a common – central – goal. Rather, Systems Theory emphasizes that systems are comprised of individual entities, each of which follows its own individual goals. Assuming that the purpose of a supply chain is to accomplish a common goal of the member firms thus misses the point and puts a strain on the inferences. The normative nature of the paper becomes apparent in statements such as the following:

> "The chain members need to rank the increase of throughput on the priority list before reducing investment and operating expenses. In addition to this scale of importance, *all other local or departmental metrics are less important than the global, or supply chain-wide metrics*" (Simatupang et al. 2004, p. 62, emphasis added).

Although the (normative) claim that organizations should sacrifice individual benefits for the sake of overall supply chain performance is frequently repeated in the SCM literature, there is, in fact, little empirical evidence that this is ever consciously done by organizations. In order to break the dilemma between global efficiencies and the economic logic of firms that pushes them to focus on local efficiencies, the authors suggest an entirely different distribution system for supply chain profits. Rather than through sales from echelon to echelon, the authors propose that benefits are only allocated once the product has been sold to end customers (ibid, p. 63).

dos Santos et al. (2010) follow the same line of thinking as Simatupang et al. (2004) and argue on a normative basis that members of a supply network should abolish local efficiencies and aim to involve the entire network to use the same metrics and adopt a central and commonly agreed upon mechanism for benefit sharing that replaces the market mechanism of individual contracts and exchange of goods and money between a buyer and a seller:

> "At last, a new paradigm to be followed by SC's partners could be established in order to assure an efficient implementation of this described TOC's approach: the benefits ($) of the SC's members will be guaranteed only if the products were sold to the end-customers.

> This paradigm contrasts with the traditional rule usually adopted where each SC's member produces benefits ($) by selling to others partners. In this way, all SC's members should align its goals to a global profitability SC, and the waste in the SC will be lower. Furthermore, it should be elaborated in a common agreement with all SC's members a hierarchical local and global indicators structure (...) to assure complete visibility of SC's performance for all stakeholders, so that partners can individually assess as well, as seeing their real contribution to the global SC's performance" (dos Santos et al. 2010, p. 87).

Besides the emphasis of an entirely different allocation of benefits throughout the supply network the authors focus on buffer management.

Wu et al. (2013), too, discuss buffer management and inventories in supply networks and propose a "brand new (sic) inventory replenishment mechanism, namely the TOC supply chain replenishment system (TOC-SCRS)". This replenishment concept consists of two guiding principles: (1) minimize inventory, i.e., keep only enough inventory for one replenishment period, and (2) replenish only the material you have sold (ibid, p. 80). These two principles, however, are not novel and, although certainly part of it, do not originate from ToC but have been at the core of Lean for a long time.

Mathu (2014) has identified major constraints in the South African coal production and supply. The actual – or possible prospective – application of ToC remains unclear, however, as the suggestions for improvement are limited to high-level recommendations.

It appears that many publications in the field of ToC lack some academic rigidity, which clearly sets them apart from Lean/JiT where serious research has been conducted for thirty years and publications of high quality are abound. Nonetheless, ToC does provide useful ways of thinking about material flow and therefore does represent a valuable knowledge base upon which this work can build.

3.4.2. Ramifications for Bottleneck Management

Although the literature reviewed that aims to transfer concepts from ToC to SCM turns out not to be particularly fruitful, ToC does provide a variety of concepts which are worthwhile taking up and which are indeed made use of in this dissertation.

First of all, ToC introduces a bottleneck perspective. Goldratt (in his various publications on ToC) puts bottlenecks at the center of his concepts for production control and improvement and develops a theory around the idea that bottlenecks – due to their inherent importance for material flow – are the central levers and deserve most attention. Because supply networks are material flow systems, too, it has been attempted in this thesis to develop a bottleneck perspective on supply networks so as to find out if such a perspective can support management of supply.

Furthermore, ToC proposes a systematic approach to the management of bottlenecks. There is a tremendous amount of literature on SCM that discuss a variety of tools, concepts, and strategies. It seems, though, that methodological-wise there have been only few developments, such as categorizations of supply networks (Harland et al. 2001) and the dichotomy between responsive and efficient network strategies (Christopher et al. 2006). Because a bottleneck perspective on supply networks has hardly been discussed in the literature, there is little methodology that supports such a perspective. The systematic character of ToC arguably is what made ToC popular and applicable. It has thus been one aim of this thesis to contribute to a better methodological base for the management of supply networks so as to make the field more accessible and applicable.

As part of its five-step methodology, ToC introduces the concepts of bottleneck identification (step one), bottleneck exploitation (step two) and bottleneck elimination (step four, "elevate"). These steps provide the foundation and support the development of the bottleneck management methodology for supply networks in this thesis.

One frequent pattern in "*The Goal*" is that physical capacity often is not the cause of reduced or interrupted material flow. *Policies* are emphasized in ToC as a root cause of less than optimal throughput. The identification of weak policies and operational deficiencies has also been emphasized in this study, and both policies and operations provide an important lever for bottleneck management measures, as demonstrated in the data analysis of sections 6.2 and 6.3.

This short overview demonstrates that ToC provides a rich foundation of concepts and ideas that can enrich the methodology for the management of supply networks. The system-level comparison of supply networks with production systems (cf. Section 3.7) illustrates that the fundamental mechanisms of material flow in both systems are similar. Hence the transfer of concepts seems promising.

3.5. Agile and Leagile Supply Chains

3.5.1. Short Description

Agile supply chains, *Agility* or just "*Agile*"[4] started off as a production paradigm that has risen in popularity as of the second half of the 1990s, often considered an alternative to Lean (Mason-Jones et al. 2000). Several British researchers, perhaps most notably among them Martin Christopher from Cranfield University, have brought the concept to wide attention.

Agility is meant to support *responsiveness* of supply chains to ensure customer demand can be met. In this respect, Agility prioritizes effectiveness higher than efficiency, i.e., rather than the reduction of cost the availability of the product to the customer is subject to the optimization effort (Christopher 2011). Agility, as defined by Christopher & Towill (2001), is a "business-wide capability that embraces organisational structures, information systems, logistics processes and in particular, mindsets. A key characteristic of an agile organisation is flexibility" (p. 236).

Christopher and his co-authors explain the concept by contrasting it from the Lean paradigm which, through the elimination of waste, aims to increase efficiency. Thus, Lean and Agile represent the two poles of the *efficiency-flexibility trade-off* in Supply Chain Management. Furthermore, Christopher & Towill

[4] As to the spelling, Agile will be spelled with uppercase "A" when referred to the concept while lowercase "a" will be used when referred to as an adjective. The same applies to Lean/lean.

(2001) characterize Agile as an "organizational orientation" (p. 236) and thus position it as a way of thinking or a paradigm in parallel to Lean/JiT which is referred to as both a way to organize a production system and a management philosophy (e.g., Hayes 1981).

While the two extreme poles, Agile on the one hand and Lean on the other hand, are mutually exclusive concepts when it comes to implementation in one particular segment of a supply network or an organization, the two concepts can be combined to form hybrid, *Leagile* chains in consecutive order. More specifically, the upstream part of a supply chain would be designed to be lean whereas the downstream part of the supply chain would be designed to be agile. The two segments would be connected by the *decoupling point* (also called *order penetration point*, OPP) at which some inventory is held (Mason-Jones et al. 2000, Christopher & Towill 2001). The chain would carry "generic" goods which would then be customized according to actual customer demands from the OPP on downstream[5].

Alternatively, the two concepts can be used in parallel for different products – or supplied components of a product – when these are subject to different demand patterns, e.g., Lean for predictable demand and Agile for volatile demand. Christopher & Towill (2001) suggest the application of the Pareto rule. They refer to Gattorna & Walters (1996) for another option which would be the distinction between *base* and *surge production* capacity with base capacity being suitable for Lean principles and surge capacity being suitable for an agile approach.

The principal guideline of Agile to put effectiveness – i.e., availability of the product or service to the customer – first, corresponds well with the bottleneck focus of this work.

3.5.2. Ramifications for Bottleneck Management

The prioritization of effectiveness over efficiency in order to keep the material flow uninterrupted with some certainty can be said to be aligning well with pri-

[5]The customization of generic goods as far downstream in the supply chain as possible is commonly referred to as *postponement* (Klaus & Krieger 2008, p. 457).

orities of large segments of manufacturing industry. Some companies spend enormous resources in order to ensure the timely arrival of supply so as to not "starve" their production processes. In the automobile industry, it is not uncommon to use quick yet expensive means of transportation such as helicopters to reduce transportation time if incoming goods inventory stock-out could not be avoided otherwise (Beer & Liyanage 2011). In such situations, the cost of transportation easily exceeds the cost of parts; the *much* higher cost of idling the factory can be avoided, though.

Means such as helicopter transportation capacity are not normally "active"; helicopters tend not to be part of production company's assets. Instead, such services are received through contracted providers. In agile systems, the means to increase flexibility and responsiveness tend to be internal. Examples are more flexible machines and robots or higher skilled workers. Such assets are often more expensive, yet due to their better responsiveness to market needs they help the organization be more profitable. Nonetheless, the principle remains the same: avoiding interruptions of material flow by maintaining flexible production or transportation means at one's disposal, whether internal or contracted. Thinking in terms of Agility, including its coupling with Lean – Leagile – does inform and support the conception of bottleneck management activities.

Conceptually, it is not quite clear how Agility relates to concepts such as production capacity flexibility (PCF), both internal and at suppliers. PCF translates into "excess capacity". While excess capacity could easily be declared "waste" in a Lean mindset, it is also one of the primary tools of Lean, often embodied in overtime or additional work shifts, to make up for variation. That is, PCF seems to be right at the interface between the two seemingly opposed concepts Lean and Agile, which suggests that definition and demarcation of either concept are not quite sharp.

3.6. Supply Chain Risk Management

A thesis about bottlenecks in supply networks would be incomplete without reference to the wide body of literature in the field of Supply Chain Risk Management (SCRM). In fact, many might consider the emergence of bottlenecks in a supply network and subsequent supply shortages a typical supply chain risk.

However, the relation of bottlenecks and Supply Chain Risk Management is not as straightforward and has more facets than the above example suggest. Before details will be elaborated, it seems sensible to define *risk*.

While ambiguity and lack of precision in the use of key terms is a widespread problem (e.g., “performance”, “system”, “strategy”, “supply chain”, etc.), “risk” is certainly one of the terms where the lack of common understanding is most prevalent. Aven (2010) has dedicated an entire book to different (mis-) conceptions of risk. Fortunately, many writers in the field of risk management do provide “a” working definition of risk. Two common elements in many definitions of risk are the *probability* of an event and its *consequences* or *significance* (e.g., (Mitchell 1995, Harland et al. 2003, Hallikas et al. 2004)). Aven (2011*a*, 2011*b*) refers to this risk definition as

$$Risk\,(A,C,P) \tag{3.6.1}$$

where A describes the event, C describes the consequences, and P describes the associated probability. Probability (regardless whether in a frequentist or Bayesian/subjective/knowledge-based setting) is used to express uncertainty. There is, however, uncertainty beyond what can normally be expressed as probability, i.e., probability is an imperfect representation of uncertainty (Aven 2012). Harland et al. (2003), for instance, differentiate between the “likelihood of a trigger that will realise the risk” and the extent of exposure to the risk (p. 54). Furthermore, a risk definition that includes a frequentist perspective on probability would be inadequate to describe risk in a context where an event cannot be expected to be repeated. Subjective probabilities, on the other hand, may be based on strong assumptions and “the origin and amount of information supporting the [probability] assignments are not reflected by the numbers produced” (Aven 2012, p. 43). A more “modest” way of expressing risk which emphasizes uncertainty would then be

$$Risk\,(A,C,U) \tag{3.6.2}$$

In this equation, uncertainty U replaced probability P. Accordingly, the definition of risk would be as follows:

Definition 3. "Risk associated with an activity is to be understood as uncertainty about and severity of the consequences of an activity, where severity refers to intensity, size, extension, scope, and other potential measures of magnitude, and is with respect to something humans value (lives, the environment, money, etc.)" (Aven 2010, p. 227).

The last sentence of the definition is important as one would not care about consequences for an object or entity the existence of which is unknown or of no relevance to us. Accordingly, everyone may perceive risk differently in a very subjective manner depending on his levels of responsibility and liability, his relevant performance objectives, and his personal goals (Peck 2006). The consequences of an event can be both tangible and intangible, the resulting damage can range from major to minor, and may be clearly visible (also in its extent) to the person (or organization) affected and to others, only visible to the person affected, or mostly invisible both to the person affected and her environment. Harland et al. (2003) provide a list of different types of risk according to their impact. They mention strategic risk, operational risk, supply risk, customer risk, asset impairment risk, competitive risk, reputation risk, financial risk, fiscal risk, regulatory risk, and legal risk. Each of these types if risk bears different implications for the parties affected.

Among the many definitions of risk that exist in the literature, the one provided above was chosen because it seems that uncertainty plays an important role in supply network management in general and in bottleneck management in particular. As outlined in sections 2.5.4 and 3.7, uncertainty is involved in "drawing" the imaginative system boundary, it is involved in the actions of other autonomous (and possibly opportunistic) actors in the network, it is involved in new product development and introduction to markets, medium-term economic swings as well as long-term market and technological developments, it is involved in global politics and in the natural environment; essentially, uncertainty is – directly or indirectly – involved in all possible events that may lead to unplanned bottlenecks.

Although risk does not by definition mean something negative (Stone & Grønhaug 1993, Aven 2010), it often is negatively connoted as something inherently unpleasant, not least in management of supply risk (Peck 2006). Mitchell (1995), for instance, explains that negative connotation of risk in the managerial context is one of the important differences to the conception of risk in decision theory:

> "There is, therefore, a persistent tension between 'risk' as a measure (e.g., the variance) of the distribution of possible outcomes from a choice and 'risk' as a danger or hazard. From the former perspective, a risky choice is one with a wide range of possible outcomes. From the latter perspective, a risky choice is one that contains a threat of a very poor outcome" (Mitchell 1995, p. 117).

A similar conceptual tension exists with bottlenecks. The existence of bottlenecks, is a necessity, and there is nothing inherently unpleasant about bottlenecks, just as there is nothing inherently negative about variation in possible outcomes.[6] One might even choose to internalize bottlenecks in order to control system throughput and thus to avoid dependence on external factors. Bottlenecks cannot be entirely removed for this would mean that throughput became infinite. If the bottleneck of a system is removed, another bottleneck will appear, and even when all bottlenecks within the system can be removed, the system will still be constrained by an external bottleneck. In the context of a factory, the external bottleneck could be customers' demand or suppliers' production capacity; in the context of manufacturing networks this could be market demand or regulatory policies (e.g., antitrust law). The ultimate purpose of bottleneck management therefore is to make sure the bottleneck can be utilized without unplanned interruption at any point in time (i.e., fully exploited). In this case, the system will achieve its maximum theoretical throughput (Goldratt & Cox 2004).

The distinction between unplanned and planned bottlenecks (cf. Section

[6] Another difference between the concepts of risk and bottlenecks is that risk can be subjective or socially constructed (Slovic 1999, Aven 2011*b*) whereas the existence of bottlenecks is an objective, positive (in the sense that its existence can be logically inferred) fact.

2.3.3) brings some clarity into the relationships between risk and bottlenecks. While bottlenecks cannot be entirely removed and a system will thus always be constrained by some limiting element, it is useful to distinguish between bottlenecks that emerge unplanned and those that are deliberately planned into the system. The latter result from a conscious design decision, i.e., uncertainty as one of the constituents of risk is low. The former, however, can pose a risk as it is unclear where the bottleneck emerges and what the consequences are.

Unplanned bottlenecks can therefore be understood as risk factor for the supply network. How big this factor is depends on the likelihood of the bottleneck's occurrence, its impact, its duration, and the options for its exploitation or elimination. Moreover, the options for exploitation or removal of the bottleneck may depend on whether the bottleneck has emerged internally (i.e., within organizational reach) or externally (e.g., at a supplier).

It seems reasonable to assume that bottlenecks in external locations (i.e., in the supply network) pose a higher risk to the organization than a bottleneck within physical reach. Likewise, a bottleneck that is outside its organizational control increases uncertainty for the focal firm; the system-level comparison in Section 3.7 provides more detailed explanations of this point. The effects of unplanned bottlenecks that exist over an extended period of time are less likely to be buffered by inventory (inventory buffer will be used up at some point) and are more likely to "buffered by time" (in terms of Hopp & Spearman 2008) than effects of bottlenecks that exist only for a short period of time. Static bottlenecks can be more easily identified than wandering bottlenecks, which allows measures to protect the bottleneck. Accordingly, wandering bottlenecks arguably pose a higher risk to the firm. If the only way to increase throughput is to increase capacity of the bottleneck and no other way is conceivable, then cost incurred for the capacity increase can be significant in some cases, but at least much higher than for many alternative measures that can help exploit bottleneck capacity already available. Whether the severity of the bottleneck effects is higher for bottlenecks due to organizational, physical, or operational causes and whether short-cycled, mid-cycled, or long-cycled bottlenecks pose a higher risk, very much depends on the circumstances.

There is little empirical research on the actual effects of supply interruptions on firm performance. One important reason certainly is that network effects on individual firm performance are difficult to single out. A more fundamental problem may be that *performance* is a poorly defined and ambiguous concept and that measurements may yield different results depending on the dependent variable that one chooses to measure. “Performance is never objective” (Lebas 1995, p. 27) and the reason is that goals differ depending on the stakeholder concerned and on the purpose of the measurement (Sink 1993, p. 8-3.12; Lebas 1995, p. 24; Simons 2000, p. 10). The survival rate of network relationships has been used as an approximation to measure success (Gulati et al. 2002, p. 293). Supply relationships are often not intended to persist forever but will end with the phase-out of a product, however. In this case, a termination of the relationships does not yield information about the success of the relationship (Kenis & Oerlemans 2008). In contrast, continuation of a supply relationship does not mean it is successful; instead, switching or exit cost may simply be high (Kim et al. 2006). Stock market effects were used as an indicator for the effect of supply chain interruptions in Hendricks & Singhal (2003) and Hendricks & Singhal (2005*a*,*b*). These authors found that both stock prices and operating performance respond significantly to “glitches” in supply. As outlined above, however, such findings should not be generalized as the consequences of delays or interruptions of supply will differ for firms.

3.7. A Synoptic Systems Perspective on Manufacturing Networks and Production Systems

3.7.1. Introduction: Purpose of a System Level Comparison

The following section will present a short systematic comparison of the two archetypal material flow systems factory and supply network.[7] Because ma-

[7] An earlier version of this section was presented as a paper at the World Congress of Engineering Asset Management 2013 in Hong Kong and was published as Beer (2015).

terial flow systems are similar in some respects but will show differences in others, such a comparison can support the understanding of both potential for improvement as well as possible limitations in the management of material flow in either system.

The comparison draws on different streams of literature, such as Systems Theory, Operations Management, and Supply Chain Management, and is partly informed by findings from earlier research conducted in supplier management in the automobile industry (Beer 2011).

The objective of this thought-experiment is to capitalize on the large amount of research that has been done on material flow and bottleneck management in factory settings and to derive lessons for the improvement of material flow in supply networks.

3.7.2. A Systems Perspective on Factories and Supply Networks

The two systems can be compared across a variety of systemic properties. The outcome of such a comparison to some extent would depend on the specific type of factory and the specific supply network selected; either system differs widely in its respective characteristics in practice. There are some archetypal properties which, while not always present, tend to be characteristical for the two systems. Nonetheless, the comparison will remain a thought experiment.

One premise of this comparison is that both factories and supply networks can be understood as material flow systems. As such, they share certain characteristics. For instance, both systems are comprised of entities that stand in some relationship to each other. In this case, the relationships are primarily defined by the flow of material between those entities. The entities convert incoming material or products into another type of outgoing material or products. Some entities may only have a relay function, such as cross-docking stations of logistics service providers or warehouses.

Furthermore, both factories and supply networks show characteristics of *open systems*, albeit to a differing degree. In both systems, the constituting elements may be changed by external influx of energy or material. In fact, both systems depend on the influx of energy and material which, after transformation during the production process, will leave the system again.

Though a more extensive comparison might yield interesting results, this short review shall be limited to the following:

- degree of system openness,
- degree of system complexity,
- focus on flow, and
- autonomy of nodes.

3.7.3. Systemic Differences Between Factories and Supply Networks

3.7.3.1. Degree of System Openness

While both factory and supply networks are open systems, their system borders differ in permeability. In each case, the system border allows influx and outflow of material and energy required for the value-adding production process. There are significant differences, however, in the extent to which each system is subject to undesired and possibly interruptive impact from the system environment.

The main reason lies in the spatial distribution of the systems' nodes. Not every supply network is globally dispersed (nor are factories necessarily well shielded from undesirable external impact), yet for a general, albeit stylized dichotomy, it is certainly valid to claim that nodes in a supply networks tend to be wider dispersed than nodes in a factory system. Indeed, there are two extrema in the layout of supply networks: on the one hand, supply networks can be globally dispersed; on the other hand, supply networks can be concentrated in a small geographical area, as in the case of supplier parks. However, even in the case of supplier parks, (additional) raw material and parts have to be delivered either directly to the OEM or to the suppliers which predominantly represent only the first tier of the supply network. That is, a large part of the supply network remains outside the geographically concentrated area and thus remains vulnerable.

Large geographic dispersion involves long distance transportation with a variety of transportation modes. Furthermore, the nodes in the supply network are exposed to different environmental (i.e., political, social, natural, and cultural) conditions that can impact on the production and transportation of goods. The high exposure to various, possibly adverse, factors increases the uncertainty involved in the business. Furthermore, the variety of factors possibly impacting on the supply network and the resulting uncertainty limits management in its effectiveness when attempting to safeguard the functioning of the system. Given the various sources of uncertainty – and especially the number of *unknown unknowns* – in a widely dispersed network, the risk of interruptions is difficult to grasp.

Of course, large geographical concentration of suppliers is not without risk, either. Obviously, the occurrence of significant events in the environment (e.g., natural disasters, political riots, wars, etc.) would impact a larger number of suppliers at once. In such an event, significant interruption must be expected as it is unlikely that production and supply can be kept upright. The use of alternative sources for supply within a contingency plan is unlikely to be able to avert interruptions when a large number of suppliers is involved. Accordingly, Craighead et al. (2007) found that geographical concentration of suppliers ("supply chain density") is likely to create more severe disruptions. Simplified, the risk of supply interruptions with respect to geographical dispersion (or geographical concentration) of suppliers may be visualized by a U-shaped graph: While the risk of interruptions may be high due to the higher number of vulnerable links in a globally dispersed network – that is, probability (or uncertainty) of adverse occurrences is high –, the risk of interruption in geographically concentrated suppliers is high due to the severity of the possible occurrence. Uncertainty and severity both are part of the risk definition introduced earlier (cf. p. 172). An example for high risk due to high exposure of the supply networks to a broad variety of possible impacts can be found in the frequent interruptions automobile manufacturers had to cope with in 2010 and 2011 due to a combination of natural disasters, political turmoil, and economic conditions (e.g., interruption of the volcano Eyjafjallajökull in southern Island, political uprise in North Africa, severe floods in Europe and Asia, suppliers struggling financially due to the effects of the recent financial crisis, etc.). An example for interruptions due an incident that affected several suppliers at once can be found in the earthquake that hit Japan's eastern coast in 2011 which had put a halt to the production of many industrial firms, (Leckcivilize 2012), among them several automotive suppliers. [8] Also in 2011, the automobile industry suffered from shortages of semiconductors and glass panels which were not induced by natural or political disasters. Here, the reasons for supply delay and disruption were not insufficient production capacity from suppliers *per se* but rather decisions to allocate production capacity differently. Suppliers of semiconductors and glass panels did in fact have production capacity that would have met demand from the automotive sector alone; however, in the face of insufficient production capacity for a total of all their customers they had to make decisions concerning capacity allocation and preferred to supply customers from other industries such as consumer electronics as margins there were much higher. That is, lateral effects in the supply network from nodes that belong to system's environment rather than to the system itself led to distortion (cf. Section 2.5.4 on page 96 and Beer et al. 2012). This case suggests another apparently important difference: While the system boundary of a factory system is relatively easy to draw, this is much more difficult to do and more ambiguous in a supply network. When there is ambiguity about system boundaries, then planning and preparing for contingencies is much more difficult. The likelihood that the focal firm in the supply network experiences some adverse impact it was unable to prepare for seems to

[8]Compared to supply networks, factory systems obviously are an extreme form of geographically concentrated value creation. In contrast to supply networks, however, nodes of a factory system cannot be spread over any significant geographical area without invoking severe inefficiencies. Following the arguments that have been made about risk of geographically dispersed or geographically concentrated suppliers, respectively, one could conclude that factories are subject to high risk because when they are hit by external adverse impact this entire material flow system would come to halt. Whether alternative solutions are worth seeking, such as redundant production capacities in other locations or parallel production in several plants, depends on various factors, among them the product margin and the product maturity in terms of its life cycle. Interruption of production of high-margin products on an early stage of their life cycle can hurt the firm badly as market share may be irretrievably lost to competition. Apparently, the trade-off here is between efficiency and responsiveness, which is the questions that needs to be answered for the design of supply networks, too (cf. Fisher 1997).

be high.[9]

3.7.3.2. Degree of System Complexity

It is difficult to characterize differences in complexity of two generic systems in theory. It is possible, though, to identify drivers of complexity that may or may not be present in either system. It will be argued that such factors are likely to cause a higher level of complexity in supply networks than in a factory.

The higher openness of the system resulting from higher permeability of the system boundaries is likely to have an impact on the nodes within the system. Nodes in a supply network can be described as agents which are acting according to a set of rules (cf. Section 2.4.4). That is, the nodes in a supply network are *active* in nature; they act and they react based upon the conditions they find, part of which are an inherent part of the system whereas another part of the conditions may consist of external stimulus from the system's environment. Such external stimulus can be environmental incidents (market conditions, political conditions, natural disasters, etc.) and lateral effects, such as indirect demand from other industries. Due to their status as (typically) autonomous firms that are legally independent of their customers and thus not subject to fiat within a single firm hierarchy – as it is the case with process stations in a factory – nodes in a supply network (i.e., suppliers) can choose from a much more comprehensive set of possible courses of action. Nodes in a factory system thus are rather passive than active and exhibit a lower level of autonomy. Mathematically spoken, nodes in a factory system have fewer "degrees of freedom".

Availability of information generally helps decreasing and controlling complexity. The emergence of the *bullwhip effect*, for instance, can partly be explained by a lack of information about actual customer demand which requires companies upstream in a supply network to interpret ambiguous data which, in turn, often leads to over- or underestimation of actual demand, resulting in strongly oscillating inventories (Forrester 1958, Lee et al. 1997). That is,

[9] This case can also serve as a powerful reminder of the inadequacy of the supply chain model that invokes a linear single-threaded chain where lateral effects cannot occur (cf. Section 2.5.4).

each agent acts rationally according to his local rules and the information locally available, thereby unintendedly creating turbulence for the entire network. There are several reasons why availability of relevant information to all nodes involved is less likely to be achieved in a supply network than in a factory system:

- The spatial dispersion of nodes requires some type of information system to bridge geographic distance since information does not just “happen to arrive” at the right place in the right time as it might occur between locally concentrated nodes.
- For an information system to work effectively, it must be defined what kind of information shall be made available to other nodes. Besides that humans sometimes make wrong decisions, it is not always known in advance what information is of importance to other nodes. Hence, it is possible that important information is not transmitted.
- A delay is often involved in the transmission of information between nodes in a network. In some industries, e.g., automotive, it is common to have nightly EDI call-offs sent from the OEM to its tier-1 suppliers. The tier-1 suppliers, in turn, may have nightly EDI call-offs for their supply from tier-2 suppliers. If disadvantageously scheduled, it can take two days before the call-off information reaches the tier-2 suppliers. In case of long supply chains – some chains have six tiers and more – a significant delay can occur before information is processed.
- Not all information will be disclosed to other nodes and sometimes the level of information available is purposely kept low in order to protect confidential information from competition. In a factory system, on the other hand, each process station normally belongs to the same legal organization and information tends to be more freely shared than between legally independent firms.
- Transmission of feedback from other nodes in the network to the focal firm suffers from similar problems, i.e., possibly incomplete or delayed

information, which fortifies the problem.

Due to the reasons outlined here, it is less likely that availability of information can help decrease or manage complexity in a supply network to the same extent as in a factory network.

3.7.3.3. Focus on Flow

Significant improvements in factory throughput have shown to be possible as a consequence of paradigm shift from centrally controlled push systems with focus on efficiency to improvement of material flow.[10] Many of the changes can be traced back to the development of variety of production philosophies, some of which could also be referred to as management philosophies due to the generalizability of their underlying principles. Examples are Just-in-Time (or: Lean), Total Quality Management, Theory of Constraints, and Six Sigma. These philosophies employ different thematic and methodological foci and different lexica, but are similar in some ways. One aspect that is shared across all these philosophies is the improvement of material flow, either as central theme (e.g., in Theory of Constraints) or as consequence (e.g., of reduction of variability, as in Six Sigma). The changes that have (arguably) been brought about in many manufacturing environments are due to the significantly different mindset that has guided production planning since the wide adoption of Material Requirements Planning (MRP) throughout the 1970s as compared to the "new" philosophies. MRP (as well as Manufacturing Resources Planning, MRP II) is a *central* planning approach to control production along two dimensions: quantities and timing (Hopp & Spearman 2008). Lean (or JiT), on the other hand, though providing a set of general rules, is an inherently *decentralized* approach that allows individuals to act based upon local conditions (while obeying the general rules). Instead of dealing with quantities or timing from an aerial perspective and *pushing* material through the system, production is directly triggered (*pulled*) by demand. The ideal is to produce the exact amount needed

[10]See Hopp & Spearman (2008) for a more comprehensive account of the content and implications of different management philosophies.

so that it is finished right when it is needed. Large amounts of WIP that accumulate due to large production batches and variability – and, in turn, increase variability even more – can be avoided and cycle time thus be reduced. Ideally, the material *flows* through the factory with fewer delays.

Various direct and indirect advantages are associated with improved material flow and many have been widely recognized – at least in the literature.[11] They include (but are not limited to) improved throughput, reduced cycle time, reduced inventory (both on stock and in process, i.e., WIP), improved quality, higher reliability, and eventually higher customer satisfaction.

The advantages of the flow principle have been discussed in the literature and have been embraced by in the industry. Successful implementation and operationalization of the flow principle have predominantly been achieved within the boundaries of factory systems, whereas in the larger manufacturing supply network groundbreaking changes have not occurred. There are attempts to implement the flow principle in supply networks; the umbrella category Supply Chain Management does, in fact, contain tools and concepts such as Just-in-Time (JiT), Just-in-Sequence (JiS), Efficient Consumer Response (ECR), Collaborative Planning, Forecasting, and Replenishment (CPFR), and some other.

JiT and JiS in particular seem to be the logical extension of a factory-internal implementation of the flow principle. At second sight, however, the actual implementation of JiT and JiS in practice demonstrates difficulties inherent to the management of supply networks and thereby reveals some differences between supply networks and factories. A look at the automotive industry suggests that the implementation of JiT and JiS in many cases is limited to the delivery mode between a supplier and his customer (e.g., the OEM), and does *not* link the internal pull systems across several tiers. A study of the supplier relations in the automotive sector (Beer 2011) suggests that some OEMs' intention for the implementation of "JiT" is to reduce inventory in incoming goods warehouses – and instead move it to supplier site and responsibility. The *amount* of inventory remains essentially unchanged, but location and ownership change. Accord-

[11] In the course of the research done for the case studies in this thesis, some differences between the state-of-the-art knowledge in production planning in the literature and the situation in several firms have become quite apparent.

ingly, the benefits of this “fake JiT” implementation turn out to be unevenly distributed. In their study, Göpfert & Braun (2010) show that OEMs indeed greatly benefit from such implementations, whereas the positive effects for supplier are small, if at all, and sometimes even negative.

There are some possible explanations as to why this kind of fake implementation is being pursued. Arguably, the automotive industry has characteristics other industries do not have, so that the emergence of this phenomenon cannot be expected to exist elsewhere. Additional studies in other industries are necessary to find whether the findings with regard to JiT and JiS implementation can be generalized.

One typical characteristic of the automotive sector is that the cost of OEM plants being idle are extraordinarily high. Therefore, OEMs have strong interest in reliable supply and require suppliers to maintain a safety buffer of parts from which they can supply the OEM. One indicator that this might be one factor can be seen in the popularity of another delivery mode that is employed for many parts: delivery to consignment warehouses. In consignment warehouses, the inventory is owned by the supplier while the warehouse is located on or close to the OEM site. Ownership of parts changes only when the OEM takes the part out of the warehouse. Together, JiT/JiS and consignment warehouses have replaced traditional delivery-to-warehouse mode in which the OEM owns the inventory for many parts (Beer 2011). So arguably, the main objective of OEMs is to reduce ownership of inventory – and not to reduce inventory as such.

An extension of the previous proposition is that one actor in the supply network does not care about the amount of inventory that other actors in the supply network hold. This might be the case because they do not feel the negative consequences of other actors holding high inventory, or because the advantages of other actors holding high levels of inventory, e.g., (arguably) higher supply reliability, overcompensate potential disadvantages. With regard to potential disadvantages, one could argue that higher inventory levels and thereby higher holding cost incurred may also lead to higher cost for the customer. The response to this argument is two-fold: first, the cost of suppliers holding inventory (and the customer, i.e., the OEM or the lower-tier supplier paying for this inventory through higher prices demanded by the supplier to compensate his additional cost) might still be lower than the cost of supply interruptions; second, a quick glance on the history of relationships between OEMs and suppliers in the automotive industry suggests that OEMs might not be fully aware of the negative consequences for them when they maintain adverse supplier relationships, or they are at least ignorant about concerns of suppliers (cf. the role and work of José Ignacio López de Arriortúa at General Motors, Opel and Volkswagen and the "López Effect"; Mitchener 1997-03-14, Willutzki 2001).

In addition to the lack of concern of OEMs and downstream suppliers about inventory levels of upstream suppliers, there is a lack of interest of some upstream suppliers to align with possible "low-inventory, smooth-flow" ideals with customers. This lack of interest is embodied in minimum order quantities. In one case encountered during an earlier study of supply management in the automobile industry (Beer 2011), a logistics audit conducted by an OEM on a tier-1 supplier production site revealed that the supplier's warehouse for incoming goods was filled to the top with 300.000 units of one specific plastic part. The warehouse manager at the supplier, asked by the auditors why his company holds this high amount of inventory of this one part on stock, respondet that their supplier, i.e., the OEM's tier-2 supplier, required them to buy the minimum order quantity of 300.000 units in spite of his actual need of only some hundred units. The tier-2 supplier which holds a powerful position in the network did not have to fear any consequences or negative effects on his business from the relatively unimportant customer. While this case is certainly extreme in its magnitude, it is conceivable that serious JiT or JiS implementations in other buyer-supplier relationships and in other industries can fail for similar reasons.

Beamon (1998) provides a literature review of performance measures used in SCM. None of the authors she reviewed uses throughput explicitly as performance measures whereas cost reduction is a dominant parameter. Reduction of inventory and reduction of variability ("Minimize product demand variance and demand amplification") is mentioned as performance indicator by some authors, cycle time is hidden in "customer responsiveness", however. For the management of a factory system, Goldratt & Cox (2004) suggest using throughput as primary indicator, inventory as secondary indicator, and operating expenses (i.e., cost) as tertiary indicator. The priorities in the literature reviewed by Beamon (1998) seem to be different. Also, while inventory levels are mentioned as a decision variable in supply chain modeling, no attention is paid to delivery (regular warehouse, JiT, JiS, consignment warehouse, VMI...) and transportation (road, air, water, rail) mode. The different modes do, however, have implications for the steadiness of the flow as well as the size of the inventory (both planned and actual) as they determine the equivalent of what is referred to as the production batch size in a factory.

The arguments above illustrate why tools, methods and principles for the improvement of material flow in supply networks can experience problems in implementation. The arguments referred to diverging interests among suppliers and customers, imbalance of power relationships (and the exploitation thereof), trade-off between objectives of a firm, and lack of foresight.

3.7.3.4. Autonomy of Nodes

One important difference between the management of material flow in a factory and management of material flow in a supply network lies in the amount of control and influence management can exert over the various nodes and edges of the system (or in different terms: over the assets and processes). In a factory, management is working on behalf of the owners of the assets and employees are contractually bound to obey management's directives. This is not to say that management has *full* control over assets and processes; in fact, there is much research on phenomena such as opportunism (e.g., in Transaction Cost Economics, cf. Williamson 1975) and organizational culture (cf. Schein 2009) which suggests that while management can use the power of fiat it may still be unable to achieve all of its objectives within an organization. Nevertheless, it seems to be a valid claim that management and owners do have considerable control over assets and processes in their organizations.

In contrast, there rarely is a legal foundation in a supply network for a focal company's interference in internal organization of its suppliers. Although the term "Supply Chain Management" and its definition suggest an active role of the focal firm in the organization of and interplay between nodes in the network (cf. Section 2.5.4), researchers are in disagreement as to what extent a supply network can be managed and to what extent the focal firm merely has to cope with the network (cf. Section 2.5.5.2). On the other hand, field research in some industries shows that focal firms do have some control over their suppliers in some cases. It is very common, for instance, that automobile OEMs conduct audits on supplier sites and actively point out issues that have to be resolved before the supplier can enter into a supply relationship with the OEM, or to maintain this relationship, respectively. Bicheno & Holweg (2009) claim there are only two mechanisms to "align incentives" in supply networks: *power* and *shared rewards*. Whether and to what extent it is possible to exert power in a supply network depends on the power configuration resulting from interdependencies as well as the type of network governance (cf. Section 2.5.5.2). Furthermore, it may not always be wise to exploit advantageous power positions in a network. As pointed out earlier (cf. Section 2.5.5.2), the exploitation of a powerful position in the network can, in fact, deteriorate performance as the disadvantaged party might rather accept switching costs (which can be conceived of as a representation of dependence) and leave the network. It may thus be necessary to focus on incentive alignment instead (Narayanan & Raman 2004).

3.7.3.5. Implications for Bottleneck Management

The differences discussed in the preceding paragraphs have implications for the maagement of bottlenecks.

There is a variety of methods for the *detection* of bottlenecks in manufacturing systems. Common methods for bottleneck detection in factory systems are utilization-based methods, queue length-based methods, wait time-based methods, and experiments (Roser et al. 2002, 2003). The reasons for the existence of multiple methods include:

1. The understanding as to what constitutes a bottleneck varies,
2. different systems are subject to different limitations, which can render some methods for bottleneck detection inapplicable, and

3. depending on the method and the definition of a bottleneck, different elements of the systems could be identified as a bottleneck. Different methods may thus be necessary to validate the findings of the detection process.

The literature review in Section 2.3.2 indicates that many authors are imprecise in their definition of bottlenecks and in stating the characteristics they exhibit. Some confuse, for instance, the definition of bottlenecks with the methods to detect bottlenecks. There are several indicators that can suggest the existence of a bottleneck, such as high utilization of a certain system element, long queues in front of a system element, elements that are blocked from releasing material or are starving from a lack of material. Depending on what indicator is employed for the detection of bottleneck results may vary. The second point refers to the fact that design decisions in the material flow system can render some indicators or methods for bottleneck detection useless. A physical limitation of queue length in front of a machining station, for instance, will not allow to employ a queue length-based method for bottleneck detection. A maximum waiting time in the queue before prioritization is changed or (occasionally or even frequently) changing prioritization by urgency will render methods useless which rely on wait time. Low availability of a machine due to frequent break downs or maintenance measures may lead to high utilization and may wrongly suggest the existence of a bottleneck where there is none. Hence, as indicated in the third point, detection results may be unreliable and validation necessary.

Apparently, bottleneck detection suffers from ambiguity even when conducted within the boundaries of a factory. In a supply network, the level of transparency with respect to indicators is lower, the autonomy of nodes is higher, the level of complexity is higher, and so is (arguably) the level of opportunism. In fact, suppliers may be black boxes to customers if the latter do not possess a particularly powerful position that allows them to enforce a certain level of transparency through audits and agreements. Suppliers may even have strategic interest in not revealing information that would allow other firms to use indicators for bottleneck detection. Furthermore, in spite of the buzz around “managing the whole supply chain from raw material to customer”, focal firms are not normally involved in the business with sub-suppliers, so they often do not receive any information from them. Essentially, the most common case may be that the focal firm is dependent and has to rely on information provided by its suppliers by their own choice.

The same obstacles that make identification of bottlenecks in a supply network difficult make their elimination a challenge. More than anything else, autonomy of suppliers may represent the major constraint for effective supply network bottleneck management on part of the focal firm. Autonomy of suppliers causes a lack of control for the customer. Measures to protect or resolve the bottleneck are therefore difficult to enact. Protecting the bottleneck means that it should never starve and that it should never be blocked from releasing parts that have been processed. Furthermore, it must be avoided that the bottleneck wastes capacity (Goldratt & Fox 1986, Goldratt & Cox 2004).

Focal firms would need to go into tier-n management, i.e., they would need to "manage" not only direct (tier-1) suppliers, but need to expand their activities over several tiers. A look at the automotive industry, where there are powerful OEMs with high efficiency requirements and thus high vulnerability towards bottlenecks, suggests that even the most powerful firms are not doing it. Only very recently, some (very few) OEMs have started to expand their tier-n activities (Beer 2011). However, even when companies intend to do tier-n management, the problem remains that suppliers remain autonomous and, if their power position in the network allows, are unlikely to let customers interfere with their internal processes in any significant way. Conflicts of interest with other customers could be expected.

In an interview conducted as part of an earlier case study (Beer 2011), a supplier manager at a large automotive OEM stated that most supply shortages result from quality problems. This statement indicates that suppliers run out of production capacity when scrap rate is high and rework necessary. Bottlenecks emerge due to quality problems because there is too little extra capacity available to make up for the waste of capacity due to work on defective parts or work on parts that then do not meet quality criteria, respectively. Because OEMs generally demand low prices – and expect yearly reductions in the prices they pay to their suppliers throughout the product life cycle – suppliers have to maintain high utilization of their production assets to ensure cost efficient production. Put differently, suppliers are pushed towards the "efficiency pole" of the efficiency-flexibility trade-off.

Another important implication concerns the purposeful location of a planned bottleneck. Every system has a bottleneck. One way, however, to facilitate control of the bottleneck is to plan it consciously into the system. This allows the firm to protect the bottleneck and thereby ensure high throughput. In practice, firms may want to select those resources as bottlenecks where high utilization is desirable. Commonly, for accounting reasons these will be resources with high fixed cost, such as paint shops or other processing stations with particularly expensive machines. What does this imply for the management of a supply network?

To better understand the implications, we can draw on the concept of *Supply Chain Orientation* (SCO) as introduced by Mentzer et al. (2001). They define SCO as "the recognition by an organization of the systemic, strategic implications of the tactical activities involved in managing the various flows in a supply chain" (p. 11). That is, SCO describes a specific organizational mindset, an aspect of the organizational culture. In order to achieve anything that comes close to the claim of strategic coordination for the well-being of the entire supply chain (instead of local optimization), as included in various Supply Chain Management definitions (e.g., Council of Supply Chain Management Professionals (CSCMP) 2010, Mentzer et al. 2001; cf. Section 2.5.4), such Supply Chain Orientation needs to exist not only in one firm, but is required "across several companies directly connected in the supply chain" (Mentzer et al. 2001, p. 11). The multiple-case study conducted as part of this dissertation as well as earlier case study research in the automobile industry suggest that the existence of SCO across several companies cannot be taken for granted. It seems more likely that each firm in the supply network enjoys the economic benefits of high asset utilization to the extent the supply contract allows. For that very reason, supply contracts often stipulate terms regarding the maximum amount of working shifts per week a supplier may use for production of the forecast amounts so that production capacity flexibility can be maintained and production can be scaled up in case demand increases at short notice. Apparently, the same economic logic that may lead management as the central power in a firm to choose high-value assets as bottlenecks to ensure high utilization comes into play in the supply network. The important difference is, however, that in a decentralized supply network no powerful central entity can make such a decision on behalf – and for the sake – of the whole network. Accordingly, firms will tend to prioritize their individual outcome over the network outcome as a whole. To what extent individual firms will make sacrifices for the good of the entire network is still subject to ongoing research. Questions of firm ownership (shareholders) and governance may play an important role, and so do interdependence and power relations in the network (cf. Section 2.5.5.2).

3.7.3.6. Conclusion

By comparing supply networks with factories, some systemic differences between these two types of material flow systems could be highlighted. The differences provide explanation for the difficulties a focal firm may encounter when trying to establish measures to improve material flow in a network.

On the one hand, the level of variability in the network is increased due to higher system openness and complexity. On the other hand, the focal firm's means to reduce variability are rather limited since nodes in the supply network enjoy higher autonomy than nodes in a factory system. Higher autonomy of nodes tends to reduce the transparency of material flow and possible impediments to material flow and thereby limits the focal firm's ability to control and steer. The lack of transparency further increases complexity. Hence, the focal firm cannot expect to be able to manage its supply networks' material flow on a level that is roughly comparable to the options it has in its own factory.

The increased difficulties reflect the need to make careful design decisions right from the beginning. Because directly approaching an existing bottleneck seems to be a problem in supply networks, design decisions should involve careful preparation for the prevention of unplanned bottlenecks. Possibly, bottleneck placement could be an option worthwile investigating. Conscious bottleneck placement is a familiar topic for production planners (cf. Goldratt & Fox 1986) but seems to be non-existent in the literature on supply networks (or "Supply Chain Management"). Additionally, the focal firm's manufacturing characteristics in terms of flexibility and efficiency should be reflected by the characteristics of the supply network since a mismatch is likely to lead to inefficiencies and loss of throughput.

3.8. Summary

This chapter represents the second part of the review of relevant literature. While the first part was focused on more fundamental topics, this one touched upon concepts that emerged from those fundamental topics and gained importance through application in practice. The topics covered in this chapter include Purchasing Portfolio Analysis, Lean/Just-in-Time, Agile and Leagile, Theory of Constraints, and Supply Chain Risk Management. The chapter closes with a systematic comparison between material flow in a factory and material flow in a supply networks. This purpose of this comparison was to identify system properties of supply networks that have implications for the management of bottlenecks in supply.

4. Conceptual Model for Bottleneck Management in Supply Networks

4.1. Introduction

In this chapter, insights and findings from the previous review of literature will be used to extract useful ideas, concepts, and categories in order to create a tentative conceptual model of bottleneck management in supply networks. The model shall serve to guide both the collection and the analysis of empirical data that will follow after this chapter. Also, research questions will be defined at the end of this chapter. These build on the general research aim as articulated in Section 1.2 and take into account the information – and more specifically the *gaps* in information – from the theoretical review.

According to Shehabuddeen et al. (1999, p. 13), "a model supports the understanding of the dynamic interaction between the elements of a system". The causes of bottleneck emergence and the activities organization perform to manage bottlenecks in supply are inherently dynamic; they are subject to frequently changing conditions and to dynamic interations between suppliers, the focal company, as well as organizations outside the dyadic relationship and possibly even outside the system that is referred to as supply network. Shehabuddeen et al. (1999) elaborate further that understanding of the model involves ability to make predictions (ibid, p. 12). Hence, the conceptual model drafted in this chapter serves as a precursor to the theory which this study aims to create eventually.

4.2. Categories of Bottleneck Management

The review of literature in the preceding sections brought up a variety of important aspects for the stabilization of material flow and thus for the management of bottlenecks in supply networks.

There is currently no standard body of literature that defines the key tasks – or *categories* – of bottleneck management. Moreover, bottleneck management is hardly recognized as a discipline but seems to be predominantly considered a sub-topic of production scheduling in the context of factory material flow planning or as sub-topic of Supply Chain Risk Management in the wider context of supply networks.

When dealing with unintended or undesirable incidents, *prevention* is an important, almost universal principle. A good share of the literature on risk management deals with strategies to minimize the likelihood of the occurrence of adverse effects. In the context of supply networks, the field *Supply Chain Risk Management* (SCRM) (cf. Section 3.6) has gained popularity. Many researchers discuss and investigate ways to make supply networks more resilient against disruptions. The most obvious activity production firms can pursue in order to stabilize their material flow therefore is to prevent bottlenecks in their supply network in the first place. Also, prevention is the focus of *purchasing portfolio analysis* (PPA; cf. Section 3.2). In PPA, market and product analysis are combined so as to be able to devise norm strategies and develop action plans in order to prevent supply shortages from happening. Prevention is also a the implicit focus of the *Agile* approach to SCM (cf. Section 3.5). Agile emphasizes flexibility which is to help avoid mismatches between supply and demand.

Hence, many measures known from literature and industrial practice can be summarized under the category of *bottleneck prevention*. Bottleneck prevention is the first category of bottleneck management activities to be included in the tentative conceptual model. Bottleneck prevention is comprised of activities and methods whose purpose it is to prevent the occurrence of unplanned events that will lead to lower throughput in the system. In system theory terms, it is concerned with planning out throughput-related characteristics of the nodes and of the paths. Such characteristics are the production capacity of the nodes and their flexibility (*production capacity flexibility*, PCF), buffers, production schedule, transportation routes, transportation means, and quality control. Quality control does not only refer to quality check of processed parts but refers to process quality, too. Thus, it includes supplier audits, e.g., for sourcing decisions.

A typical measures for bottleneck prevention is to include a required rate for production capacity flexibility in the supply contract. In the automobile industry, for instance, it is common to inflict 10% required flexibility on suppliers and to determine the maximum amount of work shifts per week (e.g., 15) suppliers are allowed to use to produce the amount of parts the customer demands. This enables suppliers to scale up production at short notice. Also, in case of delivery to consignment warehouses, OEMs and suppliers negotiate the amount of inventory days on hand.

Not always will prevention measures suffice, however. Supply shortages can occur nonetheless. Force majeure is a prominent topic for international trade and supply. Volcano outbreaks that interrupt flight traffic, tsunamis, war, strikes, and riots are only some of the many events that are difficult to plan for and impossible to prevent. Accordingly, the *elimination* of an existing bottleneck is the second category of bottleneck management activities that can be derived. *Bottleneck elimination* is an important topic in the literature on ToC and generally appears to follow logically from the higher-level aim of stabilizing material flow. Bottleneck elimination is concerned with the removal of an unplanned bottleneck. Because a system would have unlimited throughput if there were no bottlenecks (and because this case does not exist in practice), a new bottleneck will emerge once the old bottleneck has been eliminated, or a planned bottleneck will become the binding constraint. Technically, it would thus be more accurate to refer to *shifting* the bottleneck rather than to eliminating it. What measures will effectively eliminate an existing bottleneck depends on the causes for that bottleneck. Elimination measures either have to aim at the root cause of the problem that causes the bottleneck or they have to open up alternative streams of material flow.

There is more companies can do, however, than preventing the bottleneck

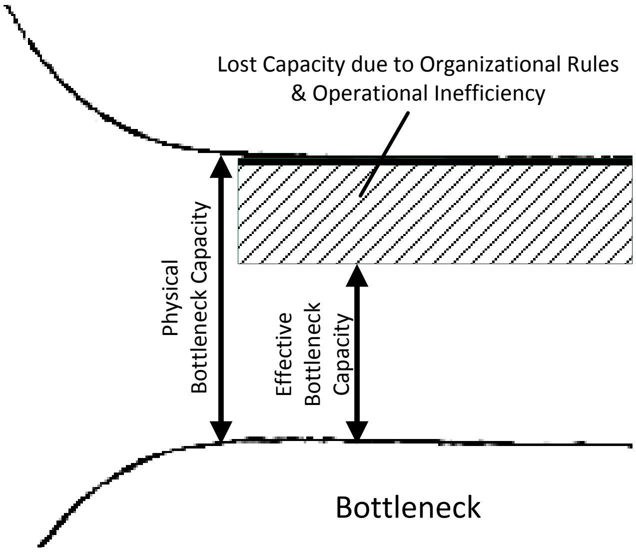

Figure 4.2.1. – Physical Capacity and Effective Capacity of a Bottleneck

from emerging or making it disappear (or shift). Accordingly, besides reducing the likelihood of adverse incidents, the second big focus of SCRM is on the mitigation of consequences of such incidents. As indicated in Section 2.3.3, a bottleneck does not necessarily exist due to limits to its physical capacity but may exist because the theoretical (physical) capacity available is not sufficiently used. Capacity can, for instance, be limited due to organizational rules that represent an impediment to higher bottleneck utilization. Also, operations on the bottleneck might be inefficient and thus waste capacity. A look at Figure 4.2.1 can make this clearer. The converging lines at the upper and lower end of the figure represent the total capacity of the system at the bottleneck – the physical throughput capacity. The shaded area represents capacity losses. The definition of the bottleneck provided earlier in this document already hinted at "organizational rules and operational practices". These can reduce the physical throughput capacity of the bottleneck. What remains can be called the effective bottleneck capacity.

Bottleneck elimination – the second category of bottleneck management activities previously identified – means that the entire bottleneck is removed (or shifted elsewhere, that is). This can take time, though. It can, for instance, require the buying firm to approve a new source of supply. In the meanwhile, the buying firm would be well-advised to fully use the physical throughput capacity at the bottleneck by reducing the shaded area in the illustration. This can be called *bottleneck exploitation* and it represents an additional category of bottleneck management activities. Bottleneck exploitation aims at maximizing the effectively available throughput capacity at the bottleneck until the bottleneck can be eliminated for good. Stabilizing the throughput at the bottleneck also corresponds to the flow principle that is emphasized in the Lean/JiT paradigm (cf. Section 3.3). At the same time, it seems that the converse concept, Agility, could contribute to the conception this activity. Agility values effectiveness higher than efficiency (cf. Section 3.5). That is, it puts emphasis on making something happen in due time, as demanded by the market, rather than make it as cost-efficient and with as little waste as possible. Rather than running the risk of drying out the inbound material stream, expenses are committed to maintain as high a level of uninterrupted inbound material flow as possible and necessary so as to not starve internal production processes. Therefore, agility seems to be a good theoretical anchor for the concept of bottleneck exploitation.

The importance of maximizing bottleneck throughput is obvious: “An hour lost at a bottleneck is an hour lost for the total system” (Goldratt & Fox 1986, Goldratt & Cox 2004). The reason is that the bottleneck does not have excess capacity that could be used to catch up with any loss of throughput. Therefore the bottleneck must be *protected* from interruptions to its operations and from waste of its capacity. Specifically, that means (Goldratt & Fox 1986, Goldratt & Cox 2004)

- the bottleneck should never *starve*, i.e., it should never run out of input material to work on,
- the bottleneck should never be *blocked*, i.e., it should always be able to release material it has processed,
- the bottleneck should never work on parts that could be processed elsewhere, e.g., at another station or from a contract manufacturer,

- the bottleneck should never work on parts that are not needed to finish actual customer orders,
- the bottleneck should never work on defective parts,
- parts that have been processed by the bottleneck should be treated with care as each part that breaks after it has been processed by the bottleneck inevitably equals a loss of throughput for the entire system that cannot be compensated for.

In addition to measures that support throughput at the bottleneck, bottleneck exploitation is concerned with the mitigation of consequences for material flow resulting from the shortage of supply due to a bottleneck. For a factory producing discrete parts, this means that if production in a factory is running out of one specific part that is required to finalize the product, then there are essentially three possible options for production:

1. halt the entire production process in the factory (e.g., stop the assembly line),
2. sort out the product(s) for whose production process the missing part is needed – and thread in the product and continue later when the missing parts arrive,
3. keep producing and finish production without the missing part which will be added to the product later once it arrives.

Which of the three options is viable depends on a variety of parameters. These parameters include (but are not limited to):

- the share of products in the production process affected by the supply shortage,
- the technical feasibility to continue the production process and add the missing part later (and the cost thereof),

- the total cost of halting production (which should include the loss of sales and the potential loss of customers to competition although quantification of these values will be difficult),
- the estimated arrival time of the missing parts,
- the space available to sort out products from the production process.

Not all parameters and options discussed above can be transferred from the factory setting to the supply network setting. They do provide a better and more detailed impression of bottleneck exploitation and related activities and measures.

Before any action can be taken to exploit or eliminate an existing bottleneck, the company has to know about its existence – which sounds like common sense but can be a challenge nevertheless. There can be a substantial time gap between the emergence of a bottleneck in the supply network and its effect on the inbound material flow of the buying firm. It is not unusual that firms are hit by supply shortages without prior warning or indication from the supplier. In such a case, the period of time between the emergence and the actual adverse impact on the buying firm is wasted whereas it could be used productively, for instance, to activate alternative sources of supply or warn customers. Thus, *bottleneck identification* is another important category of bottleneck management activities.

Bottleneck identification is concerned with the identification of material flow bottlenecks. Intuitively, one might assume that identification of existing bottlenecks is straightforward. This, however, is not generally the case. In fact, there is a comprehensive body of literature about methods to identify bottlenecks in production environments. One of the main impediments to the identification of a bottleneck is that bottlenecks tend to *wander* (i.e., they change their location) as production schedule changes. In supply networks, bottlenecks possibly do not change with as fast a pace as in a factory environment and it is rather obvious which of the various tier-1 suppliers is unable to deliver as promised when a specific component is missing. The root cause of the problem, however, may remain unclear nevertheless. The buying firm might not have any insight in the supply network beyond its first echelon of suppliers and suppliers might be reluctant to provide information about the actual root cause of the problem (or they may not even know about it, either). Essentially, bottleneck identification can be translated into information gathering. Information about possible or actual supply-related problems in a supply network are imperative to informed decision making. Literature on the bullwhip effect (Forrester 1958, Lee et al. 1997) demonstrates how lack of information and unexpected shortages can amplify supply problems along the network. Therefore, bottleneck identification appears to be more than a pro forma category; it is, in fact, important.

These four tasks identified hitherto are mainly concerned with *unplanned bottlenecks*, i.e., bottlenecks that have not been purposely and consciously planned into the system, albeit bottleneck exploitation refers to both planned and unplanned bottleneck. *Bottleneck placement* then could be considered a fifth key task that is concerned with finding the right location for a planned bottleneck. In every material flow system, throughput is limited by some bottleneck. If this were not the case, throughput would become infinite. The idea behind *bottleneck placement* is this: if there has to be a bottleneck anyway in our system, we can consciously place it somewhere so we have full control of it, i.e., we can *protect* it and *exploit* it.

In a factory environment, we may have certain stations which perform energy, time, or – more generally – cost intensive processes or which require high investment upfront. For economic reasons, it might be desirable to dimension those stations in such a way that they do not provide significant excess capacity. On the one hand, it might be short-sighted to dimension capacity too tightly so that new machines and tools will be required if demand develops positively. On the other hand, (accounting) production cost per unit become very high if production capacity is over-dimensioned. In some cases, it might be necessary to load and operate the machine batch-wise. Examples are furnaces for thermal hardening and tanks for chemical hardening of glass. Such stations require both time and energy, each of which in economic terms translates into “cost”. So there is a trade-off between the generally undesirable interruption of material flow along with an increase of variability induced by the creation and processing of batches on the one hand, and the *economics of efficiency* of this particular process step on the other hand. Certainly, there is no point in heating up a furnace for one single glass panel; and yet, delaying the process until, say, 500 glass panels that make up one complete batch could also turn out to be uneconomical.

The planning problem that comes with this trade-off is particularly obvious for stations that are very expensive and whose capacity cannot easily be expanded without another major investment, so that the decision "locks in" the firm in the short or even medium term. In cases where certain process steps are particularly costly but where capacity *can* be increased with reasonable effort and investment, such a station that demands high utilization (for reasons of efficiency) could be designed to represent the bottleneck of the production system and "beat the drum" (Goldratt & Fox 1986). The production system could be then be designed in a way that protects the station in question from starving and blocking. In practical terms and to improve flexibility, it would be more advisable to have the station comprise several smaller machines (e.g., smaller furnaces) of which some are idle in normal times and activated in busy times than having one large machine that requires large batches and is over-dimensioned for normal demand.

To summarize, five key tasks can be synthesized from the literature as constituting bottleneck management:

1. bottleneck prevention,
2. bottleneck identification,
3. bottleneck exploitation,
4. bottleneck elimination, and
5. bottleneck placement.

The streams of literature leading to the categories of bottleneck management activities that were identified and explained above are illustrated in logical and chronological order in Figure 4.2.2. Placement is separated by a dotted line because it is not part of the logical and chronological sequence. It remains

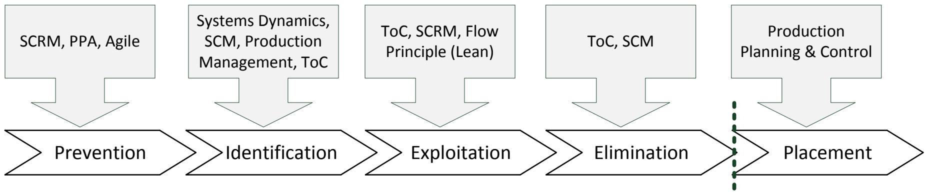

Figure 4.2.2. – Streams of Literature that Inform Bottleneck Management Activities

to be seen whether (and if so: to what extent) these categories of bottleneck management activities can be found in practice.

The categories of bottleneck management constitute a core element of the tentative conceptual model of bottleneck management in supply networks.

4.3. Measures of Bottleneck Management

In the previous section, categories of bottleneck management activities were defined. These categories were derived from various streams of literature, such as Supply Chain Risk Management, Supply Chain Management, Production Planning and Control. Lean Production, and Theory of Constraints. The content of these categories are the actual measures organizations can take in order to manage bottlenecks in their supply network. These measures represent the second element of the model.

Some measures are well-known and can easily be related to the management of bottlenecks. Multiple sourcing is an example of a measure that is commonly associated with increased supply reliability, that is, with the prevention of bottlenecks. In other cases, the effect of a particular measure on bottleneck management is less obvious. Different than in the previous section on categories, a list of actual measures shall not be provided here. The identification of such measures in industrial organizations is one of the objectives of the multiple-case study conducted as part of this project.

4.4. Causes of Bottleneck Emergence

The definition of bottlenecks proposed in Section 2.3.2 refers to "physical throughput capacity, organizational rules, and operational practices", either of which can determine the throughput threshold beyond which a bottleneck becomes active or binding. In other words, causes of bottleneck emergence could be classified into *physical*, *organizational*, and *operational* causes. Physical causes represent limitations in absolute terms; an increase of throughput at a physical bottleneck necessarily requires a physical expansion of the bottleneck – or that another channel opens up for material flow and the bottleneck thereby becomes eliminated. Organizational and operational causes, on the other hand, allow the exploitation of the bottleneck without application of physical changes.

Accordingly, the type of reason for bottleneck emergence can have important implications for the cost involved in managing (exploiting, eliminating) the bottleneck. Such a categorization is therefore likely to provide value to the bottleneck management effort for early orientation as to the selection of appropriate measures.

Figure 4.4.1 illustrates the categorization of causes of bottleneck emergence together with the five categories of bottleneck management activities. The black triangle pointing to the bottom indicates the position in the logical and chronological order of bottleneck management activities where the bottleneck sets in. If bottleneck prevention is unsuccessful, the bottleneck will become effective and the next bottleneck management activity the firm can pursue is bottleneck identification. As in Figure 4.2.2, placement is separated from the other four activities by a dotted line for it is not part of the sequence. The scheme outlined in Figure 4.4.1 will also serve to present a summary of each individual case in Section 6.

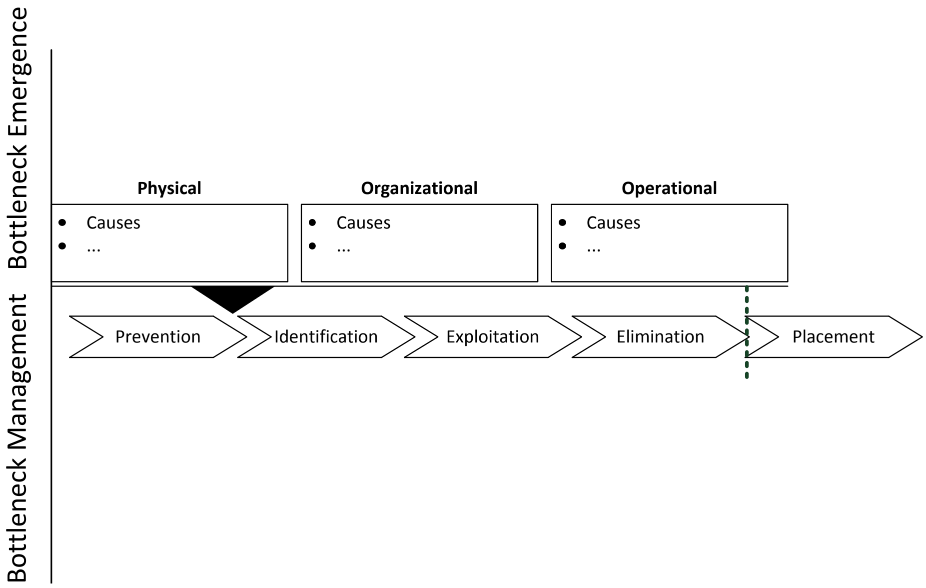

Figure 4.4.1. – Categorization of Causes of Bottleneck Emergence and Bottleneck Management Activities

4.5. Influencing Factors for the Selection of Measures

Not all organizations choose to employ the same measures for they are facing different circumstances. Companies are operating in different industries and are located on different positions within their network; they are of different size and have suppliers of different size, which often translates into questions of power (and dependency). Companies serve different markets with different requirements; in some cases, reliability of supply may be first priority whereas in others not much happens if supply is delayed. Different classifications and requirements of supply networks were discussed in Section 2.5.6. That is, what measures are chosen depends on a variety of parameters. These parameters can be broadly divided into *requirements and needs* and *limitations*. A distinction between these two categories is not necessary yet can make things clearer: whereas limitation can be seen as invariable parameters that may need to be accepted and coped with, at least in the short term, requirements and needs are more flexible or variables and may possibly be altered.

4.5.1. Requirements and Needs

Because organizations are subject to different environments and different expectations by stakeholders, they have to fulfill different requirements in their management of supply bottlenecks. The purchasing portfolio analysis, for instance, analyzes *supply market* and *product characteristics* to devise suitable purchasing strategies (cf. Section 3.2). Also, the downstream effect of supply shortages needs to be taken into account. Competition can be an important factor, too. That is, all three echelons the firm directly relates to are of importance: upstream, downstream, and competition on the same value-adding stage. At the same time, organizations may follow certain management or manufacturing paradigms or strategies. If the company wants itself and its network to be lean, then extensive inventories of supply may not be an option. The discussion of differnet types of supply networks and supply strategies in Section 2.5.6 as well as the discussion of different types of manufacturing systems in Section 2.2 provide an overview of various factors that should be taken into account when making decisions about the selection of the right measures.

4.5.2. Limitations to the Management of Bottlenecks

Limitations or limiting factors represent impediments to the firm and as such prevent or impede the firm from doing something it seeks to do. Extremely high prices for raw material, for instance, can challenge the firm's ability to keep the material on stock as a buffer to maintain flexibility and responsiveness to customer orders. Also, in a very competitive market environment, a firm might not be able to gain much in negotiations with suppliers as these would easily be able to reject unfavorable terms and conditions.

Some concepts that may represent limiting factors to the management of bottlenecks were discussed in preceding sections. *Complexity* was mentioned as one factor whose exact impact is difficult to determine. It was said to be potentially limiting a firm's ability to predict, which limits its ability to manage.

Power and *dependency* were discussed in the context of organizational networks and modes of their governance. Situations where lack of power of an organization inhibits its ability to perform certain actions in order to stabilize its income material stream are easily conceivable. Power can be a function of, or at least be influenced by, the structure of the network an the focal firm's position in it.

Limitations may not only arise from the external environment, however, but can be internal, too. Organizational procedures, limited knowledge or qualification of staff, and organizational culture are examples of factors that can limit the firm's ability to respond appropriately and quickly to bottlenecks.

4.6. Summary: Conceptual Model

Four broad themes emerge from the review of various streams of literature that are likely to have implications for the management of bottlenecks in supply networks.

The *supply market* was explicitly mentioned in PPA (cf. Section 3.2) and frequently is subject in publications on SCRM (cf. Section 3.6). It might be the most obvious and – possibly – most important determinant for suitable action.

Characteristics of the *buyers' market* are of relevance because they partly determine the severity of the consequences of a supply shortage. A supply shortage might cause little or no problems to the focal firm's customers or the consequences might be grave. Measures to protect customers from supply shortages should be selected accordingly.

Competition at the echelon of the focal firm can weaken or limit the focal firm's ability to pursue certain measures. Suppliers might not be willing to accept certain terms and conditions in supply contracts that imply increased cost for them and might choose to do business with other customers than the focal firm.

The three determinants mentioned hitherto are external to the firm. *Internal characteristics of the organization* can play an important role for the selection of appropriate bottleneck management measures, too. Characteristics of the products, the production technology, the firm's (technological) capacity or ability and the strategy it has chosen to follow all influence the choice of measures for bottleneck management.

From each of the four determinants arise limitations to the actions of the firm as well as specific requirements and needs. Concepts such as power and dependency are inherent to each of the four broad determinants; complexity relates to all of them in combination.

The conceptual model is illustrated in Figure 4.6.1. The figure shows similarity to Porter's Five Forces model (Porter 1979, 2008). This is no coincidence: Porter's model attempts to describe competition of the firm and is a proxy for the financial attractiveness of the particular market niche the firm has chosen or considers choosing. Competitive forces – not only with respect to peers but also in the supply and the demand market – play an important role in this model, too.

Each activity, factor, limitation, or determinant mentioned above that influences the design of the conceptual model represents a proposition that this parameter exists in reality. It remains to be seen if the data analysis will provide support for these parameters of bottleneck management.

4.7. Research Questions

The aims and objectives for this dissertation have been articulated in Section 1.1. More specifically, the work on this dissertation is guided by the following research questions which represent more specific objectices and will help accomplish the more general aims:

1. What are some of the reasons why supply shortages occur in supply networks?

2. Can the causes of bottleneck emergence be structured in a useful way?

3. What do organizations do about bottlenecks in their supply networks?

4. Can the bottleneck management measures of organizations be structured in a useful way?

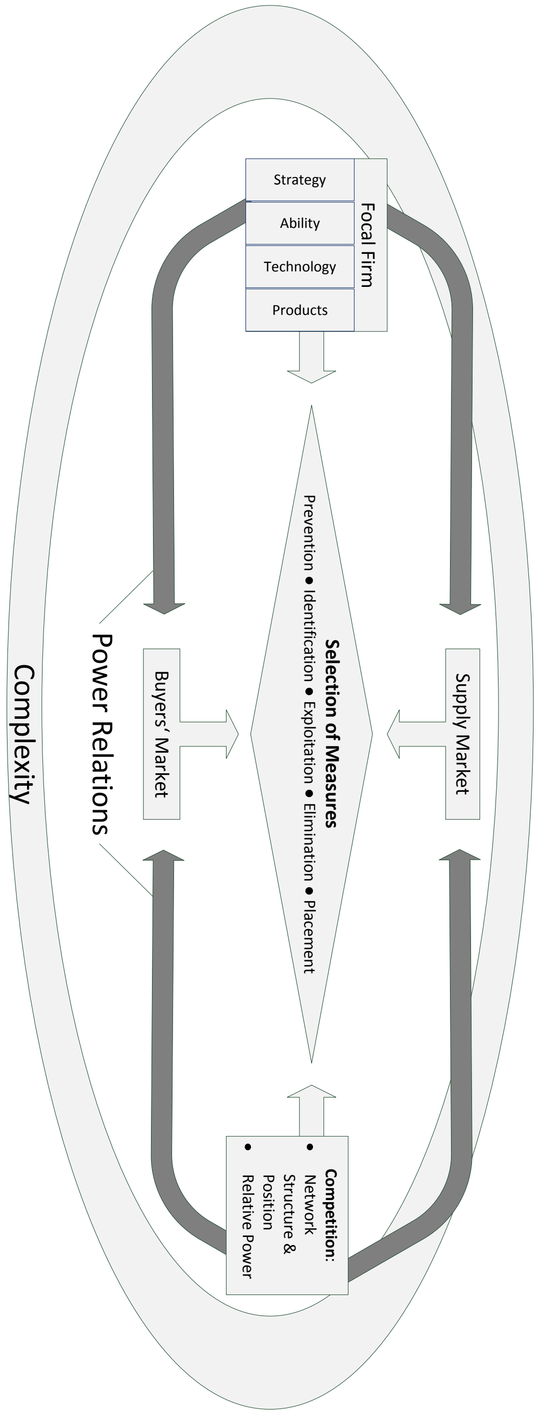

Figure 4.6.1. – Conceptual Model for Bottleneck Management in Supply Networks

5. What *can* organizations do about bottlenecks in their supply networks?
6. Are there parameters that influence or determine what organizations can do in order to stabilize inbound material flow? How do organizations choose their measures? And what seem to be the parameters?
7. Concerning the adequacy of the terms supply chain and Supply Chain Management:
   a) Is the notion of supply chains (as opposed to supply networks) useful and does it represent interorganizational structures which the case companies are part of?
   b) Is Supply Chain Management a pointed description of the activities organizations perform or seek to perform in order to ensure the stability of their inbound material streams?
   c) How does the understanding of supply relationships change if the notion of supply networks (as opposed to supply chains) is adopted?

In Section 1.4.1, it was referred to Whetten (1989) who suggests that a complete theory consists of the constituents *What*, *How*, *Why* and of the boundary definitions *Who*, *When*, an *Where*. As can be seen, the questions are put in such a way all of these constituents are addressed.

The results of this research project – the answers to the research questions stated here – are intended to constitute a basic theory of effective bottleneck management in supply networks. The theory shall provide guidance for firms which seek to improve the management of their incoming material flow in strategic (e.g., what design decisions in supply network planning can help improve supply reliability?), tactical (e.g., what is the risk resulting from an existing network configuration?), and operational (e.g., what actions can be taken to get the most out of a supply bottleneck?) matters.

4.8. Summary

From the various topics covered hitherto, this chapter sampled out important concepts and ideas as elements for a tentative conceptual model. The conceptual model includes causes of bottleneck emergence, categories of bottleneck management, and parameters for the selection of specific measures (requirements and limitations). The model is to guide the collection of empirical data in the multiple-case study as well as their analysis.

Moreover, the chapter presented the research questions that could be distilled from the theoretic review. The research questions address the gaps identified in the first chapter as well as the general research aims and objectives of this thesis and could be formulated now that a review of the state of the art in the relevant disciplines has been completed.

5. Collection of Empirical Data: Multiple-Case Study

5.1. Introduction

This chapter elaborates on research design and research approach as introduced in Sections 1.4.2 and 1.4.3. It provides information about how the data collection was prepared and conducted. The sources of information (company representatives and experts) are discussed and how they were selected is explained. Structure of and reasoning behind the interview questionnaire are elaborated on. The chapter aims to enhance transparency about the research process so that data analysis and conclusions drawn are better comprehensible.

5.2. Case Study Design

Yin (2009, p. 18) defines a case study as follows:

> "A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when then boundaries between phenomenon and context are not clearly evident."

Woodside & Wilson (2003, p. 493) include some more specific objectives in their definition of case study research:

> "CSR is inquiry focusing on describing, understanding, predicting, and/or controlling the individual (i.e., process, animal, person, household, organization, group, industry, culture, or nationality)."

The authors emphasize “deep understanding” as *the* principal objective among the several objectives of case study research (ibid, p. 497).

For this dissertation, a *multiple-case study* has been conducted consisting of ten individual cases. The multiple-case study is comprised of semi-structured interviews, site visits, and – when possible – analysis of archival data and documents. The formal request for case study participation that was sent to all companies by email can be found in Appendix B. All companies which participated in this research project were promised anonymity. Instead of real names pseudonyms are used whenever a specific company is referred to. The pseudonyms are of the format “case company [i]”, where “i” refers to the number of the case company in chronological order of the case data collection.

The multiple-case study conducted in this research project is guided by the research questions stated in Section 4.7. It is *exploratory* in that it aims to identify relevant practices for bottleneck management in a supply network. There are examples for such measures that can be found in textbooks and there are earlier research projects that studied such activities (e.g., Beer 2011). However, the ability to access a broader base of organizations provides a promising opportunity to create a database of activities. Such a database serves two purposes:

1. it provides value by enabling interested organizations to learn what activities other organizations perform, and

2. it allows subsequent analysis of the activities with respect to contextual information, such as certain enabling or limiting parameters.

In this sense, the exploratory part of this project provides the foundation for the *explanatory* part. The project is explanatory in that it attempts to explain the significance of problems with bottlenecks in different settings (e.g., different characteristics of production and supply and different demand patterns), i.e., *why* manufacturing firms encounter more problems with supply shortages in one setting than in another. Moreover, *how* do methods employed for bottleneck management function and *why* do firms use a particular set of methods whilst ignoring others (e.g., are there limitations in the use of those other methods in the particular setting?). The main *unit of analysis* thus is bottleneck management practices.

It should be noted that the use of the term exploratory in this thesis might differ from the use in other publications and context. Yin (2012), for instance, suggests that exploratory case studies should be conducted as a separate task and be completed *before* the actual, "real" case study is begun. In that context, the exploratory case study serves as an instrument to create some preliminary framework or theory that serves as input to the final – often explanatory – case study. While legit, this understanding of exploratory research should be seen in the light of rejection of brute naïve realism that led to the development of research concepts such as Grounded Theory (Suddaby 2006). In this project, however, a conceptual model was developed prior to the case study that guides data collection and analysis. The term exploratory is used in its more common, literal meaning: One aim of the collection of empirical data was to identify (i.e., to *explore*) relevant organizational measures that aim to stabilize inbound material flow. These measures were then analyzed (*explained*) and related to contextual information and literature (cf. Phase III of the data analysis).

The case study began with semi-structured interviews conducted on-site with personnel in relevant positions (procurement, supplier management/supply chain management, plant manager, CEO). An interview guideline was developed that was intended to stimulate discussion and find out about

- the frequency and severity of supply interruptions,
- the state of knowledge about supply interruptions and their root causes,
- measures to deal with and to avoid supply interruptions, and
- the structure and the properties of the supply network.

Companies were asked to be available for follow-up interviews and discussions later in the project in case new questions would arise. The complete interview guideline can be found in Appendix C; a more detailed account of the interviewing process can be found in Section 5.5.

The multiple-case study is not intended to be used for quantitative cross-case analysis. The number of cases involved is too low to draw meaningful statistical conclusions with any confidence. Accordingly, no statistical generalizations are intended to be made based upon case study results.

5.3. Expert Interviews

In addition and in parallel to the case study interviews, three expert interviews were conducted. Two interviews (experts 1 and 2) were semi-structured and guided by an interview questionnaire while one interview was an open conversation (expert 3). The expert interviews took place in an early stage of the data collection at the case companies and before the data analysis. Because the expert interviews did not have much direct impact on the study, they shall be only shortly described.

Expert 1 is a researcher and lecturer in Supply Chain Management, Logistics, and Operations Research at the Chair of Operations Research at a German university. The interview took place in the expert's office at the university and was audio-taped.

Expert 2 is a former SCM practitioner and current PhD candidate in the UK. The interview was conducted on the phone and notes were taken manually.

Expert 3 is raw material expert at DERA, the German Raw Material Agency, a part of the Federal Institute for Geosciences and Natural Resources (BGR). The conversation was had on the phone and notes were taken manually, based on which a summary of the conversation was written up.

The objective was different for each individual interview, but the overarching motivation behind the expert interviews was the hope that the experts would raise points of view which this researcher had been unaware of hitherto (i.e., they were *exploratory*). Also, some ideas and concepts intended to be used in this dissertation were described in the interviews so that the experts could criticize them or raise objections (i.e., they were used to improve *validity*).

The interviews with experts 1 and 2 did not reveal new information that would have altered the objectives or the content of this thesis. They did confirm some perceptions and ideas this researcher had, which is worthwhile noting.

The interview with expert 3 was, in fact, exploratory and the interviewee did raise some interesting points about the raw material market. This interview supported the discussion of limitations to bottleneck management in Section 6.3.8.

5.4. Selection of Companies for Case Study

The companies asked for participation had been selected based upon the following criteria:

- Some companies should represent different industries to account for the effect of industry-specific phenomena,
- some companies should be of different size,
- some companies should exhibit different production characteristics, and
- some companies should have supplier networks with different characteristics.

The reason as to why it was chosen to do a cross-sectoral analysis is that industry-specific parameters can influence the type and number of options available to the focal firm. Limiting the analysis to only one industry may possibly leave ideas untapped that would be worthwhile investigating and transferring to other industrial contexts. The same logic is followed by companies when doing cross-industry benchmarks.

At the same time, a cross-industry case study may reveal in what setting – i.e., in what combination of industrial and organizational parameters – bottlenecks are more likely to occur and to have adverse impact than in others. In fact, if we accept the notion that supply networks can be described as open systems, as proposed in Section 2.4.4, then environmental parameters are key to the understanding of the supply system. As Gharajedaghi (1999, p. 32) puts it: "Open systems can be understood only in the context of their environments."

Table 5.4.1. – Overview of Participating Case Companies

Company Key	Size	Industry
Case Company 1	SME	Manufacturing of glass-based products
Case Company 2	Large	Manufacturing of agricultural machinery
Case Company 3	SME	Manufacturing of heating systems and solar panels
Case Company 4	Large	Raw material trading
Case Company 5	Large	Production of copper and copper-based products
Case Company 6	SME	Raw material trading
Case Company 7	SME	Manufacturing of soldering powder
Case Company 8	SME	Manufacturing of radiation shielding and anodes for metal extraction
Case Company 9	SME	Raw material trading
Case Company 10	Large	Raw material trading

When selecting the companies, care had been taken to identify both companies and networks that show similar properties and companies and networks that show different properties. Thereby, control groups have been created that could help avoid premature conclusions about certain properties and their effects. This is an important part of replication logic as Yin (2009) suggests should be used in multiple-case study design.

The companies participating in this research project are summarized in Table 5.4.1.

In each company, example products were selected so that questions and responses in the interviews could be related to practical cases.

5.5. Method for Data Collection: Cross-Industry Interviews

5.5.1. Structure and Reasoning of Interview Questionnaire

Semi-structured interviews were chosen as primary format for data collection. It was initially unclear whether the structure of bottleneck management activities proposed in this thesis, and for which it was intended to obtain empirical data, would make make sense to respondents. In fact, this is one point that was to be clarified. Accordingly, it was allowed for interaction between interviewer and interviewee in order to explain the concept and key terms to interviewees. Also, interviewees may not be fully aware of the details that the researcher hoped to hear from them without him probing; the fields of supply network management and bottleneck management are simply too broad as to expect that professionals would answer in the way the researcher would hope for. Thus, unstructured interviews seemed inadequate. Neither was it known what information *could* be got from respondents, which made structured interviews too rigid an instrument that would bear the danger of preventing interviewees from providing unexpected and possibly valuable information. Therefore the midway had been chosen in order to preserve the chance of receiving unexpected information and serve the partly exploratory nature of the research endeavor while being able to provide guidance, probes, and explanations to help respondents focus in case they would wander off the topic or otherwise spend too much time.

Gillham (2005) suggests that in preparation of the interview the questions comprising the questionnaire should be grouped into topics and that a narrative sequence should be identified. The questions used in the interview questionnaire are grouped into eight parts:

- Part I: Industry Characteristics, Firm Characteristics, and Product Characteristics. In this part, it is aimed to improve the understanding of the specific circumstances the organization has to cope with. This is important because organizations face different constraints in what they do depending on market environment and firm parameters (e.g., size). For different circumstances different configurations of the supply network are suited best to accommodate the requirements of customers, focal firm, and suppliers (Fisher 1997, Chopra & Meindl 2010).

- Part II: Bottlenecks in Supply Networks: *General*. In this part, it is aimed to get an impression of the perceived severity of bottlenecks by the interviewee and his firm. The interviewee's responses to this section set the direction for the remainder of the interview: if the interviewee indicates that bottlenecks in the firm's supply network is a minor problem, it will be tried to determine the parameters as to why this firm apparently is less affected (or at least: feels less affected) by material shortages occurring in its supply network. If the interviewee's responses indicate that bottlenecks are a severe problem, it would be tried to elaborate on the constraints the supply manager faces in that company. While the interview questionnaire will guide the conversation in either case, one might assume that the supply manager who perceives bottlenecks as a major problem and deals with them on a daily basis has invested more time and thought in practices of bottleneck management than the supply manager who largely feels unaffected. In the latter case, the meaning of interview questions that follow might not be as obvious to the interviewee and thus might need further explanation.

- Part III: Bottlenecks in Supply Networks: *Prevention*. In this section, it will be asked about measures the firm takes in order to prevent unplanned bottlenecks in the first place. That is, the first of the five core activities of bottleneck management as devised in this thesis is addressed. The questions are designed such that the interviewee can respond freely and extensively first before supplementary questions follow as a means to prompt a more focused response. The section includes a question about the interviewee's personal opinion about the adequacy and suitability of the measures the firm employs to prevent bottlenecks.

- Part IV: Bottlenecks in Supply Networks: *Detection*. In the fourth part of the questionnaire the aim is to hear from the interviewee how his company finds out about bottlenecks in the supply network. The questions predominantly address the information flow between the focal firm and its suppliers.

- Part V: Bottlenecks in Supply Networks: *Exploitation*. This part of the interview addresses the measures the company takes once an unplanned bottleneck has emerged and the output is to be maximized under this constraint. Similar to part III, the interviewee's personal opinion as to whether the current activities are sufficient or should be amended is aimed for.

- Part VI: Bottlenecks in Supply Networks: *Elimination*. This part addresses measures to eliminate (i.e., remove or shift) the bottleneck from the network. This section contains one open question which encourages the interviewee to speak freely about the measures the company takes to eliminate bottlenecks, and one question that, as in parts III and V, addresses the interviewee's ideas for additional measures.

- Part VII: Bottlenecks in Supply Networks: *Placement*. In this part, the concept of bottleneck placement is explored and it shall be found out to what extent it can be practically applied in supply networks. The opening question is complemented by two follow-up questions that address possible parameters of bottleneck placement (production capacity flexibility) to find out more about the concept even when interviewees would not fully comprehend the idea.

- Part VIII: Supply Network Characteristics. The interview concludes with inquiries about characteristics of the supply network, such as delivery modes, power relationships, and number of direct suppliers. This information is important to make sense of the interviewee's previous responses about the severity of bottleneck problems and bottleneck management measures. Hence, part VIII complement part I in creating a context for better understanding and analysis.

The grouping and ordering of the questions along the core tasks of bottleneck management that were derived in the conceptual model – prevention, detection, exploitation, elimination, and placement – provide the narrative sequence of the interview in logical and chronological order. That is, the theoretical conceptual model provides the general structure for the empirical part of the research project.

5.5.2. Interview Preparation, Initiation, Process, and Follow-up

Gillham (2005) defines five stages for the conduct of the interview:

1. preparation,
2. initial contact,
3. orientation,
4. substantive phase,
5. and close phase.

A sixth stage is added – *follow-up* – and the activities and how they relate to each stage shall be shortly described and explained below.

Preparation Phase Contact to interviewees was established by email or telephone. Upon contact initiation, a short[1] description of the formal project background, of the research topic, of the interview format, and an affirmation of confidentiality were sent to the interviewee by email. Preparation of the interviews included familiarization with the organizations' most important products, size of the organization, as well as recent developments if this information was publicly available. All interviews were conducted face-to-face in the facilities

[1] One A4 page

of the interviewees' organizations if possible; in one case (case company 10), the interview had to be conducted via telephone.

The "hand luggage" for the interviews included a hard copy of the project description that had been sent by email earlier and which was offered the interviewee for his files, a short description of the organization and its products as an overview for the researcher, a taxonomy of key terms likely to be used during the interview so that handy definitions were available, a table with examples of causes of bottleneck emergence that could be used as prompts to support more focused responses of the interviewee, business cards, a dictating machine, paper, and pen.

Initial Contact and Orientation Phase All interviews were initiated with a short introduction of the researcher and of the research project. Interviews were recorded as audio files if the interviewee agreed and indicated that he would not feel uncomfortable being recorded. When interviewees did not want the interview to be recorded, handwritten notes were taken (no complete transcription but all important information for a lack of better options). Key terms and structure of the interview questionnaire were introduced by shortly explaining the five core activities of bottleneck management as defined in this thesis.

Substantive Phase As Gillham (2005) writes, the substantive phase represents the "*central core of the interview*". For each part of the interview (cf. Section 5.5.1) the kind of information looked for and how this is different from the other parts were defined. Generally interviewees could answer each question for as long time and as extensive as they wanted to and probes were used to re-align the focus as was felt necessary to obtain the information desired.

Closure Phase After all questions from the questionnaire had been discussed, interviewees received information about how much longer it would take before the study would be finished, so that they would get a better idea of when the researcher would get back in touch with them to present his findings (a presentation of the study results upon completion of this dissertation was offered if interviewees indicated interest). Also, options were evaluated for possible follow-up emails or phone calls in case the need would arise to clarify any unclear point that would come up during the interview analysis.

Follow-Up Phase Both audio records and handwritten notes were transferred to the computer. Eight interviews were audio-taped, seven of which were fully transcribed while one was selectively transcribed. For the telephone interview with case company 10 notes were taken manually and checked and approved by the interviewee right after the interview. The case descriptions presented in Phase I of the data analysis were sent to the interviews for correction and approval. Approval and confirmation of correctness of the information could be obtained in all but one case where an official statement from another than the interviewed person's apartment was still pending by the time the thesis was submitted.

The researcher's personal impression of confidence in interviewees' responses was added to his personal notes if the impression was significant. Emails or calls would follow if unclear statements were stumbled upon.

5.6. Summary

This chapter described in detail the design of the multiple-case study. This includes a discussion of the criteria for the selection of the case companies as well as a detailed description of the interview questionnaire and of the interview process. Also, the expert interviews conducted as complementary element were explained. The information provided in this chapter complement the information on the research method for this project as introduced in the Chapter 1.

6. Findings and Discussion

6.1. Introduction

In this chapter, the findings of the multiple-case study will be presented. The data analysis is divided into three parts.

The first part of the data analysis consists of individual case analyses. The information is structured along the categories of the interview questionnaire which, in turn, is based upon the categories of bottleneck management identified in the review of relevant literature as presented in Chapter 4. The first part of the data analysis represents the exploratory nature of the study and provides rich case descriptions. The information received was categorized yet not interpreted and remained unmodified and in its essence in this first part.

For the second part of the data analysis, the information retrieved at the individual case companies is drawn together and summarized. Hence, the second part, too, does not contain interpretation of the findings but a synopsis of all causes of bottleneck emergence, all bottleneck management measures, and all limitations to bottleneck management which could be identified at the case companies.

The first two parts of the data analysis will provide the answers to research questions 1 through 4. These *What* and *How* questions require descriptive answers, which is reflected in by the style of these two parts.

The third part of the data analysis relates the case study information to the literature and the conceptual model defined in Chapter 4. It aims to explain *why* some organizations are subject to certain causes of bottleneck emergence which do not affect other organizations. Moreover, it is tried to explain the selection of specific measures of bottleneck management by the case companies.

To that end, some concepts identified in the literature review are related to the choice of bottleneck management measures. In so doing, roles of bottleneck management measures are identified. The explanations in this part of the data analysis provide the answers to research questions 5 and 6. Lastly, the third part of the data analysis investigates the terms supply chain and Supply Chain Management and tries to provide an answer to research question 7.

6.2. Analysis of Interview Data Phase I: Individual Case Analysis

6.2.1. Introduction

One task of data analysis is deriving categories from data (Gillham 2005). Since the interview questionnaire used to collect data is structured along categories (representing the core activities of bottleneck management as derived in Section 4), there is already a useful descriptive categorization of the data obtained so that the categorizing and *coding* was facilitated. Because the case data is partly structured along the categories that were derived in the conceptual model, the categorization of data also served as a test of the meaningfulness of the categories.

This first phase of data analysis is both exploratory and descriptive. Rich case descriptions were created in this section based upon the data that could be obtained from the case companies. The case descriptions include both information about the activities companies pursue in order to manage their supply bottlenecks as well as contextual information that help put the bottleneck management activities each company pursues into perspective. The descriptions were created based upon interview transcripts (if audio record was available, else based on handwritten notes) which were coded with key words. The key words were derived from the conceptual model. Archival records and information received in informal talk served as supplementary material.

6.2.2. Case Study 1

6.2.2.1. Short Description

The case company is a medium-sized manufacturer of glass-based products with production locations in six countries. The company receives raw glass from glass producers and intermediate dealers and applies various technologies such as chemical and thermic hardening, printing, coating, cutting, as well as some assembly operations. The products are then supplied to a broad range of business customers who use them in their final products, such as TV screens, scales or control panels.

6.2.2.2. About the Data Collection

The interview took place in one of the company's production sites in Central Europe. Interview access to procurement staff was granted upon direct request by the researcher who knew the company from an earlier internship. Manual notes were taken during the interview. Present during the interview was the primary interviewee whose position is Project Manager Purchasing, a second long-term employee, also from Purchasing, who was listening during most of the interview and who occasionally provided additional information, and one intern. The interview took 1:20 hours. The project description was sent to the interviewee one week in advance.

6.2.2.3. Market Situation

The interviewee describes the case company's industry as largely stable with few firms entering or leaving the industry. Technological advancement within the industry is incremental with little groundbreaking innovation.

The case company's products are described as complex by the interviewee due to the various product characteristics that customers demand.

Three to five other companies in the industry compete with the case company with similar products.

6.2.2.4. Supply Situation – General Information

The company receives raw glass partly directly from manufacturers, partly from specialized dealers, as well as additional components for assembly operations directly from manufacturers. Suppliers are located globally. Most parts are single-sourced, which the company is about to change, aiming for two to three sources for a greater share of parts. Parts are delivered to conventional warehouse.

Bottlenecks in supply are perceived by the interviewee as a severe problem and he states that management shares this view.

6.2.2.5. Production Process

Production steps involve cutting (with different technologies available), cleaning (between all operations), hardening (chemical and thermic), coating, printing, assembly, and quality control. For most products, several of these operations have to be combined so that eight to twelve production steps are involved to give the product the properties customers demand.

6.2.2.6. Bottleneck Emergence

There is no tendency as to where bottlenecks emerge in the company's supply network.

The interviewee names three reasons that have repeatedly led to problems:

1. amounts of products requested by customers are increased on short notice,
2. customers request very short lead time, and
3. dealers/producers of glass run out of stock while running a different production batch.

The implications of and difficulties attached to the first two reasons are obvious; the third reason requires explanation, however. The interviewee explains that suppliers' tooling time required between production of different types of raw glass is more than one week. Therefore each type of raw glass is produced in large production batches which are referred to as "campaigns" in the industry's language. At the same time, glass has limited shelf-life. Quality of glass deteriorates, often as early as one year off production – especially when coating (e.g., Anti-Reflex coating) is involved. That is, glass producers have to produce batches large enough to meet expected industry demand yet not so large that significant amounts remain on stock for too long a period so that quality would deteriorate. According to the interviewee, producers occasionally err on either side with implications for availability of raw glass for customers like the case company.

A then existing bottleneck was used by the interviewee as an example for another reason for bottleneck emergence. One customer ("A") of the case company ("B") set a sub-supplier ("C"), i.e., a direct supplier for the case company which was to supply plastic parts to the case company for assembly of a product the case company produced for that customer ("A"). The sub-supplier ("C") that was set by the customer maintains a contract with the customer ("A"). All common supply procedures, however, such as call-off of the plastic parts, were managed by the case company ("B"). The sub-supplier ("C") turned out be unable to supply the case company ("B") with all the parts needed for assembly of the product the customer ("A") demanded because the sub-supplier's capacity was used up by other jobs for the same customer ("A"). In this constellation of contracts, solving the problem and coordinating the use of the sub-supplier's production capacity proved difficult so that the bottleneck remained active for a relatively long period of time.

The interviewee remarks that there is a tendency that supply shortages occur with those suppliers compared to which the case company is relatively powerless.

6.2.2.7. Bottleneck Management: Prevention

The case company maintains a framework agreement with all suppliers. The agreement requires suppliers to be able to supply the demand forecasted by the case company plus 10% production capacity flexibility. There are quality agreements with suppliers, requirements for certain certificates, and audits conducted by the case company.

The interviewee states that the case company plans to qualify more suppliers for increased supply reliability. The aim is to find both regular permanent suppliers as second or third source and suppliers that would step in in case supply bottlenecks emerge. Maintaining at least two sources is a requirement the case company has to meet for some customers. Also, a broader supply base is a reaction to the dependency on certain suppliers and the notion expressed by the interviewee that bottlenecks tend to emerge in supply relationships with more powerful suppliers. The broader supply base is expected to lessen the dependency on and thus the power of certain suppliers. Moreover, by sourcing globally the case company reduces the risk of locally confined impact on suppliers in certain regions.

Another option the company aims for in the future according to the interviewee are contractual penalties that would be included in sourcing contracts for cases of violation of the agreements.

6.2.2.8. Bottleneck Management: Identification

Three situations can be distinguished.

1. When the case company sends an order the supplier is expected to confirm the delivery date. The supplier is called when no confirmation of the delivery date is received within three to four days. In case the supplier rejects the delivery date requested by the case company it is already obvious that promised delivery dates with customers will need to be renegotiated.

2. The supplier notifies the case company right away that the expected delivery date cannot be met.

3. The expected delivery date passes without delivery and without notification by the supplier.

All three situations occur. As a response to this uncertainty induced, the case company plans to get in contact with suppliers shortly before the delivery date to reconfirm if the date can be maintained.

6.2.2.9. Bottleneck Management: Exploitation

No measures of bottleneck exploitation could be identified in this case study.

6.2.2.10. Bottleneck Management: Elimination

Generally, when a supplier is unable to deliver the case company seeks out an alternative source. This can be done quickly when an alternative supplier has already been qualified and it will take more time when a new supplier has to be qualified after the bottleneck kicks in.

6.2.2.11. Bottleneck Management: Placement

The concept of bottleneck placement did not apply to this case study.

6.2.2.12. Bottleneck Management Limitations

A major limitation arises out of the production logic of raw glass. The significant changeover time requires producers to run batches based on forecasts rather than on actual demand. When producers and dealers run out of stock of a specific type of glass there is nothing customers, i.e., glass manufacturers, can do besides looking for yet other suppliers or dealers. For some products and applications it might be conceivable that certain types of glass could be substituted for others; the interviewee did not mention this option, however.

The interviewee suggests that more powerful suppliers are more likely to cause supply shortages than suppliers of equal or less power. This does not pose a permanent limitation to the case company, however, as the company decided to react by qualifying additional sources of supply to counter power imbalance with suppliers.

6.2.2.13. Summary of Activities (Graphical)

Figure 6.2.1 presents a graphical summary of the reasons for bottleneck emergence and the case company's bottleneck management activities.

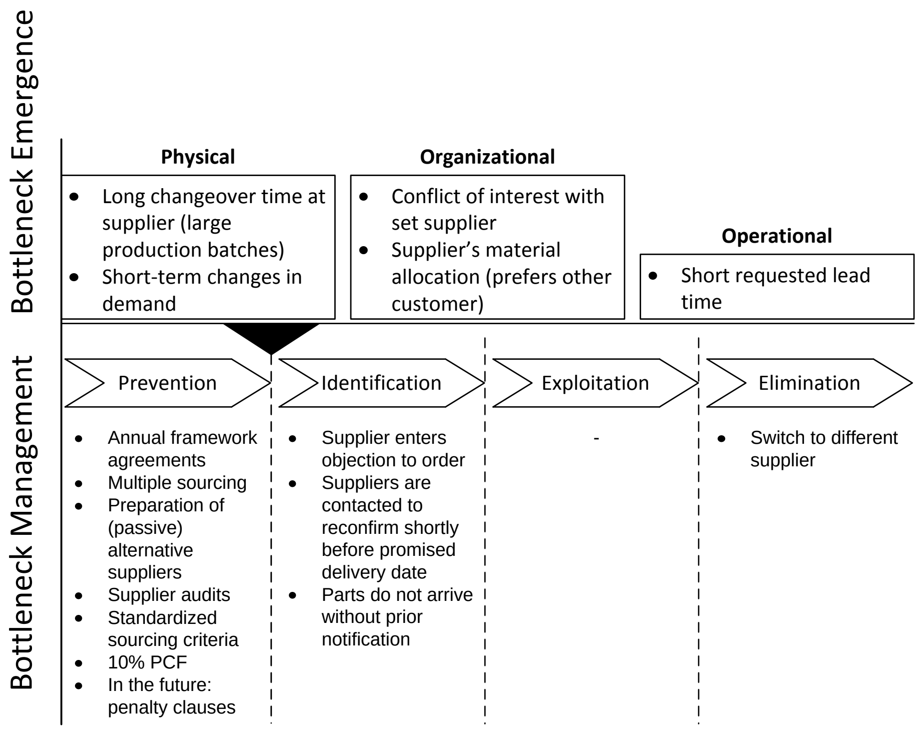

Figure 6.2.1. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 1

6.2.3. Case Study 2

6.2.3.1. Short Description

The case company is an international producer of agricultural machinery, headquartered in Central Europe with production and sales locations under different brands in many countries around the world.

6.2.3.2. About the Data Collection

The interview took about 30 minutes and was conducted in the company's headquarters in Central Europe. The interviewee was part of the Supplier Management department at the time of the interview and is now Head of Logistics. The interview was audio-taped and some additional notes were taken manually. The project description was sent to the interviewee some days in advance and explanation of the concept of bottleneck management preceded the interview (not included in interview time).

6.2.3.3. Market Situation

As a globally operating actor, the case company's economic situation is affected by the various economic developments as well as climate conditions around the world. Times with good harvesting returns for agricultural business are often followed by increased investment activity in agricultural machinery.

The industry for agricultural machinery is described by the interviewee as one that is incrementally and continuously innovating, e.g., for steady efficiency improvements in the harvesting process. At the same time, more radical innovation such as the introduction of automated harvesting processes, supported by GPS technology and real time data analysis, is increasingly gaining pace. Overall, says the interviewee, the agricultural machinery industry might be more innovative than, for instance, the automobile industry.

With its products, the company competes with about five, partly larger, direct competitors. Strong competition notwithstanding, the case company's business has developed positively over the last couple of years.

6.2.3.4. Supply Situation – General Information

Products are complex – a harvesting machine consists of about 65.000 parts. About 70% of value is added by suppliers. Accordingly, stable supply processes are given great weight in the company. Shortages of supplied parts occur frequently; interruptions of the internal production process due to part shortages, however, could be averted for more than five years.

Supplied parts are received in “all” different delivery modes, i.e., JiS/JiT, conventional warehouse, and consignment warehouse. Large parts and expensive parts, such as engines and cabins for tractors, are received JiS.

The case company has developed an elaborate set of measures and processes for supplier management, often paralleling measures and processes employed in the automobile industry.

6.2.3.5. Production Process

Due to the complexity of the products, the production process comprises a broad variety of activities and technologies, involving complex metal works, engine and cabin assembly, installation of electrical equipment, and many more. As pointed out before, on average suppliers add about 70% of the products’ value before they reach the case company.

6.2.3.6. Bottleneck Emergence

Shortages typically occur on tier-1 stage; according to the interviewee, bottlenecks have emerged on tier-2 level only two times in the past five years. Bottlenecks are a frequently upcoming topic yet are managed well, so that the company can usually prevent delay in internal production processes.

As two examples for parts that have repeatedly been in short supply the interviewee cites engines and tires. In both cases, suppliers are large and powerful companies with a broad variety of customers. Tires are known to require long delivery time because of tooling time (two to three days), which, says the interviewee, makes planning of availability more difficult. Missing tires are no reason to interrupt the production process, however, as provisional wheels can be used to "roll" the vehicle along the production line and can later be replaced once the correct tires arrive. Such an aid would not be available for engines, however, as the effort to mount and replace a temporary engine is too big.

Typical reasons for bottleneck emergence are short-term changes in demand and short-term technical changes. Other reasons that have occurred, albeit less frequently, are, for instance, supplier bankruptcies and a ship with supply from India sinking.

Furthermore, the interviewee suggests that cultural difference with suppliers seem to make a difference for supply reliability. As examples he cited suppliers from India and from France that require more attention than suppliers from less culturally remote regions.

Suppliers which underperform become "focus suppliers". Such focus suppliers will receive special attention from supplier managers and closer contact and more intense communication is maintained. Focus suppliers represent about 1% of all suppliers, which adds up to about 20 to 25 suppliers per year.

Specifically asked for problems related to indirect demand from competing customers of the same suppliers or related to schedules breaks or holidays, the interviewee states that he is not aware of problems that have been caused by such reasons.

According to the interviewee, problems tend to arise with parts that are delivered JiT or JiS. C-Parts delivered to conventional warehouse do not normally cause problems.

The interviewee suggests that by tendency supply-related problems emerge more often with large and powerful suppliers than with smaller ones.

6.2.3.7. Bottleneck Management: Prevention

The Interviewee states that his company generally is well-prepared for bottleneck emergence and can deal with such problems very efficiently. The facts that the company has a dedicated supplier management department and that supply interruptions have not caused delay in internal production for a long time support this statement.

The case company maintains long-term contracts with suppliers, which contributes to trustful relationships and facilitates planning and investment in production capacity.

Suppliers are provided with a forecast of 12 months. When actual orders are sent, the supplier has seven days to enter an objection. When no objection is entered the order counts as confirmed by the supplier. Suppliers are required to maintain safety stock of parts from which they can supply the case company in case their production is not able to keep up with demand.

Contracts with LSPs are signed with the case company, not with the individual suppliers. Thereby, the case company can use its influence and combined purchasing power to receive better offers – and possibly to benefit from extra effort LSPs are willing to make for a large customer. Also, there is quick communication with LSPs in case problems arise in transportation.

The case company uses an ABC classification scheme for suppliers (referring to purchasing volume and part criticality). Quality and logistics audits are conducted with new A-suppliers immediately upon contract closure. B-suppliers and in some cases also C-suppliers are audited later in the process. To further improve the process the interviewee suggests that audits should be conducted with all suppliers (i.e., including C-suppliers) for which, however, manpower is missing. Audits are followed-up by workshops on supplier sites in order to resolve the problems identified during the audits.

One element of the audits the company conducts with its suppliers is their suppliers' supplier management. By evaluating the processes suppliers have in place to manage their suppliers, the case company removes the need for tier-n management. Thus, tier-n management is not the rule and only been done in rare exceptions. Employees in relevant departments receive training for supplier audits.

Suppliers are located globally. While this might not be a conscious network design decision for the sake of better bottleneck prevention, it does contribute to prevention by spreading risk and reducing the impact of locally confined developments or occurrences leading to irregularities.

The company uses guidelines to decide for which part single-sourcing is sufficient and for which parts multiple sources shall be used. Parts sourced to low-cost countries, for instance, are often sourced to more than one supplier. Likewise, tires – cited above as an example for a component that frequently causes problems – are received from three to four different sources of supply.

When bottlenecks are encountered, measures to prevent the same or similar problems in the future are mutually agreed upon with the supplier.

6.2.3.8. Bottleneck Management: Identification

According to the sourcing contract suppliers have to inform the case company if they are unable to supply according to schedule. The length of the notification period differs depending on the part and the reason for delay; in case of engines and tires, notification of shortage may be two to three months before delivery. Only infrequently do suppliers notify the case company about delays in supply on short call, e.g., one day in advance.

Suppliers can enter an objection to orders received by the case company within seven day, which would indicate immediately that supply problems can be expected.

6.2.3.9. Bottleneck Management: Exploitation

Upon notification of delay the case company inquires into the reasons for the bottleneck. Support is then offered by the case company. For instance, the case company may organize express delivery (quicker road freight or air freight instead of sea freight). The expenses incurred are usually carried by the supplier.

One measure of bottleneck exploitation the company uses is to access the stock of parts intended for use as replacement parts in order to avert interruption of the production process. The stock of replacement parts will then be replenished to normal levels once the supply shortage could be eliminated. Another short-term measure is to take parts out of finished products that have been produced to stock (and are currently not covered by actual customer order) and build them into products that have been ordered by a customer so that actual customer orders can be finished without delay.

The interviewee attributes this pragmatic hands-on attitude to the case company's culture and flat hierarchies: employees maintain a high level of communication and generally try to support each other and solve problems if they occur. There are few, if any, compartmental silos. In case of bottlenecks, often five to ten people from different functional areas (e.g., purchasing, production, sales, supplier management) work together to solve the problem. Accordingly, the interviewee states that the company already does everything he can think of in order to exploit bottlenecks.

6.2.3.10. Bottleneck Management: Elimination

Besides immediate short-term measures as described in the previous section, the case company investigates into the root cause of the bottlenecks in order to find ways to eliminate it. The interviewee emphasizes that lack of production capacity is not normally the root cause of bottlenecks. Rather than by capacity constraints problems are caused by organizational, operational or technical reasons. Accordingly, capacity increase tends not to be the problem solution to the bottlenecks the case company encounters.

Since many smaller companies are part of the supply base and may be less experienced and professional, the case company offers suppliers support with analysis and solution of the problem. Both parties agree on measures to avoid the problem in the future.

6.2.3.11. Bottleneck Placement

The concept of bottleneck placement could not be applied to this case study.

6.2.3.12. Bottleneck Management Limitations

Generally, the case company seems to face only few constraints when it comes to efficient supplier and bottleneck management.

One limitation the company does face, however, is due to the fact that some competitors are larger and demand larger volumes from some shared suppliers, suggesting higher priority for competitors in case of capacity allocation decisions.

The interviewee expresses that (human) resources represent a constraint as more capacity would be needed to conduct comprehensive audits with all suppliers. Currently, quality and logistics audits are focused on A- and B-suppliers.

6.2.3.13. Summary of Activities (Graphical)

Figure 6.2.2 presents a graphical summary of the reasons for bottleneck emergence and the case company's bottleneck management activities.

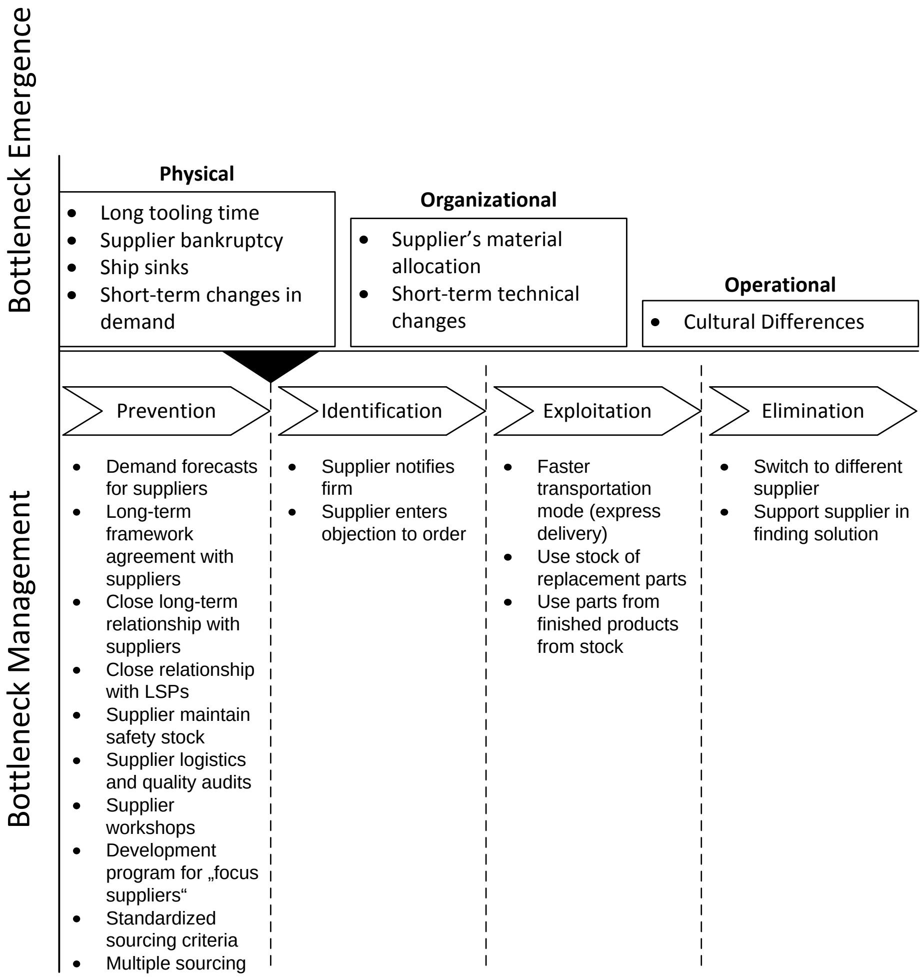

Figure 6.2.2. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 2

6.2.4. Case Study 3

6.2.4.1. Short Description

The company is a medium-sized manufacturer of high efficiency heating systems based on solar energy and other renewable energy sources such as wood pellets. The company is less than 30 years old and maintains a network of representatives and distributors in 15 countries (in addition to its headquarters' location). Customers are both private homes and businesses.

6.2.4.2. About the Data Collection

Contact to the company was established by email and followed up by telephone. The interview was conducted on the company's production and office site. The meeting began with a tour through the company's production facilities (about 1 hour) before background information to the project were provided and the interview began. The interview was audio-taped (47 minutes), transcribed and coded. The position of the interviewee is Team Leader in Procurement and Logistics. The meeting took about three hours in total.

6.2.4.3. Market Situation

There is strong competition with about ten competitors of the same size and four larger competitors. Overall, the market for solar energy related products has experienced a downturn recently which also affects the case company's business. Production of solar thermal collectors, for instance, at the time of the interview was limited to one shift per day. Several companies within this industry have filed for bankruptcy in the last few years. Nevertheless, the industry can be described as largely stable; all important competitors are known and technology of the products is subject to incremental improvement.

6.2.4.4. Supply Situation – General Information

The company maintains a supply base of about 350 suppliers of which about 80 – 120 supply main components of the company's products. The normal delivery cycle for many components is 14 days while some other components (e.g., smaller parts from China) are purchased only three times a year.

There is little insight into the supply network beyond tier-1 stage. In some cases, collaboration with tier-2 suppliers is fostered for reasons of product development.

Delays in supply are perceived as a problem both by management and by the interviewee. Because products are customer-specific delays in supply may well lead to delays in delivery of the finished product.

Supply is delivered to conventional warehouse. Parts of the supply base are globally dispersed with suppliers located in countries like China and Italy.

6.2.4.5. Production Process

The company produces to order and often customized to customer requirements, albeit similar components are used for each product within the same product group.

The production process involves the manufacturing and assembly of discrete parts. Some process steps are fully automated while others are done manually. Manual labor sometimes involves scrap rates that occasionally led to reordering of certain components in the past.

In-house production of some components normally produced by suppliers is possible. At the same time, contract manufacturers add additional production capacity for components normally manufactured in-house.

6.2.4.6. Bottleneck Emergence

Bottlenecks tend to surface on tier-1 level. Most common reasons are machine breakdowns at the suppliers' production sites and high scrap rates in suppliers' production. Especially during the introduction phase of new products delays have occurred.

The interviewee reports that supply was delayed because suppliers served other – "more important" – customers first. The interviewee mentioned the relative small size and thus lower purchasing volumes as reasons for this prioritization in favor of other companies.

Sales partners of the company are not able to provide reliable long-term forecasts, so that customer orders may come unexpectedly. At the same time, lead time for reordering certain components can be significant with up to 60 days for certain components from Italy and even longer for deliveries from China. The combination of long supply lead time and unexpectedly high level of orders has led to difficulties in the past.

The interviewee reports that supply shortages have emerged because of human error in the case company's call-off of supply as well as in the processing of orders at suppliers.

Another reason as to why supply has been delayed was that in spite of delays in production suppliers were trying to produce enough components to complete the agreed upon transport batch size – instead of delivering the components that had already been produced in smaller batches to allow the case company to continue production.

Bankruptcy of suppliers is another reason for delays that have occurred.

6.2.4.7. Bottleneck Management: Prevention

The case company provides its suppliers with forecast data. At the same time, however, the case company's sales partners often are not able to provide reliable forecast data to the company. In order to deal with the combination of long supply lead times and lack of reliable forecast data from sales partners high inventory levels have been held on stock to buffer demand peaks.

The company has traditionally fostered long-term partnerships with sole suppliers rather than using multiple sources of supply for increased reliability. According to the interviewee, this may change for certain components both to increase negotiation power for part prices and to improve reliability of supply. Nevertheless, the interviewee emphasizes the importance of partnerships with suppliers. One of the factors for the mostly well-working supplier relationships is the "emotional factor" as suppliers realize they work with a company that has pioneered products for sustainable life style.

One important sourcing criterion for qualification of new suppliers is lead time: suppliers with short lead time are preferred, which helps cope with short-cycled demand peaks.

In order to be able to better deal with variability in demand, suppliers are contractually obliged to provide 20% of production capacity flexibility per month. According to the interviewee it often is possible to get even higher increase (up to 50%) in output from suppliers in one month when no significant increase of production output is expected in the following month.

Supplier delivery to consignment warehouse is desirable but currently not an option. The primary reasoning in favor of consignment warehouses is reduced capital cost rather than improved supply reliability, although the interviewee suggest that for reasons of supply reliability suppliers might maintain higher inventory levels in a consignment warehouse than the case company would in its own conventional warehouse.

Although penalty clauses are part of some supply contract, the case company does not normally make use of them. According to the interviewee, in 90% of all cases the case company does not retreat to contractual penalties.

6.2.4.8. Bottleneck Management: Identification

The interviewee distinguishes between predictable and unpredictable delays. Delays in supply are predictable when a supplier does not confirm the delivery date in his order confirmation or when he suggests a later date.

In other cases, when delivery dates were confirmed but problems surface that make delivery on schedule unlikely, suppliers generally notify the case company. Suppliers usually provide notification of delays three to five days prior to the promised delivery date. In case of machine breakdowns notification may be given only one day in advance. Only infrequently do deliveries not arrive without prior notification.

It does happen that inventory levels at the case company are not as planned because consumed material had not been properly booked in the IT system. In such cases the supply shortage is not related to irregularities in supply.

6.2.4.9. Bottleneck Management: Exploitation

There are several measures in place to maximize throughput when supply bottlenecks emerge.

When delays occur at suppliers, the case company expects suppliers to use faster means of transportation. According to the interviewee suppliers sometimes simply do not think of this option. Furthermore, transportation lot sizes that had been agreed upon with suppliers for economic reasons can be reduced so that production can be continued.

The interviewee also reports that refurbishing of material that is locked due to quality problems is increased so that more parts become usable for production.

6.2.4.10. Bottleneck Management: Elimination

When it comes to the company's attention that a supplier will be unable to meet promised delivery dates and the dispatcher is unable to find a viable solution with the supplier, the dispatcher will contact his purchasing manager who will inform the company's management. Management then will get in touch with the supplier to check if a solution can be found through negotiation on a higher hierarchical level.

In cases where a second source of supply is available the case company switches to this source when delays are expected from the primary source. One of the improvement measures the interviewee suggests is that alternative suppliers shall be qualified for most parts so that time can be saved and the case company does not have to begin the search process for new suppliers in case bottlenecks emerge.

For certain components that are normally sourced to suppliers internal production capacity is available so that the component in short supply can be manufactured in-house.

In case the bottleneck shifts to the case company's internal production capacity, contract manufacturers have been qualified to support internal manufacturing of components of some of the case company's products. In so doing production capacity available for these components can be doubled.

The interviewee suggests that supply shortages sometimes should simply be accepted before high cost is incurred to resolve the situation. Instead of eliminating the bottleneck at any cost there should be an evaluation of the damage that will be caused by the bottleneck. Possibly internal production is scheduled such that the material would not be immediately needed upon arrival on the promised delivery date. Also, before additional actions are triggered, the case company should assess whether its own delivery date promised to the customer is in fact critical, which according to the interviewee might not even be the case.

In some cases, substitute material that can provide the same function as the material in short supply is temporarily approved for production after careful evaluation by quality assurance.

6.2.4.11. Bottleneck Management: Placement

The interviewee states that the case company has purposely chosen to work with only one supplier for an electronic component so that they are better able to coordinate and cooperate in the development and production of the component. Hence, they have consciously limited their possible sources of supply, albeit not for reasons of efficiencies. Hence, the situation does not reflect the reasoning behind bottleneck placement.

6.2.4.12. Bottleneck Management Limitations

There are not many obvious constraints the case company has to deal with when managing supply bottlenecks.

The overall market situation in the case company's industry is currently characterized by relatively low demand, which has driven several manufacturers of related products, e.g., producers of solar panels, into bankruptcy. Low volumes have been mentioned as one reason as to why the qualification and introduction of alternative or second source suppliers for certain components is currently not viable. Introducing additional suppliers in a market of already decreasing volume would lead to unfavorable conditions for the relationship with each supplier.

The interviewee reports that one supplier openly communicated that production jobs for other, larger customers (of the supplier) were prioritized over those for the case company. This indicates clearly that the purchasing volume of some components is such that some suppliers do not regard the case company as highly important customer. This implies that the case company has less negotiation power when it comes to prevention, exploitation, and elimination of bottlenecks, but also in price negotiations.

Because sales partners are often small and medium-sized local handicraft businesses reliable forecasts are not received and difficult to create. This limitation is inherent to the way the organization is set up and linked to the market and thus cannot easily be resolved.

The interviewee mentions that because of the market downturn for solar energy related products in recent years banks have become suspicious of firms in that industry, so that the case company prefers to describe itself as a manufacturer of heating systems with focus on solar energy technology rather than as a solar energy company or as a producer of solar panels and solar thermal collectors. This indicates that conditions for loans from banks to expand the business or to deal with difficult business situations – as might be caused by supply-related problems – may be unfavorable or loans might not be available at all. That is, the company is currently subject to financial constraints, as are other companies in the same industry.

The case company has traditionally focused on long-term relationships with one or very few suppliers per component. Part of the reason why this is so is the company's ethical stance, suggesting that putting trust on one supplier is a better thing to do than spreading orders across many suppliers. The interviewee indicates that this mindset has sometimes led to single-sourcing agreements where there should have been multiple sources instead. That is, the case company's organizational culture has been a limiting factor for the prevention of bottlenecks.

6.2.4.13. Summary of Activities (Graphical)

Figure 6.2.3 presents a graphical summary of the reasons for bottleneck emergence and the case company's bottleneck management activities.

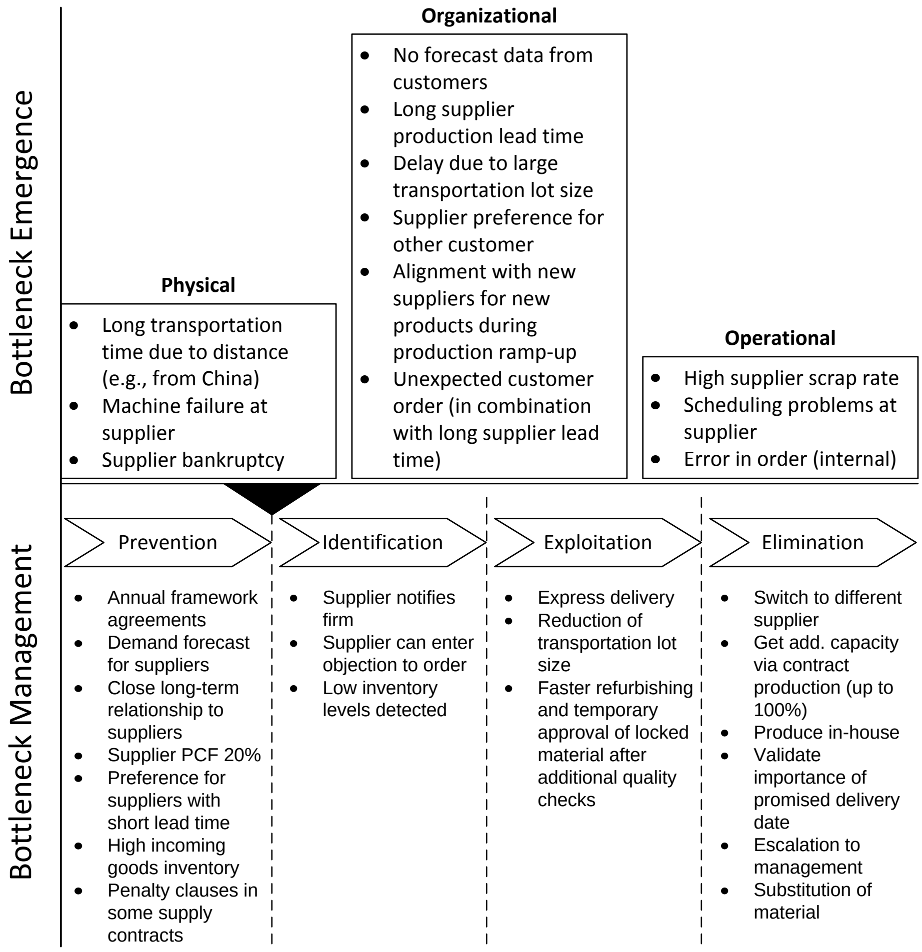

Figure 6.2.3. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 3

6.2.5. Case Study 4

6.2.5.1. Short Description

The case company is a large international trading firm for different types of metal with headquarters in Europe. Customers come from diverse industries and are of different size, reaching from small firms to large corporations.

6.2.5.2. About the Data Collection

The interview was conducted in the company's headquarters in Central Europe. Two interviewees were available for the interview. Both interviewees are specialized on tin trading and the interview thus focused mostly on supply networks for tin.

The interview was audio-taped and the recorded interview time was about 46 minutes. Before the interview began, an introduction to the research project as well as explanations about terminology and bottleneck concept were provided.

Contact to this case company had previously been established by the purchasing and logistics manager of another case company.

6.2.5.3. Market Situation

Global demand for tin currently exceeds supply. Accordingly, prices are stable on a high level. One interviewee suggests that despite the slight imbalance of (global) demand and supply "enough" tin will be available to the market in the next couple of years as there is still some slack in the effective use of production capacity in the producing countries such as Indonesia.

There are only "a handful" of companies active in tin trading in Europe which are competing with the case company. The case company has a strong market position.

6.2.5.4. Supply Situation – General Information

The supply situation for the case company is largely stable. The largest amounts of tin are shipped from Indonesia and South America and are received in conventional warehouses in three locations, one of which is the incoming material stock of a facility for tin production whereas the other two are dedicated warehouses without production capacity attached. Customer orders are fulfilled with material from stock, which normally allows processing and delivery of customer orders within 48 hours. According to the interviewees irregularities in supply do occur but can generally be buffered or otherwise managed.

6.2.5.5. Production Process

The case company is active in metal trading, that is, they receive material to conventional warehouses and sell it from there. There is no further modification of the material.

6.2.5.6. Bottleneck Emergence

According to the interviewees, political instabilities in the producing countries affect the availability of tin in the global markets. In most cases, however, this is merely reflected by rising prices for tin; a real supply shortage has not emerged. Also, political events in other countries influence the price level, such as the ongoing political crisis in Crimea. One of the interviewees considers the politically induced turbulence in the Indonesian tin market as “a game they play in order to keep prices high”.

One important aspect is the existence of a multitude of different brands of tin with differences in purity and amounts and types of by-products. According to one interviewee, not all brands can be held on stock in large amounts so that mismatch might occur between which brand a customer wants and which brands are available. Some customers are flexible as to the brand, others have very specific needs.

Since all material is shipped from overseas, delays of cargo ships do sometimes occur.

One interviewee reports that one reason why supply shortage of other metals than tin sometimes occur – more specifically, he refers to magnesium and some other metals mostly supplied from China – is that suppliers hold back deliveries when they expect rising prices and then sell material to other customers who are willing to pay higher prices. The interviewee refers to this pattern as a Chinese business peculiarity.

6.2.5.7. Bottleneck Management: Prevention

According to the interviewees, two measures are dominant to prevent the emergence of bottlenecks in supply: the use of multiple (about two to four) sources and good relationships with suppliers. Although three warehouses are maintained, the inventory kept in these warehouses is not intended to cover long periods (e.g., several months) of supply as the price for tin is too high and hence impact on cash flow significant. Instead of relying on large inventories as buffer, the use of multiple reliable sources is emphasized. At the same time, the interviewees stress the importance of good relationships to LSPs in order to make sure no delays will occur in the outbound stream. The interviewees state that overall the company reaches a service level of 99% and with most customers even 100%.

The interviewees suggest that because the case company belongs to the big players in the tin market suppliers generally put much effort into ensuring that the supply process goes smoothly and uninterrupted. That is, the company's reputation as a large and important customer does play a role.

The case company has information about the total production capacity of its suppliers as well as about their production output. This information helps the company estimate whether problems may arise out of short production capacity.

6.2.5.8. Bottleneck Management: Identification

The interviewees state they are informed by the warehouses when inventory reaches a critically low level. In such cases, information about estimated arrival time will be retrieved from the cargo ships that are on their way to find out if the inventory levels will suffice until arrival of new material.

As described in the previous section, the case company is aware about slack in suppliers' production capacity and thus can estimate in advance if a bottleneck may emerge.

6.2.5.9. Bottleneck Management: Exploitation

Two of the three warehouses are dedicated to holding inventory for trading whereas one warehouse is attached to a production facility for tin-based products. Normally, all orders for unprocessed tin are served from the two dedicated warehouses. The interviewees explain, however, that it is possible to access material from the production warehouse in case inventory levels in the other two warehouses are too low to fulfill customer orders.

6.2.5.10. Bottleneck Management: Elimination

The most obvious measure for the case company to eliminate a bottleneck in one supply relation is to switch to another supplier. The company maintains parallel supply relationships with two to four tin producers. According to one interviewee, one relationship normally is the preferred one; however, the other suppliers do receive their share of orders. In case suppliers would be unable to supply the right material in the right amount on time, the case company would also buy material from competing trading firms. The overarching goal is to fulfill the customer's order even when order fulfillment would cost the company money.

One interviewee states that in case a bottleneck exists the company approaches the customer to validate the promised delivery date. The reason is that customers sometimes set arbitrary delivery dates – sometimes weeks before they actually need the material. In such cases promised delivery dates can be postponed by some time in order to reduce the stress on the supply relation.

When a customer orders a particular brand of tin which at that time is not readily available, the case company may approach the customer to offer another brand with similar characteristics. Depending on the specific demands of the customer, such a substitution may resolve the bottleneck situation.

6.2.5.11. Bottleneck Management: Placement

The concept of bottleneck placement could not be applied to this case study.

6.2.5.12. Bottleneck Management Limitations

There are few – if any – obvious limitations to the company's ability to manage bottlenecks.

One physical constraint certainly is that material has to be shipped from overseas and thus requires transportation by cargo ships, which is usually slow and prone to interruptions and delay due to weather conditions. Alternative transportation modes are not available, however, due to weight and amount of the material.

6.2.5.13. Summary of Activities (Graphical)

Figure 6.2.4 presents a graphical summary of the case company's bottleneck management activities.

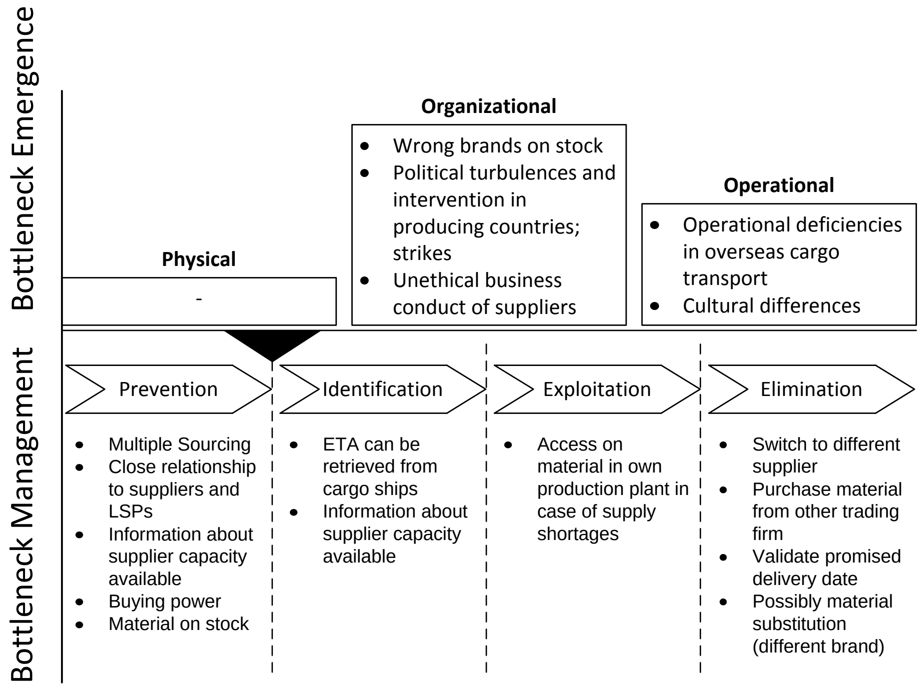

Figure 6.2.4. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 4

6.2.6. Case Study 5

6.2.6.1. Short Description

The case company runs several large production plants in Europe where it produces copper and some by-products such as gold. The company sells copper cathodes as well as copper-based products, the latter of which are manufactured in a separate division of the company. Among the case studies conducted for this thesis, this company might be the one which is located furthest upstream in the supply network.

6.2.6.2. About the Data Collection

The interview was conducted in the company's headquarters in Central Europe. The interviewee's position is Head of External Logistics. The interview took about 45 minutes, was conducted in English, and was audio-taped. The researcher's contact to the company was established by another case company's procurement and logistics manager. Although the project description was sent to the company some days in advance it was not forwarded to and received by the interviewee prior to the meeting. The interview was preceded by an introduction to the project and an explanation of some concepts used in the thesis. Although the interviewee emphasized that he might not be able to answer all questions as some touched upon other departments' responsibility and function most questions were answered during the interview.

6.2.6.3. Market Situation

To this day, the company has maintained a relatively high level of integration as compared to some competitors so that competition exists for products and intermediate products at several points in the company's value chain. Although several competitors are smaller than the case company they have good market positions in their respective local geographic markets. Likewise, the most important market for the case company is the domestic European market. Current market demand for copper cathodes is strong and the interviewee describes the market as a sellers' market.

6.2.6.4. Supply Situation – General Information

The case company receives copper concentrate from copper mines and purchases recycling copper globally. The interview was focused on the inbound stream of copper concentrate.

Most of the raw material is received to a conventional warehouse which is operated by an external service provider. Since the proportions of ingredients (copper and by-products) in copper concentrate change depending on the location of the mine and also over time, upon arrival from overseas freight different copper concentrates are blended by the service provider before the concentrate is processed in the plant. A smaller share of raw material is delivered directly to the production plant where there is a smaller storage area where the material can be prepared for use in the production process.

The purchasing department of the company is given great weight. Production of copper cathodes is a continuous chemical process and interruption of supply would incur significant cost. The interviewee does not recall a situation of supply shortage that has occurred in the last couple of years. The stable supply, in turn, allows the company to achieve a high service level with its customers.

6.2.6.5. Production Process

The basic metallurgical processes have remained similar over long periods of time. Changing quantities of, for instance, toxic material in the copper concentrate, however, that requires special attention in the process, such as arsenic, induce the need for technological innovation.

The production of cathodes in the electrolytic process takes roughly three weeks.

6.2.6.6. Bottleneck Emergence

The interviewee states that he is not aware of any externally induced interruption of the production process of copper cathodes due to a shortage of supply in the past years. This suggests that the order and supply processes are stable.

Since demand for both copper-based products and copper cathodes is currently strong, copper cathodes represent a supply bottleneck as more copper-based products could be produced and sold if more copper cathodes were available in the market. The reason for this shortage of copper cathodes are production capacity constraints. Since cathode production is a continuous process, there is little flexibility to scale up production, for instance by adding additional work shifts. That is, production of copper cathodes generally remains stable over long periods of time whereas demand changes and thus determines availability of copper cathodes in the market.

One bottleneck for cathode production was created internally due to maintenance work in the production of anodes which are required pre-material for cathode production. Planning for the maintenance work began three years in advance and anode stocks were increased for several months in order to have sufficient inventory and minimize impact on cathode production. The result of the deliberate planning process was that losses of cathode production could be minimized – albeit not avoided completely – although maintenance of the anode production area persisted for several weeks.

Both constraints described in this section do not represent bottlenecks in supply but internal bottlenecks.

6.2.6.7. Bottleneck Management: Prevention

The primary measure to avoid shortage in raw material – should it occur – according to the interviewee is the diversification of supply sources. The concentrate purchased from the various sources is buffered in an external warehouse where different concentrates are then blended to reduce variety of chemical proportions in the material for the production process. The blending process as such can be seen as a prevention measure in itself.

The blending reduces the dependency on specific qualities of copper concentrate and thus on specific sources of supply. Irregularities in supply from one source can thereby be compensated for by other sources without compromising on the chemical properties of the copper concentrate.

The raw material inventory kept in the external warehouse is able to feed supply to the production process for several weeks so that a possible gap in the inbound material flow can be bridged.

Diligent planning and multiple sources notwithstanding the mere importance of the case company as a customer for its suppliers may be another reason why irregularities in supply of raw material could be averted for several years.

Furthermore, the company engages in scenario planning. The interviewee explains that potential global problem areas are investigated and possible options for counter measures assessed. One result of such planning activities is an increased awareness and thus possibly shorter reaction time. Examples for possible problems that are assessed in these planning activities are, for instance, union activities in mines and strikes at important sea ports.

6.2.6.8. Bottleneck Management: Identification

The interviewee states that the case company is an active participant in trade organizations and other networking opportunities within the same and related industries in order to exchange and capture information about the supply situation worldwide. This way, problems that are possibly coming up can be identified in an early state so that counter measures can be put into action.

6.2.6.9. Bottleneck Management: Exploitation

The blending of copper concentrate from different sources has been described above as an activity to prevent bottlenecks. With some justification, however, it can be considered a measure of bottleneck exploitation, too. The blending process allows to better utilize the resources available as copper concentrate – which may include an unfavorable proportion of ingredients – to make it suitable for straight use in production process can be made usable by blending it with copper concentrate from other sources.

Other measures of bottleneck exploitation could not be identified in this case study.

6.2.6.10. Bottleneck Management: Elimination

The most important measure for bottleneck elimination is switching the sources for supply. However, problems with supply bottlenecks were not reported.

6.2.6.11. Bottleneck Management: Placement

For supply of raw material from external suppliers the concept of bottleneck placement did not apply to this case study.

Internally a bottleneck had been created through massive maintenance work in anode production, as described under “Bottleneck Emergence”. The intent to create this bottleneck was not to capitalize on efficiencies or to control production flow, though; rather, the maintenance work the anode production underwent was a necessity. Thus, the concept of bottleneck placement as defined in this thesis does not apply.

6.2.6.12. Bottleneck Management Limitations

Since production of copper cathodes requires large amounts of raw material which is supplied from overseas, an obvious limitation is that there are no shortcuts available to speed up transportation in case production would encounter a shortage of raw material. For transport of large amounts of raw material from continents such as South America there is no alternative to conventional sea freight.

The nature of the production process – a continuous chemical process – creates limitations as it excludes flexibility to scale production up or down according to demand and availability of raw material. That is, inherent technical characteristics of the process impose limitations on the actions the company can take to alleviate problems attached to irregularities in supply.

To this day, the limitations described here are hypothetical as the case company appears to be in full control of supply and has not faced supply shortages for an extended period of time.

6.2.6.13. Summary of Activities (Graphical)

Figure 6.2.5 presents a graphical summary of the case company's bottleneck management activities.

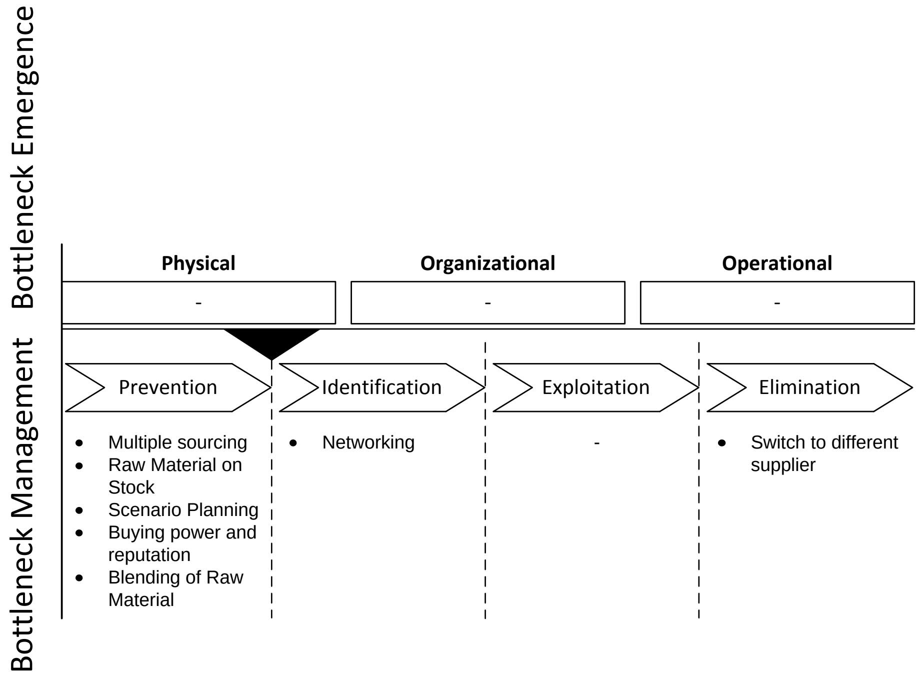

Figure 6.2.5. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 5

6.2.7. Case Study 6

6.2.7.1. Short Description

The case company is a medium-sized trader of raw material with focus on non-ferrous metal.

6.2.7.2. About the Data Collection

One interview was conducted at the headquarters in Europe on April 3rd, 2014. The contact to this case company had been established by the logistics and procurement manager of another case company. The interview was audio-taped, transcribed and coded. The interviewee is the CEO of the firm. The interview took about 50 minutes.

6.2.7.3. Market Situation

As a relatively small player in a market of mostly large companies the company fills a niche. According to the interviewee, some of the competitors are so large that they simply do not bother the case company due to its relatively small size.

6.2.7.4. Supply Situation – General Information

The supply situation was described as largely stable. That is, the company does not have to deal with supply shortages on a regular basis.

Ten different types of raw material are kept permanently on stock and several others are offered on demand. That is, most orders are served from stock, which allows the company to offer short delivery time to customers. In total, the company's supplier portfolio consists of more than 100 different suppliers. Suppliers are both smelters and other raw material traders. When regular suppliers are unable to deliver, raw material can also be ordered from competing trading firms.

6.2.7.5. Production Process

The case company trades raw material, i.e., the only modification of the material is in terms time and place. The company receives most of its material to conventional warehouse; only a small share of goods is kept in a consignment warehouse. Some ("basic") materials are permanent part of the product portfolio whereas other parts of the product portfolio change on a yearly basis.

6.2.7.6. Bottleneck Emergence

The reasons as to why suppliers fail to deliver as promised are diverse and include technical, political, natural, cultural, and operational reasons.

According to the interviewee, problems often occur related to overseas delivery. As an example she mentions delivery of lead from Thailand. Occasionally, "one container is left behind" during transfer so that delivery time doubles from four weeks to eight weeks so that delivery time exceeds inventory buffer time.

Problems are reported related to delivery from Eastern Europe, particularly from Poland and Russia. The interviewee suggests that some suppliers prefer to supply domestic customers first, which repeatedly led to delays. Also, communication with some suppliers has turned out to be difficult as clear statements as to the state of order processing could not be obtained. In some cases, material was held back by suppliers when market price was low. The same has been reported about a supplier from South America who decided not to ship ordered material overseas. The interviewee referred to this behavior as "artificial scarcity of supply".

Several smelters in Southern Europe regularly stop operations for several weeks in summer and empty their stocks. When operations are continued after the summer break and demand is high, scarcity for certain materials can occur.

In Europe, scrap metal has become the dominant raw material for production of several metals and many once "primary" smelters have become "secondary" smelters, i.e., they process scrap metal instead of ore. Apparently availability of scrap metal sometimes is limited so that delay can be caused. The case company receives scrap metal from several sources and provides smelters with scrap metal who, in return, deliver pure metal of some kind. When availability of scrap metal is insufficient this cycle is interrupted and the pure metal becomes more expensive or – in the worst case – unavailable.

Machine breakdowns in smelter's production processes also occur and cause delays. The interviewee reports that one supplier had created an order backlog of about 10.000 tons of material when several machines in his production process broke down at once.

The interviewee mentions that in case suppliers were unable to keep up with demand the case company did experience that larger customers where preferred over the case company. That is, the relatively small size of the firm occasionally has been a disadvantage when short material had to be allocated.

The interviewee cites the REACH[1] regulation that has led to the situation that for some raw materials such as cadmium the number of registered importing companies is so low that demand repeatedly exceeds supply. According to the interviewee, firms are discouraged by the cost related to REACH registration and approval of material.

One of the most prevalent problems the company has to cope with is that many customers tend to order late. Although the case company's business model is based on delivery on short notice it does require some days to organize transportation. That is, the source of the demand-supply mismatch here is not the supply base but constraints such as immediate availability of transportation capacity, which can make meeting such orders difficult.

Political and societal events such as strikes in mines or government influence such as in Indonesia occasionally lead to delays and price fluctuation.

6.2.7.7. Bottleneck Management: Prevention

One effective measure the company employs is to maintain a broad set of suppliers (i.e., multiple sourcing). Tin, for example, can be received in its various qualities from eight different suppliers, some of which are smelters whereas

[1] Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

others are trading firms. This provides the company with a variety of options in case of contingency.

The company's core business logic is to sell material from stock to buyers who need material at short notice and who thus are willing to pay a premium. That is, the company maintains a certain inventory level for its core products. This inventory level buffers irregularities in supply and demand, so that mismatch between demand and supply can be avoided if delays in supply do not exceed a certain time range.

For the purchase of some materials yearly framework agreements exist so that the supplier can allocate capacities accordingly. Such framework agreements are likely to lessen the chance of unexpected supply shortages due to strong industry demand.

Although most material is kept in conventional warehouses, the case company maintains one consignment warehouse with a supplier. Consignment warehouses are not only a means to mitigate the burden of capital cost but also allow effective inventory control by the supplier. Thus, the consignment warehouse can be seen as a measure to prevent supply shortages for the respective material.

6.2.7.8. Bottleneck Management: Identification

The interviewee has emphasized the role of networking in the metal trading and processing industry. Maintaining good relationships to other industry players can be seen as an effective "early warning system". One anecdote mentioned during the interview is that a fire broke out at one large smelter and that it took less than half an hour before "everybody in the industry" knew about the incident and contacted the supplier to learn about possible implications for supply.

Generally, suppliers notify the case companies when they become aware of problems.

6.2.7.9. Bottleneck Management: Exploitation

No measures for exploitation of bottlenecks in the company's supply network could be identified in this case study. However, one measure has been reported that can support and accelerate the transfer of material in demand to customers. The interviewee mentioned that late customer orders regularly cause problems as transportation capacities might not be immediately available although the material would be readily accessible on stock. In such cases, material pick up can be organized by customers to allow immediate access to the material.

6.2.7.10. Bottleneck Management: Elimination

The use of multiple sourcing allows the company to switch to another source of supply in case the original source is unable to deliver as planned. The interviewee emphasized that buying from alternative sources – even from competing traders – (even for higher prices while selling at loss) is an option that the company can retreat to.

In case one particular material is not available from suppliers and customer orders are pending, the company does approach customers and offers them a substitute product. For instance, lead with higher purity can be offered when lead with lower purity is currently in short supply.

6.2.7.11. Bottleneck Management Limitations

The relatively small size of the company poses limitation to its options in the face of the often external causes of bottleneck emergence in the supply network. For instance, it has been mentioned above in the description of bottleneck emergence that the case company faced situations where it was disadvantaged as compared to larger competitors in the allocation of scarce material.

As it becomes clear from the description of bottleneck emergence, the options for the company to prevent the emergence of bottlenecks in the supply network are limited as the reasons tend to lie outside its direct influence.

It seems there are financial constraints which prevent the company from following certain activities. The interviewee stated, for instance, that the company could organize the overseas transportation of certain materials on its own so as to skip one echelon of the supply chain; the constraint, however, is that this would require upfront investment which would put the firm's financials at risk.

The current terms and conditions are such that smelters, i.e., suppliers, insist on instantaneous payment or even cash before delivery whereas customers of the case company enjoy 30 to 60 days period of payment. The gap has to be bridged by the case company, which consumes capital that could be used for other activities.

One limitation for the case company's bottleneck management activities arises from the natural scarcity of certain raw material. That is, some products might only be available on the market in small amounts, at high prices, or, in extreme cases, not at all.

Also, natural distribution of material on the planet makes sourcing to remote places a necessity rather than a choice. At the same, weight and amounts of material are such that air freight must be excluded as an option and the only viable transportation mode remains sea freight, which is slow and prone to delays due to weather conditions.

6.2.7.12. Summary of Activities (Graphical)

Figure 6.2.6 presents a graphical summary of the case company's bottleneck management activities.

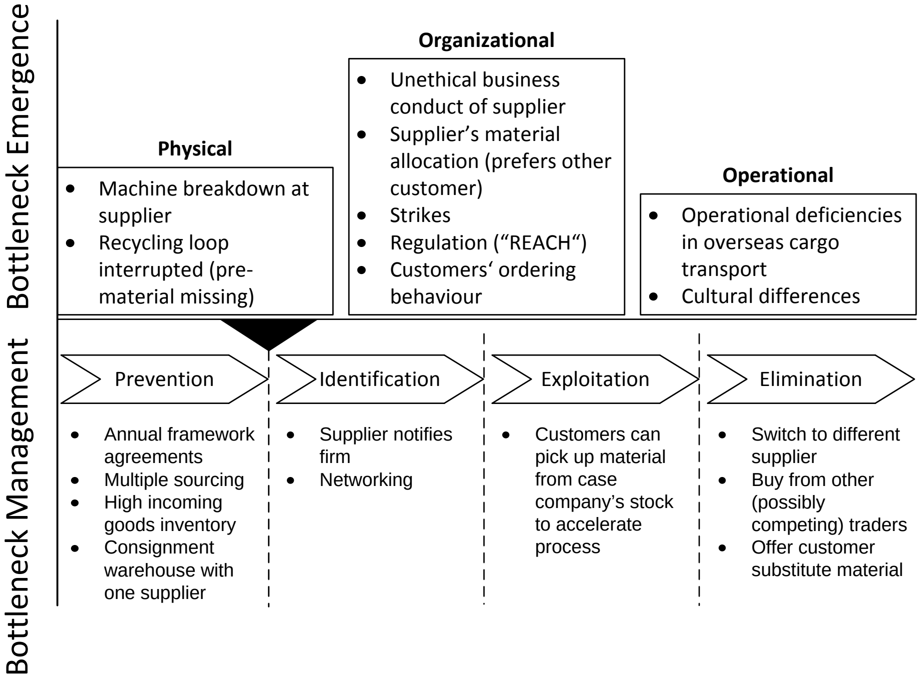

Figure 6.2.6. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 6

6.2.8. Case Study 7

6.2.8.1. Short Description

The company is a producer of soldering powder and other related products for the manufacturing of electrical components. The product portfolio consists of a wide range of different products and product variations. Customers are mostly automotive suppliers and suppliers of computer components, i.e., the company is located upstream in the supply network for electronic components. The company is part of a larger industrial group based in the same country and has one production plant in central Europe and one in China. Each plant has a production output of several hundred tons of powder per year. Further expansion of the business is planned.

6.2.8.2. About the Case Study

The primary mode of data collection for this case was one semi-structured interview. The interview took place in the headquarters of the company. The interviewee's position is Sales and Administrative Manager. The interview was audio-taped; additional notes were taken manually on a hard copy of the interview questionnaire. Limited access to archival records was granted. The researcher's contact to the company had been established by another case company's procurement and logistics manager. The meeting, including the interview, introduction of the project and introduction of the company, took about two hours.

6.2.8.3. Market Situation

There is strong competition from another producer of similar products in Europe and five to ten competitors in Asia, five of which are described as large.

One particularity is that some companies downstream the supply network perform tier-n management and approve and audit suppliers up to four echelons upstream.

According to the interviewee, many customers employ dual sourcing as a means to avoid bottlenecks in supply. That is, the case company often is not the only source of supply for its customers.

6.2.8.4. Supply Situation – General Information

Primary raw materials are tin, lead, silver, copper, antimony, and bismuth, with tin and lead representing the largest amounts. Overall, there are more than ten different types of metal required to produce the diverse range of soldering powders. The minimum order batch size for several of the raw materials is 5 tons.

The supply situation has been described as largely stable with delays occurring only on rare occasions. The forecast horizon from customers in Europe normally is only 1 month; customers in China tend to provide even shorter forecast horizon of only one to two weeks. For certain products that are part of microchip supply chains, however, the forecast horizon provided by customers is up to one year.

The company uses two sources for several materials and purchases other materials from traders that employ several sources.

Raw material is delivered by truck from continental Europe to a conventional warehouse. The normal delivery frequency is one delivery per week. The company keeps a buffer of raw material in its warehouse from which it covers regular and smaller orders. The amount purchased per months is adjusted based on sales in the previous month. Large orders are treated separately: raw material for large orders is purchased in the exact quantities needed to complete the job.

6.2.8.5. Production Process

Raw material is processed in a continuous process that runs 24 hours for five or six days per week. The production process is normally interrupted only for cleaning and maintenance work. Depending on the change of the products that are to be produced on the production lines, extensive cleaning work might be required to remove all particles of certain raw materials that must not be contained by the product to which the process is to be changed. Such cleaning for product changeover can take half a day.

6.2.8.6. Bottleneck Emergence

The interviewee reports that problems have been caused due to insufficient quality of raw material and delayed delivery by one supplier with whom the company subsequently stopped working after “many years”.

The interviewee’s interpretation of the events was that this (larger) supplier acquired some new customers which the supplier prioritized higher and to which he allocated more capacity and diligence. These new customers were not direct competitors of the interviewee’s company but purchased the same raw material. The supplier delayed deliveries to the case company several times so that the production process had to be interrupted. After such delays occurred several times, quality of raw material additionally started to vary, so that delivered batches sometimes were flawless and at other times were unusable, which for technical reasons only could be detected in the end product, i.e., after the production process for the respective product had been run. In such cases, the entire production batch had to be discarded, could only be used for customers with lower quality requirements, or had to be used otherwise. The interviewee’s explanation for the variance in raw material was that the supplier had begun to buy material from another source.

Internally, delays sometimes occur due to problems in the production process. On the distribution side, problems occur due to delays in transportation to customers in Asia when cargo ships are behind schedule. The interviewee mentions that once a ship with more than ten tons of production output sank on its way to a customer in Asia.

In cases as the ones just described the bottleneck shifts from the supplier or the distribution, respectively, to the case company. When an entire production batch is wasted due to insufficient raw material quality or when supply is delayed, the internal production of the case company becomes the new bottleneck. Likewise, when a cargo ship with finished products sinks on its way to customers, the production output of several days or even weeks is lost so that internal production capacity becomes the limiting factors.

6.2.8.7. Bottleneck Management: Prevention

Generally, the company employs annual framework contracts with suppliers that include amounts to be purchased to allow better capacity planning. The same is done with some (yet not all) customers.

Tin and lead are purchased from a raw material trading firm that itself maintains several sources for its material, all of which previously approved by the interviewed company. Material that is acquired directly from raw material producers is always sourced to two suppliers in parallel. Dual sourcing is a requirement from several customers. The use of the trader is due to bureaucratic obstacles for the direct import of tin and lead but (unmentioned by the interviewee) also has a risk pooling effect. When the Indonesian government put forth new rules for the export of tin with effect from 1 January 2014, the dealer expressed confidence that he will be able to provide all the amounts required by the interviewed company.

The purchasing of raw material is combined with another company in the same conglomerate (also, the purchasing manager is the same). This allows to leverage higher purchasing power.

Several of the company's customers and indirect customers (further downstream in the supply network) have policies in place that affect bottleneck prevention. For better inventory and capacity planning, the company operates several consignment warehouses at sites of large customers. The consignment warehouses are described by the interviewee as expensive but useful. Also, all suppliers from which the case company sources raw material for products delivered to that customer have to be qualified by a blue chip corporation three echelons downstream; i.e., this firm performs tier-n management up to four echelons upstream in this supply chain. Also, audits are performed regularly, both by some customers and by the case company itself.

Some material is sourced to domestic suppliers so that the chance of delays and interruption due to transportation issues can be minimized.

6.2.8.8. Bottleneck Management: Identification

No specific measures are in place to identify bottlenecks in an early stage.

The company maintains good relationships to a broad variety of firms in its industry as well as with suppliers and customers. For that purpose the company maintains a sales office in Singapore. That is, larger developments on the raw material market will be detected early.

6.2.8.9. Bottleneck Management: Exploitation

Measures of bottleneck exploitation touch mostly upon internal processes and actions. Several measures have been mentioned for the case that the bottleneck shifts to the internal production of the case company.

Weekend work has been mentioned as a primary measure to catch up with production schedules. Additional work on Saturdays and Sundays allows for an internal production capacity flexibility of 20% to 40%. Since normally maintenance jobs are performed on the weekend, production on the weekend comes at the cost of scheduled maintenance.

To resolve the resulting capacity shortages in the case of the ship that sank with ten tons of finished goods during distribution (as mentioned above) four measures were put into action:

1. Weekend work (see above)
2. Use of faster transportation modes. In this case, air freight was used to transport the finished goods to Asia.
3. Smaller transportation lot sizes. Material was shipped as soon as possible in smaller batches to allow the customer to continue with production.
4. Other customers were contacted to evaluate the urgency of their orders. Thereby, the production schedule could be adjusted and the production of the scarce material could be optimized.

6.2.8.10. Bottleneck Management: Elimination

The primary measure to deal with problems in supply is to use the second source of supply.

Also, because of its being part of a larger industry conglomerate, the company is able to access material on stock at the other company of the same group (which is the same organization with whom the procurement process is combined, as mentioned above).

Options to eliminate a bottleneck are limited once it shifts to the internal production of the case company. Although the sister production plant in China has the same technical equipment and similar capacity, employing its production capacity in order to elevate overall capacity is not normally an option due to bureaucratic barriers. Once an exception was made, but it required that the material would pass through several external organizations and had to be shipped by air, so the process was lengthy and expensive. Complementary use of production capacity in the Chinese plant thus is not an option at short call.

6.2.8.11. Bottleneck Management: Placement

The concept of bottleneck placement could not be applied to the business context of the case company.

6.2.8.12. Bottleneck Management Limitations

There are several limitations that do affect the way the company can manage bottlenecks.

One limitation has become apparent in the description of the reasons for bottleneck emergence. It seems there is a power imbalance between the company and some of its suppliers. Relatively low purchasing volumes in spite of combined purchasing with a sister company in the same conglomerate make the company replaceable from the position of a larger supplier. This is a condition for which there is no obvious solution. At the same time, customers sometimes are significantly larger. That is, the company of medium size finds itself as a smaller party in a position between large suppliers and large customers.

Another notable limitation is the short forecast horizon that is provided by customers for several of the company's products. A forecast horizon of one month or only one to two week in Europe and China, respectively, does not allow much time to adjust purchasing and production plans. The limitation arises out of customers' claim not to have the data available, as the interviewee states.

At the same time, increased order size on short call for certain materials such as tin is likely to remain unmet by suppliers. Some materials, such as antimony and bismuth, generally have a higher supply lead time. That is, a combination of short forecast horizon meets a certain lack of flexibility of supply. Increasing the level of inventory in the warehouse poses a financial risk as the cost for several of the materials are very high, i.e., capital cost for inventory might become unacceptable. Generally, some of the raw material can be subject to significant price fluctuation. That is, building up a larger inventory buffer for certain raw materials may not be an option to cope with the combination of short forecast horizon and the danger of insufficient availability of supply.

Switching between certain products in the production process requires extensive cleaning which lowers the overall production capacity. A combination of weekend work to catch up with production schedule when the bottleneck shifts to internal production and the need for a change-over between two products that require careful cleaning in between would turn out to create a difficult situation. Because high purity of the products is required, polluting one product with residues of a previous production batch would possibly render an entire production batch unusable.

It has been mentioned that for technical reasons insufficient quality of raw material might only become apparent after the production process has ended. Obviously, this is a major limitation to the prevention of bottlenecks. Running the production process with one flawed input material will waste the capacity needed for the production of the batch (i.e., machine capacity and manpower), the other raw material that has gone into the process (solder powder generally is a combination of different metals) and other cost such as electricity and manpower.

Import/export policies in China prevent that orders processed at one plant can be supported by additional production capacity from the other plant (in either direction). Circumventing such restrictions involves an expensive and lengthy process and thus is not an option for bottleneck elimination at short notice.

6.2.8.13. Summary of Activities (Graphical)

Figure 6.2.7 presents a graphical summary of the case company's bottleneck management activities.

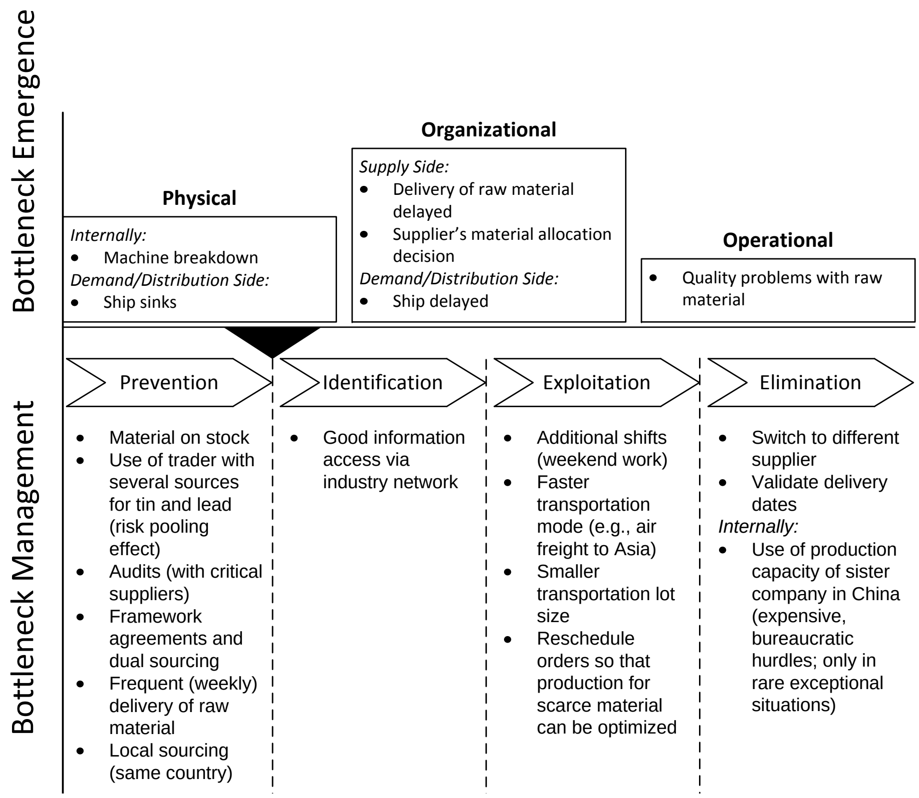

Figure 6.2.7. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 7

6.2.9. Case Study 8

6.2.9.1. Short Description

The case company is a medium-sized producer of products for radiation shielding, anodes for metal extraction, and several special alloys of non-ferrous metals. A subsidiary of the case company produces soldering products. Because of the various applications of its products the range of different customers is very broad.

6.2.9.2. About the Data Collection

Two interviews were conducted at the main production site of the company in central Europe. They were part of a larger case study over a period of two weeks during which the researcher stayed on site, participated in meetings, talked to managers and staff to learn more about the firm and the industry, and conducted an analysis of bottleneck risk at this production site. The interviews were audio-taped and are complemented by manual notes and archival records received during the two weeks. The researcher's primary contact and interview partner is the company's procurement and logistics manager (hereafter referred to as interviewee); the second interview partner is the head of the business division for anode production and he provided mostly technical information about production processes. This case analysis is mostly based on the interview with the primary contact.

6.2.9.3. Market Situation

The company has competitors for most of its products, yet no other company offers the same product range at once. For some products the barriers to enter competition are high due to the need for approval by officials and by classification bodies. Also, capital and expert knowledge required to compete in some areas can be considered an entry barrier. Some other products, on the other hand, might easily be manufactured by other companies with competencies in lead processing. Overall, there is strong competition for some products while competition is much less significant for some others.

6.2.9.4. Supply Situation – General Information

About 15 to 20 suppliers represent the major sources of goods purchased.

Although the situation can be described as largely stable delays and irregularities in supply of non-ferrous metals do occur and are considered routine work, i.e., procurement staff is familiar with such situations. For certain materials, other sources can be easily tapped while some metals with very particular specifications can only be acquired from one source. While some metals are purchased directly from producers (e.g., most of the lead), others are purchased from dealers as the amounts required tend to be smaller than minimum order batch sizes of raw material suppliers.

Also, irregularities have occurred in the supply of other components than pure metal in which certain manufacturing capabilities are involved so that the source could not easily be replaced or complemented.

Overall, irregularities and delay in the supply situation do require intervention of procurement staff on a regular basis but do not regularly pose a significant threat to the company's processes.

6.2.9.5. Production Process

The production process differs for the individual products the company offers. There is both manufacturing and assembly of discrete components as well as continuously running chemical processes. Products are generally produced and delivered to order and many of the company's products are customized to specific customer needs.

6.2.9.6. Bottleneck Emergence

The reasons for the emergence of bottlenecks are diverse.

The interviewee reports that most frequently given explanations for delays in supply are machine breakdowns and the lack of raw material on the tier-1 stage, i.e., bottlenecks on higher echelons such as tier-2. There is currently no transparency as to the reasons why suppliers of higher tiers cause raw material shortages for tier-1 suppliers.

Other reasons are related to uncertainties when introducing new suppliers. For instance, after a sourcing agreement had been closed with a new supplier in China, the supplier found himself unable to produce a certain component so that a new supplier had to be found for that part at short notice.

For certain products, e.g., products related to radiation shielding, approval of classification societies is required for reasons of safety and official approval. This sometimes takes longer than originally expected when mismatch occurs between finalization of the product and free capacity of the classification body. Also, missing documents for customs have led to delays when a Chinese suppliers had been newly introduced into the sourcing portfolio.

One particular supplier which was the sole source for an important component had caused problems (delays, quality problems and mismatch between price expectations) several times before it failed quality audits and was subsequently removed from the portfolio. The reasons as to why this particular supplier failed to comply with requirements and expectations several times are not entirely clear, yet it became apparent that the supplier did not adequately fill the role of the single source supplier for a critical component. Additionally, it turned out the supplier's business conduct diverged too much from acceptable levels. That is, the decision to use this suppliers as the sole source might not have been fully justified in the first place.

Other reasons for the emergence of bottlenecks involve internal processes. The interviewee reports that there is a lack of transparency about free internal production capacity, which complicates the process of order scheduling with customers. That is, there is a danger that promised delivery dates are 'optimistic'. Also, there seems to be insufficient communication between production staff and procurement staff so that procurement occasionally remains unaware of incomplete or delayed delivery of raw material and cannot follow it up.

6.2.9.7. Bottleneck Management: Prevention

The company uses standardized quality criteria for the selection of suppliers to ensure compliance. Generally, yearly framework agreements are used and if possible supply is sourced to at least two suppliers, often with 70%/30% allocation. Some contracts include penalty clauses for non-compliance.

Most material supply is delivered to conventional warehouse; for expensive raw material such as tin and silver the company and its suppliers have agreed upon delivery to consignment warehouse. Besides the advantage of not carrying capital cost for the material in the consignment warehouse the supplier has better transparency as to the amount of material on stock and the amount of material that need to be replenished.

With some suppliers workshops are conducted to improve collaboration on critical projects so that the chance of irregularities is diminished.

Some metals are purchased from raw material traders. Although bottleneck prevention was not mentioned as intention behind this decision – rather, it is a necessity as the amounts purchased are not large enough to be sourced to producers of such materials – it contributes to bottleneck prevention as trading firms generally employ multiple sourcing strategies (cf. analysis of interviews with raw material traders in this chapter).

In some critical cases, suppliers are closely monitored by the quality assurance team to ensure smooth completion.

The purchasing function of the case company is also responsible for the purchasing needs of a fully owned subsidiary of the company so as to leverage economies of scale in purchasing.

6.2.9.8. Bottleneck Management: Identification

The SAP system notifies procurement staff about expected delivery of raw material on promised delivery dates so that order fulfillment can be followed up. Order fulfillment is not followed up, however, for all parts, but predominantly for A and B parts.

Generally, suppliers are expected to notify the company as early as possible when delivery due dates cannot be met. The interviewee reports that this does not happen in every case, however. Occasionally delays in the delivery of raw material only surface in the procurement department when production staff calls, which in some instances has been done only three weeks after the promised delivery due date of an order.

In rare critical cases (about 5% of all orders) quality assurance closely monitors progress on supplier sites to ensure timely delivery of flawless components, which at the same time is a prevention measure.

6.2.9.9. Bottleneck Management: Exploitation

No specific measures of bottleneck exploitation could be identified.

6.2.9.10. Bottleneck Management: Elimination

The use of multiple (mostly two) sources allows switching to another supplier in case delays have to be expected. Also, some materials are bought from raw material traders who generally employ multiple sources and who are connected to other traders with several sources. While some raw material traders require significant lead time for orders, others are able to supply material from stock at short notice (albeit sometimes with a premium). In case a trader or a producer would be unable to fulfill an order, the company sometimes is able to switch to a dealer with material on stock.

Non-ferrous metals in many cases are available in different grades of purity or with different properties, e.g., with higher radiation or lower radiation. In case there is a shortage of material of lower purity while material of higher purity is available, substitution is possible.

Furthermore, the company maintains production capacity of certain alloys that normally are delivered by suppliers (i.e., “make” instead of “buy”). Although in-house production may require significant (both, time and financial) resources as compared to delivery by suppliers, it does provide an opportunity to eliminate a bottleneck and remain productive.

6.2.9.11. Bottleneck Management: Placement

The concept of bottleneck placement could not be applied to this case study.

6.2.9.12. Bottleneck Management Limitations

The case company is medium-sized and throughput of certain raw materials does not reach amounts that are considered significant by some larger suppliers. That is, buying power for certain materials is relatively low. In fact, there are concerns that in the future one specific larger supplier may not be willing to supply the small amounts needed or that he may charge a premium for small amounts that would render this source uneconomical for the case company.

The relatively small size as compared to other companies that purchase the same raw material from the same suppliers also puts a constraint on negotiation power of the case company when it comes to delivery to consignment warehouse. While it was possible to agree upon this delivery mode with some suppliers it proves impossible to convince others since the company often does not require amounts that are considered significant by the – often much larger – supplier.

Because the amounts ordered of some materials are smaller than minimum order lot sizes of suppliers, the case company has to receive such materials from raw material traders. While some traders are large multinationals or at least possess significant market share on a national level, other traders are much smaller and do not possess significant negotiation power relative to their suppliers either.

At the same time, some of the customers of the case company are also much larger. This implies lower negotiation power and limits influence, e.g., on ordering behavior.

Delays that are caused by lengthy approval processes of officials, customs, and classification bodies provide little opportunity for intervention by the case company. This emphasizes the importance of elaborate preparation and communication with these parties prior to the approval process.

There is a natural scarcity of certain raw materials, e.g., of lead with high purity or with low radiation. This creates a natural monopoly for those suppliers who possess access to these resources and hence a natural limit to the case company's selection of possible suppliers, its sourcing strategy, and its negotiation power. Because of specific technical requirements materials often cannot be substituted. Also, relative scarcity drives prices, e.g., at the London Metal Exchange (LME), which increases the price risk and the capital cost for storing extensive safety stocks in conventional warehouses.

Because of their natural geographic distribution it is necessary to source certain raw materials from remote places. Longer transportation distances and larger transportation batch sizes involve more possibilities for irregularities and delays, e.g., due to weather conditions and political conditions. Additionally, communication with suppliers, audits and on-site visits become more difficult, more time consuming and more expensive.

For economic reasons management of the case company is reluctant to approve higher travel budgets that would be required to qualify more second or third source suppliers and to conduct supplier audits. This has obvious implications for the amount and the quality of information the case company has about its suppliers, for improved bottleneck prevention and for improved bottleneck elimination.

6.2.9.13. Summary of Activities (Graphical)

Figure 6.2.8 presents a graphical summary of the case company's bottleneck management activities.

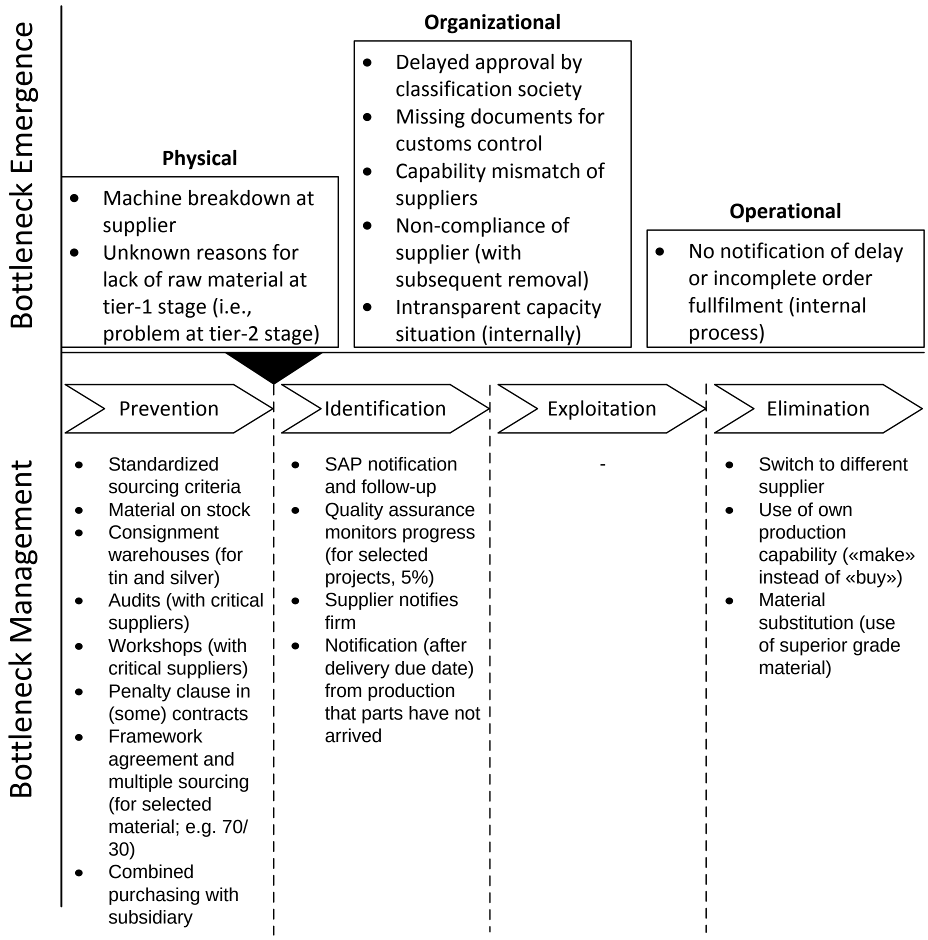

Figure 6.2.8. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 8

6.2.10. Case Study 9

6.2.10.1. Short Description of the Firm

The case company is an international medium-sized trader of non-ferrous metals. Important products of the company are zinc, copper, tin, lead, aluminium, nickel, and several "minor metals" for special applications. Customers come from diverse industries and are of different size, reaching from small firms to large corporations.

6.2.10.2. About the Data Collection

The interview was conducted in the company's headquarters. Thee members of the company participated in the interview, representing different functional areas. Due to the professional background of the interviewees special attention was given to tin and zinc throughout the interview.

The contact to this company had been established by the purchasing and logistics manager of another case company.

6.2.10.3. Market Situation

There are competitors which trade the same raw materials as the case company. The market for zinc is characterized by a small number of producers and very large traders among several smaller ones. The market for tin is more diversified with about seven competing traders. By and large, the metal trading industry is described as stable and mature and competing firms are generally known.

The customer structure for zinc is diversified in size with amounts requested between 500kg and up to several truck loads. Customers of tin tend to be SMEs which accordingly request small amounts.

One interviewee reports that the market for tin has long been dominated by buyers, which has changed in recent years. There is no tendency that powerful raw material producers exploit the market situation and dominate the case company, which has been attributed by one interviewee to the long-term partnerships the company maintains with its suppliers.

6.2.10.4. Supply Situation – General Information

The company receives its metals directly from producers in different parts of the world. No exact number of sources was mentioned, but the interviewees made clear that the availability of several suppliers with whom the company generally maintains long-term relationships is one of the cornerstones of the supply strategy. The number of possible supply sources is limited due to natural distribution of the various raw materials.

6.2.10.5. Production Process

The company does not perform any processing of the material. Raw material is received from producers and directly delivered to customers or stored in the company's own (conventional) warehouse until delivered to customers. Primary transportation mode to customers in continental Europe is delivery by truck. Raw material from overseas is delivered as sea freight.

6.2.10.6. Bottleneck Emergence

Early in the interview it was emphasized that material shortages due to bottlenecks in supply – while naturally and generally representing an immanent risk of the trading business – are no major impediment to the company's business. The interviewees made clear that the company always delivers as promised and that bottlenecks in supply have not delayed order fulfillment in the past.

Nevertheless, bottlenecks do emerge and they do require action on part of the case company. Reasons tend to be more "global" and less specific to particular relationships with suppliers. One interviewee states that supply shortages were "induced by the market, so that everybody was affected and not just us."[2] One example is the decision of the Indonesian government to pull out Indonesian tin export of the London Metal Exchange and to exclusively use their domestic exchange, which created large uncertainties in the market. That is, problems were politically induced (policies) and not due to physical problems

[2]Quote translated by the author.

in material flow. Also, strikes in South America were mentioned as another political/societal event that possibly impacts on stability of supply processes.

Climate conditions and weather in the suppliers' regions were also mentioned as factors. Delays sometimes occur during the monsoon season when ore mining activities are interrupted.

Recently delays occurred due to unavailability of cargo containers. According to one interviewee, large demand from China has led to a shortage of empty containers in Europe. The situation also exists the other way around so that occasionally too few containers are available in Asia which delays shipments from there to Europe.

6.2.10.7. Bottleneck Management: Prevention

Generally, because the reasons for bottlenecks are largely political, societal, or due to climate and weather, the case company has little influence on the emergence of such situations.

The actions the case company takes, however, aim to reduce the impact the emergence of bottlenecks has on the company's business. Prevention seems to be the dominant strategy the company chooses to deal with market irregularities as options for exploitation and elimination of bottlenecks are limited (see below).

As a trader, the case company uses multiple sources from different geographic regions for its raw material. Thereby the risk for delays in or interruption of supply is reduced as political and climate conditions vary across the different sourcing regions. Such geographic spread cannot hedge the risk of complete failure of supply from certain regions, however. For tin, for example, the dependence on one sourcing country – Indonesia – is too big so that all other sources would not be able to compensate lack of supply from that country.

Long-term relationships are fostered by the case company and one interviewee repeatedly emphasized the importance of long-term partnership: "It is our philosophy to work with the same people for a very long period of time."[3] According to this interviewee the company remains in touch with business partners

[3]Quote translated by the author.

even in times when there are currently no ongoing transactions. Maintaining a good network is seen as a measure against adverse impact of bottlenecks. In case primary suppliers fail to deliver as scheduled, the case company is thus able to tap other sources of supply.

Holding of inventory is another primary measure to deal with irregularities and delays in supply. According to one interviewee, the levels of inventory the company keeps have always been sufficient to bridge gaps on the supply side.

Generally, materials need to be certified in order to be tradable on the London Metal Exchange. That is, a certain level of quality and reliability can be expected from suppliers.

New suppliers are carefully selected. For the approval of new suppliers, small amounts of material are ordered and analyzed with respect to the material's quality and chemical properties. The supply and dispatch processes are monitored and early deliveries of raw material are only shipped to customers which can perform chemical tests to find out if the material suits their requirements. Since this process for supplier qualification takes time and is followed before potential bottlenecks emerge, it must be seen as a preventive measure rather than a measure for bottleneck elimination when a bottleneck has actually emerged.

6.2.10.8. Bottleneck Management: Identification

Continuous communication with suppliers – also in times when there are no apparent problems – was mentioned as the primary measure to learn about possible changes in the supply situation. The network is fostered on conferences, trade fairs, and via personal relationships. The goal is to learn about possible changes before they are reported in public media such as Bloomberg or Reuters.[4]

Because the reasons for possible shortages vary and generally can be accounted to factors external to the company's supply network, such as new policies by supply countries' leadership, strikes, or natural disasters, the notification period also varies. There were, for instance, indications that Indonesia would

[4] This implies that threats to stable supply with raw material are of 'global' nature (political, societal, natural causes) and are not specific to the case company's supply network. This presumption underlies most of the interviewees' statements.

change its trade policies for tin, so that possible options to circumvent supply shortages could be explored early on, as one interviewee reports. Other events such as Tsunamis or other extreme weather conditions do occur without significant lead time that would allow preparation, however.

6.2.10.9. Bottleneck Management: Exploitation

The specific characteristics of the supply network (global networks with large amounts of raw material received from overseas), of the business model (trade of raw material without further modification or transformation of the material except in terms of location and time), and of the reasons for supply shortages (global reasons such as supply countries' changed trade policies or extreme weather conditions) do not provide many options for the exploitation of bottlenecks. Faster transportation mode, for instance, is not an option due to the weight and the amount of material received, and there is no "waste" of material that could be reduced (as exists, for instance, in production environments with significant scrap rate and possibility to refurbish material).

6.2.10.10. Bottleneck Management: Elimination

Since multiple sources are used to receive raw material, switching to another source of supply certainly is the primary measure to eliminate a bottleneck in one source of supply. There is no intervention at suppliers' sites. As with bottleneck exploitation, the company's specific situation seems to make options other (production) firms pursue largely unfeasible.

6.2.10.11. Bottleneck Management: Placement

The concept of bottleneck placement could not be applied to the business context of the case company.

6.2.10.12. Bottleneck Management Limitations

Limitations arise from the nature of the causes of bottlenecks in the case company's supply network. The reasons why bottlenecks emerge seem mostly unrelated to operational causes within supplier companies. Instead, bottlenecks occur mostly due to extreme weather conditions (e.g., hurricanes or seasonal phenomena such as monsoon), strikes, and policy changes in supplier companies' home countries; i.e., most reasons can be classified as Force Majeure. While it is possible to plan so that the impact of such events is reduced, the underlying causes remain unchanged as they tend to lie beyond an individual firm's reach. The case company has adapted its strategy and focuses on the avoidance of supply shortages and the minimization of their impact.

Three measures stand out:

1. Keeping levels of inventory that allow to keep up the service level in spite of supply irregularities
2. Multiple sourcing
3. Continuous exchange of supply related information between the case companies and its suppliers as well as with other industry representatives (such as DERA[5]).

Each of the measures is subject to limitations. High levels of inventory tie up capital and it generally remains unclear how much inventory must be held on stock as the causes for irregularities in raw material supply may endure for long time periods or not. Therefore an "optimization" of inventory levels is difficult.

Because the reasons for supply shortages tend to affect all customers from suppliers from a certain region at once (as explained before), there tends to be a "run" on alternative sources in case supply bottlenecks emerge in one region. That is, alternative sources of supply may possibly be overwhelmed by suddenly increased demand from various customers.

In case of natural resources such as the non-ferrous metals traded by the case company, the natural distribution of the resources creates dependencies on certain regions and countries. In case of tin, for instance, the most important supplier country for European demand is Indonesia. According to one interviewee,

[5]Deutsche Rohstoffagentur – German Raw Material Agency, part of the Federal Institute for Geosciences and Natural Resources

the dependence on Indonesia is such that supply from all other countries would not be able to compensate for a lack of supply from that country.

Weight, amounts, and geographic distribution of the material traded require that the material is shipped on cargo vessels from overseas. This rules out the option of faster modes of transportation in case inventory levels turn out to be insufficient to bridge a gap in supply or simply unexpectedly high demand.

Because events that interrupt supply may occur instantaneously as, for instance, in the case of natural disasters, even perfect exchange of supply related information will not provide a guarantee that measures can be taken in order to minimize adverse business effects. Although this limitation generally holds in all cases examined in this project, the prominence of weather and climate conditions on supply reliability for this case company is particularly high, which is why this limitation is emphasized in this analysis.

6.2.10.13. Summary of Activities (Graphical)

Figure 6.2.9 presents a graphical summary of the case company's bottleneck management activities.

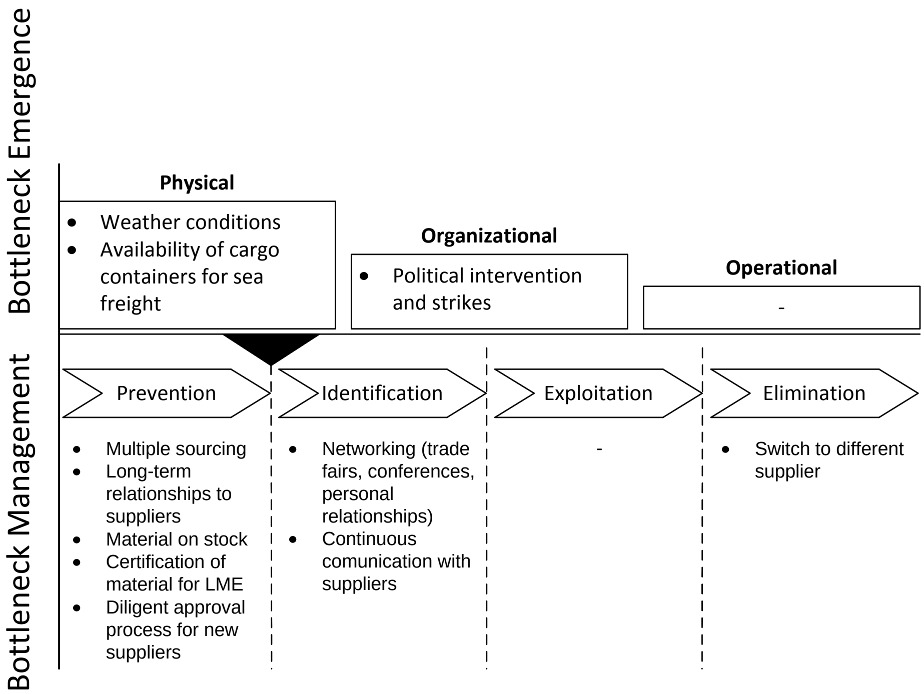

Figure 6.2.9. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 9

6.2.11. Case Study 10

6.2.11.1. Short Description

The case company is an international trading firm for commodities, among them coal and various non-ferrous metals. The company is headquartered in Europe. Customers come from diverse industries and are of different size, reaching from SMEs to large corporations.

6.2.11.2. About the Data Collection

The interview was conducted on the phone as a physical meeting for the interview was not possible for organizational reasons. Interview notes were taken manually and sent to the interviewee for sign-off on the day following the interview. The interviewee's responsibility in the case company is global trade with lead and zinc. Contact to the case company was established during a meeting at one of the case company's customer's production sites. A short introduction to the research project was given during that meeting; more detailed explanation of the bottleneck management concept preceded the interview on the phone. The interview was focused on the market for lead and zinc.

6.2.11.3. Market Situation

The case company is a big player in the commodity market. Business processes in this market have remained mostly stable over time, albeit with increasing dynamics. Commodity trade was strongly affected by the crisis following the credit crunch in 2008. Depending on the commodity, the number of competitors reaches from zero to "many". Lead is offered in many different brands, many of which are also offered by competing trade firms. Global supply for zinc is currently short due to high demand from developing countries such as China, India, and countries in South East Asia.

6.2.11.4. Supply Situation – General Information

Ore is extracted in the mine and brought to a smelter. From there, it is shipped directly to customers without intermediate stay in warehouses. Throughput time for raw material consists of the following elements (by the example of lead): extraction and transportation from mine to port – about three months; transportation from port to smelter – about 40 days; smelting – about three days; delivery from there to customers depends on customers' and smelters' location.

The case company keeps only low inventories; about seven days of supply can be covered by lead that is kept in the case company's warehouses. Order throughput process requires some weeks of lead time as orders are not normally served from stock. When customers order very specific material which has to be produced to order, order lead time will be about two months before month of delivery.

According to the interviewee, supply shortages are a frequent topic which he has to deal with about two to three times per week. Problems of this kind can normally be solved, so that the company has a reputation for being a reliable source of supply for its customers.

6.2.11.5. Production Process

Although the company does have some own production capacity, the production process of lead and zinc preceding the sale is not of interest in this context. Besides rare exceptions, material is delivered from the case company's sources right to customers' conventional warehouses without intermediate stop. Due to high cost incurred consignment warehouses are maintained only with a few very large customers.

6.2.11.6. Bottleneck Emergence

Delays and interruptions in supply do occur on a frequent basis. The interviewee states that he has to deal with this kind of problem about two to three times a week for lead and zinc.

Severe weather conditions are the most frequent cause of delays. 80% of all raw material (not only zinc and lead) is shipped from overseas, 20% comes by truck on the road way. Weather conditions may prevent cargo ships from putting out to sea or from mooring; high waves may make loading and discharging cargo temporarily impossible.

Other, less frequently occurring reasons are diverse: International trade involves customs authorities and delays sometimes occur because of customs procedures. Suppliers' machines occasionally break down. Sometimes shipping companies do not have enough empty containers available for cargo in the respective part of the world.

There are suppliers which are generally reliable and some which tend to let the case company down. As an example for the latter the interviewee refers to a smaller African supplier (whose largest customer is, in fact, the case company). Large suppliers tend to be in the first group and are generally reliable, delays due to Force Majeure notwithstanding.

6.2.11.7. Bottleneck Management: Prevention

The most important measure to prevent the existence of bottlenecks that impact on availability of supply is the use of multiple sources. In Europe alone the case company uses more than seven sources for lead and four sources for zinc; several more sources are available in Africa and Asia. The high number of sources allows the case company to keep inventory to a minimum while maintaining a very high service level for customers.

The interviewee states that more reliable demand forecasts from customers would be helpful. While some customers' forecasts are quite good, the case company is aware that others' are not helpful at all. Because throughput time of raw material from the mine through to the customer is high (see example in section "Supply Situation – General Information"), forecasts are an important tool to make supply processes more efficient.

Probably contributing to the case company's ability to reliably secure supply and maintain a high service level with customers is the long-term character of the relationships the company maintains with its suppliers. For zinc and lead, the interviewee states that there have been no changes for six years until some additional suppliers were included in the portfolio just recently.

Furthermore some suppliers belong to the same corporate group as the case company which may play a role for reliability of supply and communication.

6.2.11.8. Bottleneck Management: Identification

Suppliers are expected to notify the case company as soon as bottlenecks emerge. Although the interviewee remarks that he cannot really know for how long the suppliers has known about the problem before notification, he thinks that this process is generally reliable. New suppliers are trained to adapt to this procedure very quickly.

6.2.11.9. Bottleneck Management: Exploitation

No specific measures of bottleneck exploitation were mentioned during the interview. The interviewee does suggest, however, that both the company's reputation as a reliable long-term partner and the company's market power as a sizeable customer contribute to the stability of supply processes.

As an example for an activity that contributed to the stability in the company's supply relationships the interviewee mentions that during the global financial crisis beginning in 2008 the case company supported suppliers by purchasing raw material that was not covered by customer orders and put it on stock, which according to the interviewee helped some suppliers survive the crisis.

6.2.11.10. Bottleneck Management: Elimination

The most prevalent measure to eliminate a bottleneck in supply is to switch to another supplier of which the company maintains several for much of its product portfolio. According to the interviewee, switching to another supplier is a matter of one minute (one phone call or one email).

6.2.11.11. Bottleneck Placement

The concept of bottleneck placement could not be applied to this case study.

6.2.11.12. Bottleneck Management Limitations

As a large and powerful customer, the case company faces only few constraint in the management of its suppliers and its bottlenecks.

As with all companies that are dependent on sea freight over large distances, there is little the case company can do about weather conditions which impact on the schedule of cargo vessels. Generally, causes for bottleneck emergence that lie outside organizational boundaries and reach pose limitations, such as machine break down or fire outbreak in supplier facilities. Likewise, unreliable forecasts from customers pose a limitation to the company's ability to do better supply planning.

6.2.11.13. Summary of Activities (Graphical)

Figure 6.2.10 on the facing page presents a graphical summary of the case company's bottleneck management activities.

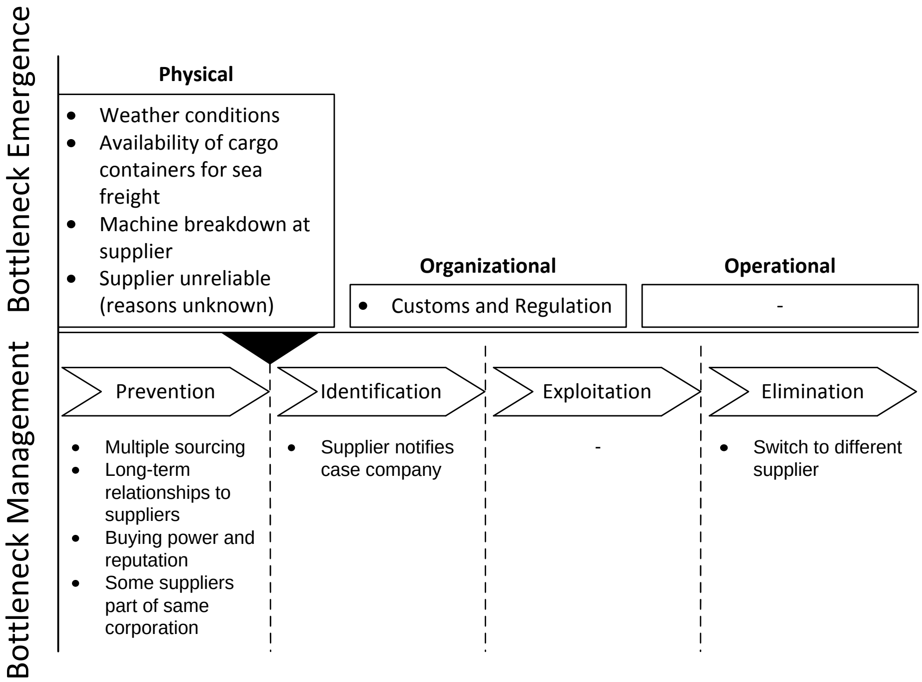

Figure 6.2.10. – Bottleneck Emergence and Bottleneck Management Activities at Case Company 10

6.2.12. Summary

This section introduced the reader to the individual case companies and presented the information gathered in the multiple-case study individually for each case. More precisely, the information presented was extracted from the data collected at the case companies. For each case company, the information was structured along elements of the conceptual model created in Section 4.6 as these had been incorporated into the interview questionnaire (for an explanation of the structure of the interview questionnaire see Section 5.5.1).

This first part of the data analysis presented the information as they were created from the data received from the case companies. It represents the explorative and descriptive character of the empirical study.

6.3. Analysis of Interview Data Phase II: Cross-case Analysis

6.3.1. Introduction

The second part of the data analysis draws together the individual causes of bottleneck emergence, the case companies' measures of bottleneck management, and the limitations they face when managing bottlenecks. These elements were described individually for each case company in the first part of the data analysis. The second part can be understood as a cross-case summary and as a different way of presentation of the findings. Hence, this section does not include interpretation; it is descriptive and provides an account of the exploratory findings of the case studies.

6.3.2. Bottleneck Emergence

In this section, the various causes for bottleneck emergence are summarized that have been identified in the case study interviews. As it is visible from the illustrations 6.2.1 through 6.2.10, the causes for bottleneck emergence have been divided into three groups:

1. physical causes,
2. organizational causes, and
3. operational causes.

The reason for this division is that the causes are so diverse that a more detailed description appears to be helpful in order to better be able to understand and solve the problem and prevent it from happening in the future. Deficient quality of the goods delivered by the supplier, for instance, require an approach that is different from coping with interruptions due to national holidays schedule in a supplier's country. The nature of the causes is so different that it is believed these causes deserve separate labels. The three categories will be explained below.

Physical causes for bottleneck emergence describe those occurrences which cause a bottleneck because physical goods or production capacity are not available in amounts sufficient to keep up production (or trade) of the case company at desired levels. Often, there is no conscious decision involved that cause the bottleneck. When a supply vessel sinks, production equipment catches fire, or a supplier ceases production because it files for bankruptcy and does not have the means to continue, then there is reason to believe that the supplier did not make a conscious decision that directly leads to this situation. When we follow up root causes by asking "Why?" we may be able to trace the supplier's bankruptcy to wrong management decisions in the past just as we may be able to attribute the fire on production equipment to incomplete fire safety instructions for workers or skipped maintenance. Likewise, the supply vessel might not have sunk had the supplier contracted a more expensive freight company that takes better care of its vessels' safety, or if the case company had sourced the supply locally instead of to a remote part of the world so that no sea freight was involved. So there have been decisions along the chain of causes and effects that have led to the very consequence that the case company's production is starving as supply does not arrive. Yet, no one has directly and consciously decided to invoke production workers to set their facility on fire and no one usually decides to make an operational supply vessel sink for any good reason. These are *unwanted* physical consequences of past decisions.

Organizational causes are those where the reason why the case company suffers from delays or interruptions in supply can be directly attributed to a *conscious* and *deliberate decision* by someone in the supply network. Other than a supplier firm's bankruptcy which is caused by a long chain of causes and effects, the supplier *decides* not to deliver the goods to the case company. A good illustrative example is a supplier's decision in the face of limited capacity to supply *another* company first and let the case company starve. The supplier would have sufficient capacity to perfectly fulfill the case company's order, but it decides not to. Even clearer might be the case where the market for a specific good experiences increasing prices and the supplier decides not to fulfill the order now and to wait instead until prices have increased even more and then to sell the material to another customer with a more recent order who is willing to pay the price. Also, deliberate decisions underlie strikes (the very purpose of which is to increase pressure in negotiations by causing operations to halt) and political inventions of governments, as in the case of the Indonesian government's decision to force all trade of Indonesian produced tin to the domestic exchange.

Operational causes exist where no conscious and deliberate decision is involved but man made action causes the problem nevertheless. Dispatchers who forgot to call off material from suppliers and suppliers that produce and deliver material which later will fail the case company's quality tests fall into this category. Likewise, high scrap rates that reduce effective production output are considered operational problems. Also, cultural differences between suppliers in remote countries and the case company can be considered an operational problem as there is no law that dictates that such problems have to exist and no one deliberately decides to have communication problems with a supplier from another country. Very short lead times till order fulfillment requested by customers are considered operational problems when orders are accepted by the case company under such terms and cannot be met. In such a case, the respective company's judgment as to the feasibility of the order turns out to be weak, which is human error and hence operational.

In some cases, the categorization of a cause is not quite unambiguous. That is, a cause could be seen either as organizational or as operational. Customs and regulation, for instance, can be expected and missing documents that cause delay at border control certainly can be seen as an operational fault by the parties involved in the supply chain. Customs can, however, take time and cause delays even when shipping documents are complete, as in case routine cargo inspection is scheduled while customs officials are still busy with other jobs. For the sake of simplicity, such causes are summarized in one category.

6.3.2.1. Physical Causes for Bottleneck Emergence

Long Lead Time (and Insufficient Forecast Data) Long tooling, production, and transportation lead time have led to problems for several case companies.

Due to long tooling time in glass production, glass producers run "campaigns", i.e., large production batches for one type of glass which they produce for several weeks before they switch over to the next type of glass. The tooling time required when switching between different types of glass is more than a week, according to one case company. At the same time, quality of glass on stock vanishes over time, which requires producers to limit batch size to amounts they are likely to sell within few months according to sales forecasts. The implication for customers such as glass manufacturers (i.e., companies that receive raw glass from glass producers and apply different types of operations to the glass such as hardening, cutting, printing, and coating) is that they may not be able to receive a specific type of glass from a certain dealer or manufacturer once production output of one glass campaign is sold out since the significant tooling time requires manufacturers to produce to forecast as opposed to actual customer demand.

The interviewee of another case company reports that occasionally supply of tires is delayed due to long tooling time of large tires for agricultural machinery. Although this causes additional effort and thus cost late delivery of tires does not normally lead to delays or interruptions in internal production processes of the case company as tractors can be equipped with provisional tires and production continued until delivery of the right type of tires.

Due to geographic distance supply from overseas, transportation often takes several weeks and makes deliberate planning of inventory and reordering crucial. Reliable forecast data is an important asset when a time gap of several weeks between actual demand and supply of raw material needs to be bridged. The interviewee of one case company points out that the insufficient availability of reliable forecast data in combination with long lead time for supply from China regularly induces difficulties. Whereas supply of a specific component from China takes 60 days from the day they order the material until available to production they do not possess a good base of forecast data. There are two reasons as to why forecast data is not available as required: customer orders for the case company's products tend to be short-term and sales are often generated through small local independent craftsman who tend not to maintain an elaborate data base for forecasts.

Some other components the same case company receives from Southern Europe with equally long lead time. In this case, transportation lead time makes up only a small fraction of the total lead time whereas production lead time makes up the largest part. Here, too, the combination of long lead time and insufficient forecast data creates a difficult situation for procurement and production planning.

Technical Problems, Machine Breakdowns, and Fire Outbreak Frequently, technical problems and machine breakdowns in supplier facilities have been named by case companies as reasons for delays and interruptions in supply, sometimes leading to huge order backlogs. One case company states that machine breakdown is the most common reason given by suppliers as to why delivery is delayed. Raw material trading firms which receive material from smelters have mentioned fire outbreak at furnaces. One interviewee mentioned that his company does not normally receive details about the exact nature of the technical problems that lead to the delay.

Short-term Changes in Demand Three interviewees mentioned short-term changes in customer demand as one reason why delays occur. When orders increase on short notice raw material sometimes is not readily available. The problem is intensified when there are long lead times for material supply.

Supplier Bankruptcy Two case companies were affected by suppliers who declared bankruptcy and were thus unable to deliver as promised. One interviewee mentioned that they encountered suppliers' bankruptcy both in cases of strong dependency (supplier was sole source and a new supplier had to be found and prepared) and low dependency (supplier was one of multiple sources). For the other case company, supplier bankruptcy "caused turbulence" but not line stoppages.

Weather Conditions Weather conditions were cited as the primary reason for delays by one trade company. The reason is that 80% of all deliveries come by cargo ship and often from regions that are prone to severe weather conditions. High waves can delay loading and discharging cargo, as well as putting out to sea and mooring.

Another trade company mentions that onshore operations, for instance in mines, are often interrupted during monsoon season. While weather conditions may play a role in domestic supply networks, they were exclusively mentioned related to overseas delivery and operations in remote sourcing countries which experience more extreme weather, such as monsoon seasons.

Availability of Containers for Cargo Transport Two case companies reported that delays in supply are occasionally caused because of a shortage of cargo containers in their suppliers' respective part of the world. The interviewee of one of these two case companies mentioned that distribution of cargo containers repeatedly is out of balance so that there is a lack of containers in one part of the world whereas there is an abundance of containers in another part.

Ship Sinks One case company reports that a ship with supply from China sank on its way so that production delay was caused. Another case company has suffered from a ship going down with more than ten tons of finished products on the way to the customer in Asia. In this case, the bottleneck shifted to the internal production of the case company as they had to catch up with production while also serving other customers.

Recycling Loop Interrupted In Europe, the most important raw material for production of certain metals is scrap metal. Availability of scrap metal, however, is not always provided. One case company states that unavailability of scrap metal is among the dominant reasons as to why supply of pure metal is delayed.

Reasons Unknown – Problem in Higher Echelon One interviewee explains that his company's tier-1 suppliers often claim that they do not have the pre-material available to fulfill the case company's orders. Since the case company does not engage in management of tier-2 suppliers and there is no transparency along the supply chain, the interviewee says that his company does not have more detailed information as to the reasons why pre-material is missing on tier-1 stage.

Reasons Unknown One case company reports that there are some – albeit very few – suppliers that tend to let the case company down. The interviewee mentions a smaller supplier for which the case company is the largest customer. More detailed information about this case could not be obtained.

6.3.2.2. Organizational Causes for Bottleneck Emergence

Suppliers' Material Allocation Five case companies reported that that they have not received material, have received material of lower quality, or have received only insufficient amounts of material because their suppliers preferred to supply other customers first. One company stated that one of their suppliers openly admitted to prioritize another customer higher. Another company received delayed shipments and material of lower quality after their supplier acquired several new customers, and the interviewee assumed there is a connection. In two cases, the interviewees attributed such decisions to their respective company's small size relative to other customers of that supplier. Additionally, the interviewee of one case company stated in case of material shortages some of their suppliers prefer to fulfill orders of domestic rather than international customers. Overall, suppliers' material allocation decisions are the single most often mentioned reason as to why a case company has experienced irregularities in supply.

Business Conduct of Supplier Related to suppliers' material allocation decision is their general business conduct. Questionable conduct in some cases directly lead to allocation decision to the detriment of the case companies.

One case company's interviewee establishes a connection between the supplier's winning a new customer and deteriorating quality and reliability of supply, probably involving a change of tier-2 sources without prior communication. In this particular case, there had been a successful supply relationship for several years before the supplier became unreliable and demonstrated questionable attitude.

An interviewee from another case company reports that there seems to be a pattern among Chinese suppliers that in times of increasing raw material prices deliveries are first held back and then sold to other customers who are willing to pay the new, higher market prices. Such behavior is clearly incompatible with commonly accepted European business conduct. Similar behavior is reported by another case company with suppliers from Poland and Russia which, according the interviewee, held back deliveries in times of rising market prices and preferably sold to domestic customers in case they had to make allocation decisions.

In another case the interviewee relates to a single source supplier which after a while became unreliable both in terms of delivery schedule as well as in terms of quality of its products. In addition, the supplier firm began to market some of the products it produced for the case company after the case company's blue print independently, so that legal action had to be taken by the case company. As the supplier was the single source for an important component, removing the supplier involved some delay.

Customs and Legislation Three case companies named reasons related to customs and legislation as causes for delays in supply. One case company reported that they ran into problems when for the first time importing material from China while some documents required by customs were missing, which led to delay of the delivery and eventually to delayed production and order fulfillment. The interviewee from another case company mentioned that cargo ships are occasionally held back by customs so that deliveries are delayed.

One case company cited REACH regulation as one reason why the supply base for some materials shrunk which makes the material more difficult to purchase. According to the interviewee, smaller companies fear the cost related to registration for REACH so that fewer companies than before import such materials that are covered by the REACH regulation. Limited availability, in turn, comes with the chance of delays.

Political Intervention and Strikes Strikes in mines have been mentioned by two trading companies as one reason why supply is delayed. South America was mentioned by one case company as a region where strikes regularly cause delays. Australia was mentioned by another case company. The trend towards the use of scrap metal as raw material for smelting processes is likely to mitigate the effects of strikes at mines as primary raw material producers for smelters.

Planned Breaks The interviewee of one case company explained that smelters in Southern Europe take a scheduled summer break each year. Before the break, they generally try to sell the material they have on stock so they do not have to carry inventory cost throughout the break. When demand turns out to be particularly high after the break, problems may occur as the producers are not able to keep up with the pace while orders cannot be fulfilled from stock.

Customers' Ordering Behaviour Several case companies cite customer order behavior as one of the most important reasons as to why deliveries do not arrive on time. Late orders or orders with short requested lead time pose a challenge to production companies and some traders alike. Sometimes the requested amounts are changed at short notice. One company cites cumulated orders at the end of the summer break as one reason as to why some materials can have limited availability and thus might be delayed.

Approval by Classification Body Some products, e.g., containers for transportation of radioactive substances, require approval by classification bodies (such as DNV-GL) who are authorized to test the containers for safety and other product properties before they are allowed to be delivered to customers. Such approval needs to be scheduled since classification bodies like any other organization have limited resources which they have to allocate to their various projects. When a producing company falls behind schedule with finishing their production order so that a scheduled appointment with a classification body cannot be met, it may happen that no free resources are available at the classification body so that approval of the products leads to additional delay until the product can be delivered to the customer – on top of the delay already incurred by internal production processes.

Internal Processes In some cases, the reason for delays in the supply network lies in internal processes of the case companies.

One interviewee reports that communication between production and procurement staff is insufficient so that missed delivery due dates of suppliers sometimes are not fed back to procurement and thus are not followed up, possibly increasing the time span until needed material arrives. In another case company, human error in procurement has led to deliveries arriving late.

Incomplete/Short/Unreliable/No Forecasts The products of one case company are partly marketed by small handicraft business. In many cases, such firms do not create elaborate forecasts which they could share with the case company. Hence, the case company cannot plan capacity and supply based on forecasts from its sales partners.

In another case, the case company's (business) customers claim not to have forecast data available for more than four weeks which they could share with the case company. Customers from China provide an even shorter forecast horizon of only two weeks.

Another interviewee explains that his company would benefit from better forecasts from customers. While some customers provide useful forecasts, other customers' forecasts are essentially useless and cannot be used for planning purposes.

Conflict of Interest with Set Supplier One case company explains that a customer has contracted a tier-2 supplier, i.e., a tier-1 supplier to the case company. Because that supplier has a supply contract with the case company's customer and not with the case company itself, the options the case company can pursue to urge the supplier to improve its service level are limited. At the time of the interview, this set supplier frequently caused problems because of insufficient production capacity. The reason was that the supplier used much of its capacity for another project of the same customer. Apparently, communication and contract constellation caused problems that could not easily be resolved in this triangle supply relationship.

Short-term Technical Changes The interviewee of one case company names technical changes that have to be considered at short notice as one reason why supply irregularities occur. In such cases, existing inventory might be rendered unusable or might require rework, so that all components required have to be produced by the supplier and inventory cannot buffer demand peaks.

Mismatch of Supply and Demand In one raw material trading firm, the interviewee explains that because of the multitude of different brands that are available for some metals such as tin, there is a chance that the wrong brands are kept on stock and that new customers may order brands that are not readily available and have to be shipped from producers overseas first. That is, while it normally takes only a few days to serve customers, order fulfillment in such a case will take several weeks.

6.3.2.3. Operational Causes for Bottleneck Emergence

Operational Deficiencies in Overseas Transportation One case company mentions that during overseas transportation with intermediate handling of cargo it happens that containers are sometimes left behind in a port so that arrival of material is delayed. Also, loading of containers on cargo ships in the source harbor occasionally is delayed. When this happens, transportation lead time can easily double from four weeks to eight weeks.

Cultural Differences Cultural differences were mentioned by three interviewees as causes that directly or indirectly can lead to irregularities in supply.

A case of questionable business conduct mentioned by one interviewee was referred to as a "Chinese peculiarity". Two case companies point out that suppliers from Eastern Europe have caused problem in the past; one interviewee expresses her dissatisfaction that communication with these suppliers tends to be dishonest and unreliable.

Quality Problems Quality problems were cited several times by case companies as having caused production delay. Two distinct situations were reported:

1. quality problems of supplied material could be detected by the case company before internal production processes began

2. quality problems became apparent only after internal production processes began or were finished

In the second situation not only the material was wasted but also the production capacity of an entire production line.

In one case, a supplier was removed from the portfolio after having failed quality audits.

Short Requested Lead Time In two interviews, short requested lead time by customers was mentioned as possible cause of bottleneck emergence. This cause is considered operational for it is up to the case company to reject orders with lead time that would make successful order fulfillment on schedule unlikely.

In another interview, the interviewee made clear that orders sometimes come up rather unexpectedly which then can lead to delays. The problems are intensified when lead times for supply are long, which sometimes is the case at this company with some suppliers.

High Scrap / Low Yield Quality problems of material intended for supply but detected by the supplier during his own production processes lower the production yield. One case company has suffered from delayed delivery because the effective production yield of the supplier was too low. Occasionally, the supplier had to scrap entire production batches so that additional time had to be allowed for to run another production batch.

Transportation Batch Size One case company has faced the situation that suppliers held back deliveries until completed transportation batches were completed. The transportation batches were contractually agreed upon to reduce transportation cost. The interviewee reported that some suppliers repeatedly waited to complete transportation batches although supply was already delayed and even partial delivery of material would have helped the case company so they could have avoided delay in the production process.

Supplier Unable to Meet Product Specifications In one case, a single source supplier from China was chosen by the case company to produce and deliver a set of products. After all contracts were signed and the first delivery was awaited, it turned out that the supplier did not have the technical expertise to produce the product according to the case company's specifications. Hence, the company had to find a new supplier for the respective component, which caused delay in order fulfillment.

Late Completion/Forgot Completion/Human Error (at Supplier) One interviewee mentions that human error at the supplier's disposition has led to late orders.

Late Order/Forgot to Order/Human Error (Internally) The same interviewee who reports on human error in suppliers' disposition explains that human error at the case company, e.g., forgotten or late material call-off, has led to delays in supply.

No Problems Known One case company's interviewee explains that he is not aware of any supply problems that have occurred in recent years.

6.3.2.4. Some Remarks About the Causes of Bottleneck Emergence

As can be seen from the preceding discussion, causes for bottleneck emergence can be found in each of the three categories identified. A summary is provided in Table 6.3.1.

Not in every case the categorization of causes is unambiguous. Some causes could be categorized as either organizational or operational, such as one supplier's inability to deliver according to agreed upon product specifications. This can be seen as the buying firm's organizational shortcoming as they did not make sure the supplier will be able to deliver before making the supplier the sole source; and it can be seen as the supplier's operational fault for not being able to produce in accordance with specifications.

Such ambiguities notwithstanding, the categorization indicates an almost even distribution of causes for bottleneck emergence across the three categories. What is remarkable is that both organizational and operational causes are as numerous as physical causes. Looking at the list of physical causes, this seems to be the category with the least level of influence for the buying firm. While both operational and organizational causes in many cases can be prevented or otherwise resolved, physical causes seem to be mostly outside the focal firm's reach. Put differently, a focal firm seems to have plenty of possible levers for intervention so that many supply bottlenecks could be resolved more quickly or be prevented in the first place.

6.3.3. Bottleneck Management: Prevention

6.3.3.1. Preventive Measures of Bottleneck Management

In this section, the measures which were mentioned by the interviewees of the case companies will be summarized.

It became clear during the course of the interviews that some interviewees did not mention measures (which in some cases others did mention) because they were not aware that a specific measure would contribute to the prevention of bottlenecks. The geographic spread of sources, for instance, can simply be seen as a consequence of the natural geographic distribution of certain resources, such as tin or copper. At the same time, however, it helps hedge bottleneck risk when supply from one region becomes unavailable or delayed, for instance because of natural disasters or political occurrences. This is particularly important as many of the producing countries of raw material (such as different types of metal) are considered politically unstable and are, in fact, prone to extreme weather conditions due to the climate in their geographic location.

Another example are forecasts that case companies provide their suppliers with. While forecasts were explicitly discussed in some interviews, they remained unmentioned in other interviews although there is reason to assume that suppliers are provided with forecasts. If it became clear from the context that a specific measure was actually in place, albeit unmentioned in the interview, the measure was noted during the interview analysis.

Dual/Multiple Sourcing Nine out of ten case companies state that they are using dual or multiple sourcing in order to prevent the emergence of bottlenecks. The one company that hitherto had not made use of multiple sources is currently planning to do so. Hence, dual/multiple sourcing is by far the most important measure that could be identified in this study.

Two variations of multiple sourcing could be identified:

Table 6.3.1. – Summary: Physical, Organizational, and Operational Causes of Bottleneck Emergence

Physical	Organizational	Operational
Long lead time (and insufficient forecast data)	Suppliers' material allocation	Operational deficiencies in overseas transportation
Technical problems, machine breakdowns, fire	Business conduct of supplier	Cultural differences
Short-term changes in demand	Customs and legislation	Quality problems
Supplier bankruptcy	Political intervention and strikes	Short requested lead time
Weather conditions	Planned breaks	High scrap/low yield
Availability of containers for cargo transport	Customers' ordering behavior	Transportation batch size
Ship sinks	Approval by classification body	Supplier unable to meet product specifications
Recycling loop interrupted	Internal processes	Late completion/forgot completion/human error (at supplier)
Reasons unknown	Incomplete/short/unreliable forecasts	Late order/forgot to order/human error (internally)
	Conflict of interest with set supplier	
	Short-term technical changes	
	Mismatch of supply and demand	

1. permanent parallel use of multiple suppliers and
2. preparation of of alternative sources that remain passive unless needed.

Most case companies use several sources of supply in parallel. This does not mean that all sources are used to the same extent: as one interviewee explained, his company does have one preferred supply relationship yet does source a certain, smaller share to other suppliers at the same time.

Some of the case companies are, in fact, required by their customers to maintain at least two sources of supply for increased supply reliability. In one case (producer of soldering powder) each source even has to be approved by the customer three echelons downstream who is a producer of microchips.

By reference to its specific organizational culture and heritage, one case company has long insisted on using one source of supply for each component to foster reliable long-term partnerships with suppliers. The interviewee told, however, that this dependency on one supplier had occasionally been taking advantage of by suppliers in order to maintain high prices per part. In order to prevent such dependency in the future, the case company plans on qualifying additional suppliers for several components.

Four raw material trading companies were part of the study. Whereas these companies follow different strategies with respect to the amount of inventory they keep, for all of them multiple sourcing seems to be the most important measure to prevent bottlenecks. Considering the uncertainties involved in internal raw material trade, such as unstable political regimes in sourcing countries, long supply lead time, and sea freight that is prone to delays due to weather conditions, employing multiple sources of supply has proven to be a successful prevention measure, given the high service level all of these companies can maintain with their customers.

Geographic Spread of Sources Related to the use of multiple sources is the geographical spread of sources. It remained unclear if companies are using sources from different geographic reasons with the aim in mind to avoid dependency on one geographic region – or if they were simply using the sources available to them which happen to exist in different parts of the world. Either way, spreading sources geographically does represent a measure to reduce dependency on sources in certain parts of the world that occasionally are subject to extreme climate and political instabilities. This measure was not mentioned in the summary figures of the individual case studies. It was found that all companies source some parts globally and alternative or parallel sources happened to be located mostly in different countries.

High Incoming Goods Inventory One interviewee mentions explicitly that his company used to keep high inventory levels in order to buffer irregularities in supply.

Two of the four raw material trading firms seem to serve customers with goods from stock while one firm hardly keeps any inventory and one keeps only enough inventory to bridge irregularities in supply. That is, there are three distinct inventory strategies among four companies that operate (roughly) the same business model. Overall, the "classic" concept of keeping inventory in order to buffer irregularities in supply seems not to be widely popular.

Annual Framework Agreements Six case companies state that they sign annual framework agreements with their suppliers. Such agreements typically include an forecasted amount of parts to be ordered by the case company and to be delivered by the supplier during the contract period. Because forecasts are rarely precise and some flexibility is needed, such frameworks also often require suppliers to maintain a certain percentage of flexibility on top of the forecasted amount.[6] By using framework agreements, companies can increase chances that suppliers have the capacity required available.

Supplier Audits Four of the case companies state that they conduct supplier audits. None of the raw material trading firms do audits, however. As the interviewee of one trading firm put it: "We do not do audits, and we do not like to be audited." An interviewee from another trading firm explains that supplier

[6] Production capacity flexibility (PCF) is counted as a separate measure in this document.

audits are conducted by the Electronic Industry Citizenship Coalition (EICC), an non-governmental organization that operates on behalf of organizations in the electronic and related industries. These audits include (i.a.) human rights aspect but also logistical questions, according to the interviewee.

Based on an ABC classification (referring to purchasing volume and criticality) one case company conducts quality and logistics audits with all A companies directly upon closure of the supply contract whereas most B suppliers and only some C suppliers are audited later. According to the interviewee the aim is to audit all suppliers, which at the time of the interview was not possible because of manpower constraints.

One interviewee reports that he would like to audit more suppliers than he currently does before contracts are signed, yet management is reluctant to approve travel expenses.

Long-term Relationships Four case companies, three of which are raw material traders, explicitly mention that their long-term relationships with suppliers help prevent the emergence of bottlenecks in supply. The interviewee of one trading firm explains that his company helped several suppliers survive the global 2008 economic crisis by purchasing material for which they did not have customer orders and put it in stock. The same interviewee states that there have been no changes in the company's supplier portfolio for several years.

It should be mentioned, however, that two other case companies experienced problems with suppliers with which they were doing business for many years. One interviewee reports that a long-term supplier all of the sudden began to deliver material of lower quality and several times was behind schedule. The interviewee attributes these occurrences to the supplier having won some new customers which it prioritized higher. The supplier had to be removed from the portfolio eventually. An interviewee of another case company suggests that some long-term suppliers took advantage of the case company's dependency and charged prices per part that were perceived as too high by the case company.

Standardized Sourcing Criteria The use of standardized criteria for sourcing decisions was mentioned by four interviewees from different case companies. In one case, such criteria are used to decide on the number of sources required for a part (i.e., whether single sourcing is sufficient or multiple sourcing required). In another case, it is the requirement for supplier certification that is always part of the sourcing decision. Yet another case company employs a standard procedure to test the ordering process and the quality of material delivered. Furthermore, the fact that some of the products the company receives from its suppliers are traded on the London Metal Exchange require certification of the material beforehand so that a certain level of reliability and quality can be expected.

Penalty Clauses for Non-Compliance Interviewees of three companies state that at least some of their sourcing contracts include penalty clauses for suppliers' non-compliance with terms and conditions. One interviewee explains that only 10% of all sourcing contracts include penalty clauses. An interviewee of another case company would like to introduce penalty clauses as a standard in all supply contracts.

It is conceivable that other case companies which have not mentioned penalty clauses are using them nevertheless as penalty clauses might not be considered a measure of bottleneck prevention. The role of penalty clauses in bottleneck prevention is to act as a deterrent. It remains unclear whether they are effective as a deterrent and whether they are normally enforced at all. An earlier study of the automobile industry suggests otherwise as some OEMs claim not to enforce penalties (Beer 2011).

Buying Power and Reputation Some of the case companies are of considerable size and are major customers to their suppliers. That is, suppliers are naturally very keen on consistently successful business relationships and are likely to do what they can in order to prevent bottlenecks in the supply relationship with their customers.

Buying power and reputation are not a measure that firms can employ. They are, however, probably one factor – albeit one that cannot easily be measured. In some cases, firms can increase their buying power by consolidating their supplier portfolio and reducing the number of parallel sources. This comes at the risk of dependency and bottleneck emergence, however. Accordingly, most case companies in this study employ multiple sources for supply.

Consignment Warehouse Two of the case companies maintain a consignment warehouse for incoming goods with one or more suppliers. Case companies – here in the role of customers – benefit from consignment warehouses because (1) they do not have to carry capital cost for inventory and because (2) suppliers tend to have better information access with respect to inventory levels, so that reordering points can be determined such that supply shortages are less likely to occur. Two possible points of failure – late ordering by customers and human error in the customers' dispatching process – can thus be avoided.

Production Capacity Flexibility (PCF) Agreement Included in some companies' framework agreement with suppliers is a certain rate of production capacity flexibility (PCF). Forecasted demand normally serves as a proxy for the supplier to install production capacity. Since forecasts tend not to be accurate customers would like suppliers to maintain some additional production capacity so as to be able to fulfill orders in case demand turns out to be stronger than forecasted. Common rates for PCF are 10% to 20% on top of forecasted demand within a defined period of time.

Sourcing to Professional Traders Production firms can receive raw material such as lead, copper, or tin directly from smelters, or they can contract professional raw material trading firms. The latter normally employ several sources of supply so that high supply reliability can be expected. That is, production firms can decrease the likelihood of supply interruptions by sourcing to professional traders, albeit for a premium they will have be charged.

Choosing to source to professional traders may not even be a choice but a necessity. At least one case company in this study receives material from professional traders because the amounts purchased are not large enough to meet minimum order size of some raw material producers. That is, sourcing to professional traders, while certainly contributing to supply reliability, may have been chosen for other reasons.

Forecast Provided to Suppliers Interviewees of two case companies mention that their companies provide suppliers with demand forecasts.

The data here are not quite consistent, however. It can be presumed that forecasts are part of all framework agreements which include production capacity flexibility rates. Also, more likely than not do companies which provide suppliers with forecasts have some type of long-term or annual framework agreement as forecasts are unlikely to be provided to suppliers which do not receive more than one order or only very few orders.

Supplier Development Programs Two case companies employ measures that might be best described as supplier development programs. One case company labels suppliers which caused problems that required intervention by supplier managers “focus suppliers”. Focus suppliers are monitored closely by supplier managers until all open issues are resolved. Similar measures are employed by another case company. Here, quality assurance monitors suppliers as to their progress on critical orders until delivery.

Close Relationship with LSP Two case companies emphasize their relationship with LSPs. In one company, all freight contracts for supply are closed between the LSP and the case company, as opposed to the supplier. The interviewee states that this constellation allows faster communication and solutions in case of delays. At the same time, the case company can use the weight of its combined purchases to be an important customer for the LSPs. The other company, a raw material trader, puts emphasis on good relationships with LSPs for the outbound stream (the inbound stream is dominated by sea freight) so as to reduce the chance of delay that due communication errors and misaligned schedules.

Information about Supplier Capacity One interviewee tells that his company (raw material trading) has information about their suppliers' total capacity as well as about their total production output. This information represents an indicator for the shortness of the material on the market so that the company is warned early should the two converge. Another case company combines has integrated the purchasing for a fully owned subsidiary. Although the interviewee did not elaborate on the reasons as to why the purchasing functions of the two companies are combined, it can be presumed that leveraging economies of scale or increasing bargaining power have been factors contributing to the decision.

Preference for Suppliers with Short Lead Time One interviewee explains that one important criterion for supplier selection is short supply lead time. In this case, the company finds it difficult to obtain good forecast data. Accordingly, the more important it is to be able to rely on fast and flexible suppliers, which is why lead time has become a primary decision criterion.

Suppliers Maintain Safety Stock One case company expects its suppliers to maintain safety stock in their facilities. The effect is similar that of consignment warehouses: the supplier bears capital cost and has full access on and responsibility for inventory. The difference is that consignment stocks tend to be located closely to the customer's production site while the safety stock at the suppliers' facilities remains untouched during most of the time and is activated only in case of contingencies.

Combined Purchasing for Higher Buying/Negotiation Power One case company has combined the purchasing function with a sister company of the same corporation. The expectation attached to combining the purchasing functions is higher negotiation power relative to suppliers, which sometimes are larger or have larger customers with whom the case company competes for capacity.

Suppliers Belong to Same Corporation In one case, several suppliers belong to the same industrial conglomerate as the case company. Although no evidence is available as to the difference this makes for reliability of supply, it seems reasonable to presume that companies belonging to the same group will not show behavior as, for instance, the questionable business conduct described in the previous section on causes of bottleneck emergence.

Blending of Raw Material One producer of metal blends the material the company receives from different suppliers. Thereby the company can achieve a steady and consistent quality of the input material to the production process which otherwise would need adaption to the specific properties of the raw material if these were changing. At the same time, blending of the raw material reduces dependency on one or very few sources since differences in quality of material from other sources can be balanced in the blending process.

The blending of raw material can be considered both a preventive measure and an exploitation measure and is therefore mentioned in both sections.

Scenario Planning One case company conducts scenario planning, thereby creating awareness of and solution strategies for possible causes of supply shortages around the world.

6.3.4. Bottleneck Management: Identification

6.3.4.1. Measures of Bottleneck Identification

In this section, the measures of bottleneck identification that were mentioned during the interviews are shortly summarized.

As with the previous section on bottleneck prevention, it can be presumed that certain measures that were mentioned in one interview but remained unmentioned in another interview may still be in place despite its not being mentioned because some interviewees would not identify certain measures as relevant for bottleneck identification. An example is the notification of the case company by the supplier in case of possibly upcoming or already existing bottlenecks in supply: although mentioned only in five cases the inference that in the other five cases notification by the supplier is not common would probably be incorrect. Likewise, it may be common practice that suppliers can enter an objection to an order even when interviewees did not explicitly mention this during the interview.

Supplier Notifies Case Company Interviewees of five case companies state that their suppliers generally notify them in case irregularities in supply will occur. As indicated in the introduction to this section this is one example of an action that might not be considered worth mentioning by interviewees, which is why one can presume that notification by suppliers also happens in cases where this was not explicitly stated.

The impression won from the interviews is that notification by suppliers is the single most important mechanism for case companies to learn about the occurrence or possible occurrence of supply irregularities due to bottlenecks.

Networking for Information Acquisition Four case companies have emphasized the role of formal and informal networking for the identification of possibly upcoming bottlenecks. Trade fairs and conferences were mentioned as events where information can be exchanged between companies within the same and neighboring industries. The interviewee of one company mentions a sales office in Singapore from where networking activities are conducted so that all relevant information concerning supply safety are captured. The interviewee of another case company states that the company's industry is known to be densely tied and that both relevant information as well as gossip spreads quickly among industry members. Yet another interviewee explains that his company maintains informal contact with former suppliers even when there are no new supply contracts to be signed at that time so as to share industry relevant information.

Companies that depend on supply of raw material such as different types of metals receive information from government institutions whose purpose it is to assemble and assess information on availability of raw material on global markets. Global availability of raw material is of major concern for the raw material traders among the case company and it is often long-term global developments they seem to be most interested in. One interviewee emphasized the importance of timely information about global developments before such news is aired on TV news channels or printed in news papers so as to be able to tap the sources of supply before everybody else will try the same.

Supplier Enters Objection to Order Some companies transmit forecasts and orders electronically to their suppliers. Suppliers then have the chance to enter an objection when delivery date expected or amount of goods ordered by the customer (i.e., the case company) cannot be met. When no objection is entered within a defined period of time, the order counts as confirmed. This procedure was described by three of the case companies, all of which are production firms (case companies 1, 2, and 3). Interviewees of these firms have stated that objection entered by suppliers is one common way for them to learn about bottlenecks in their supply network.

Parts do Not Arrive Without Prior Notification Three case companies, all of which are production firms, have stated that it happens occasionally that orders do not arrive without any prior notification by the supplier. One interviewee explains that his company thus plans to contact suppliers more often shortly before promised delivery date to confirm whether the material will be delivered as scheduled.

In another case company orders that have not arrived sometimes remain unnoticed for weeks by the purchasing department which sent the order because production staff do not provide timely notification of the supply shortage. In this case, deficiencies abound not only in the supply relationship but also in internal communication processes which aggravate the problem.

Suppliers are Contacted to Reconfirm Order As a reaction to orders that were not fulfilled on time without prior notification by suppliers, one case company decided to contact suppliers more often shortly before promised delivery date so as to reconfirm the order.

ETA of Cargo Accessed Online One raw material trading company can access estimated arrival time (ETA) of cargo vessels online. This allows the firm to identify possible slips on the delivery schedule.

Low Inventory Levels Detected One case company states that occasionally low inventory levels are detected that can pose a danger to the production schedule. That is, in this case the fault lies in insufficient inventory control and material order mechanisms rather than in the actual supply processes.

Information About Supplier Capacity One case company explains that it has information about suppliers' total production output as well as about the total available production capacity. This gives the company an early warning indicator should capacity available and capacity used converge too closely.[7]

Monitoring of Supplier Activity One case company's quality assurance team monitors activities of critical supplier for important orders. The monitoring process ends with order fulfillment. According to the interviewee, close surveillance of supplier activity is performed in about 5% of all orders.

SAP Notification Another example of an activity that could be considered a rather normal business activity but was mentioned explicitly in the context of bottleneck identification is the notification of the case company's SAP system about order delivery due dates. Upon notification by the SAP systems, orders are traced so that successful order completion can be confirmed or, if this order was not completed as expected, additional measures can be taken.

Continuous Communication with Suppliers One case company emphasizes the role of intense communication with suppliers as a measure to identify possible bottlenecks. According to one interviewee, the case company communicates with suppliers "continuously" even when there is no transaction currently pending, which is their main means of bottleneck identification.

[7] The same measure is listed in the section Bottleneck Prevention as it can be counted to either area, prevention and identification of bottlenecks.

6.3.4.2. Some Remarks About the Identification Measures

A clear difference could be seen between those companies which depend on global raw material markets (e.g., for different types of metal) and those companies which receive manufactured, assembled, or otherwise processed components from suppliers. In the first case, it seemed that companies were much more concerned about global developments and natural scarcity of the material than about actual production capacity of suppliers. Accordingly, networking both in formal ways (conferences, trade fairs) and informal ways (industry "gossip", phone calls) seemed to be higher relevance to the first than to the latter. The concern about global developments is reflected in this statement by one of the interviewees of case company 9:

> "I think continuous communication [with our suppliers] is the way we learn about those things. And we have to, so as to be able to act timely. Once it has been made public on information systems such as Bloomberg or Reuters it is too late."[8]

Information channels such as Bloomberg and Reuters do not normally report on bottlenecks that emerge due operational or organizational deficiencies in production of individual suppliers. These channels are concerned with developments that are of relevance to a broader audience. This finding is in line with the causes of bottleneck emergence that are named by companies which depend on global raw material markets (cf. Section 6.3.2.4 on page 309).

The measures for bottleneck identification described in this section could be classified into three categories, based on the party that initiates the information transfer:

1. *information pull*: information about possible or actual bottlenecks is *pulled* by the case company,
2. *information push*: information about possible or actual bottlenecks is proactively provided (*"pushed"*) by suppliers,

[8] Quote translated by the author.

Table 6.3.2. – Four Categories of Measures of Bottleneck Identification

Information Pull	Information Push	Two-way Information Transmission	No Activity Involved
Networking for information acquisition	Supplier notifies case company	Continuous communication with supplier	Parts not arriving without prior identification
Supplier contacted to reconfirm order	Supplier enters objection to order		Low inventory levels detected
ETA for cargo accessed online			
Information about supplier capacity			
Supplier activity monitored			
SAP notification			

3. *two-way information transmission*: *both* parties, case companies and suppliers, are active and support the transmission of information.

In addition, some measures are, in fact, no measures but rather reflect the absence or failure of measures: the detection of low inventory levels as well as parts not arriving without prior notification are no activities to identify bottlenecks in supply networks but findings in those cases where bottlenecks were *not* identified. The categorization is displayed in table 6.3.2.

Looking at the table, it becomes obvious that there is a clear focus on "*information pull*". That is, companies employ a variety of measures to pull vital information about supply rather than being informed by suppliers. While "networking" could be considered a "*two-way activity*", a company's intent to participate in such networking activities seems to be information gathering rather than information sharing, so that this activity was classified as "*information pull*".

6.3.5. Bottleneck Management: Exploitation

6.3.5.1. Measures of Bottleneck Exploitation

The concept of bottleneck exploitation is derived from disciplines of Operations Management such as production logistics and scheduling. More specifically, the concept is discussed in Goldratt's business novel "*The Goal*", in which bottleneck exploitation describes the attempt to maximize throughput at an existing bottleneck in order to maximize throughout of the entire system. In this thesis, the concept has been transferred to supply networks and bottlenecks in supply. In the context of supply networks, the concept of bottleneck exploitation appears to be completely unknown to date. Not surprisingly, interviewees were not familiar with the concept. Nonetheless, interviewees did comprehend the idea behind bottleneck exploitation and in some cases could contribute measures of bottleneck exploitation from the operational practice of their own company.

Different than in bottleneck prevention or bottleneck elimination, none of the activities of bottleneck exploitation were clearly dominating among the case companies. If one activity stood out, it was express delivery. But even express delivery was only mentioned twice for the supply relationship, and two more times for the transportation from the case company to the customer. This indicates that bottleneck exploitation has not yet received much attention from researchers and practitioners so as to support the emergence of standard procedures – other than, for instance, bottleneck prevention, where a large amount of literature discusses (i.a.) sourcing concepts.

Express Deliveries Express deliveries – that is, the use of quicker transportation modes to accelerate the transfer of material from suppliers to the company – were mentioned twice by interviewees. Both case companies using express deliveries to accelerate transportation are production firms and interviewees referred to relatively small components. Express delivery is no feasible option for raw material traders and production firms that receive large amounts of heavy material from distant suppliers. When large amounts of heavy material are received from overseas, there are no alternative to transportation by cargo vessels as cost incurred for air freight would render the transportation uneconomical.

Moreover, express deliveries were mentioned twice for the transportation of material from the case company to the customer, that is, the outbound relation. Although this does not directly concern the supply relation, this measure deserves to be mentioned for it does reduce the overall lead time and helps to move order fulfillment back on schedule.

Use of Parts from Replacement Stock One case company that maintains a separate stock of replacement parts for customer service occasionally accesses this inventory in case suppliers are unable to deliver material on time. In this particular case, it is mostly components that are delivered JiT or JiS that suffer from irregularities in supply, so that there is no significant regular inventory that would buffer such irregularities. Replacement stock is replenished once the components missing for regular production are received. By making use of this "passive" inventory the case company can avoid production interruptions due to stock out.

Use of Parts from Finished Products The same logic that underlies the use of material from replacement stock is built on when parts from finished products that were produced to stock are removed and built into products that are produced to actual customer order. Production interruptions and delays in customer order fulfillment can thereby be avoided in spite of delays in supply. Products on stock can be equipped again with the parts that were removed once supply is back to regular schedule.

Refurbishing of Locked Material One case company speeds up refurbishing of material that had been locked in quarantine store to make it usable for production when suppliers are unable to deliver on time. Material may be locked in quarantine because it fails quality tests. In some cases, material can be manually refurbished so that will pass quality tests and becomes usable for production.

Reduction of Transportation Lot Size One interviewee reports that in the past some suppliers have held back deliveries of material because the amount of goods finished did not meet the minimum order batch size that was agreed upon in the sourcing contract. These suppliers ignored or were unaware that even a partial delivery of material would help the case company continue production, which is almost always preferable to minimized transportation cost due to optimal transportation batch size. The interviewee suggests that some suppliers are ignorant of this fact and thus need to be reminded that even incomplete transportation batches should be delivered rather than no delivery is made.

The same concept was mentioned by the interviewee of another case company for the transportation relation between the case company and its customers. When a cargo vessel sank with ten tons of finished goods on their way from the case company to one large customer, the bottleneck shifted to the case company so that additional work shifts had to be added and the company began to fly smaller batches of finished goods to its customer so as to let him continue regular production.

Access to "External Inventory" One case company is active in trading of metal while a sister company uses the same material as input material for production. The interviewees explain that the case company would be able to access material on stock of the sister company – actually intended for production – in order to avoid delays in customer order fulfillment should a bottleneck in supply emerge and inventory in the case company's two warehouses be insufficient to meet orders.

Rescheduling of Orders (Internal) One interviewee reports that when a bottleneck shifted to his company, several customers were approached so as to renegotiate the promised delivery date for their orders. Talking to different customers it turned out that the delivery of the product was not time critical for some of them, so that production for these orders could be postponed. The purpose was to allow the case company to reschedule internal production in a way that optimizes throughput of a specific product by minimizing change-over time which in this company normally consumes considerable amounts of time due to cleaning necessary before another product can be produced on the same production line. By optimizing production schedule with respect to throughput of one product, the company was able to resolve the bottleneck and reduce the delay for the respective product.

Blending of Raw Material One case company that receives input material from several sources blends the material before it is fed into the company's production process. By blending the material the company creates a steady quality to which the (chemical) production process is adapted for optimal throughput results. Furthermore, the company reaches a certain independence of specific sources of supply as the blending process is able to balance differences in the material from the various sources. This allows the case company to maintain a high inbound stream of material for its production process even in the case that one or several sources of supply would be affected by bottlenecks.[9]

Additional Work Shifts (Internal) In one case company, additional work shifts (weekend work) were set up when a bottleneck shifted to the case company. Obviously a bottleneck in supply cannot be exploited by adding additional work shifts to the production process of the case company. It is conceivable, however, that a bottleneck in supply is resolved so that all the material needed becomes available and the bottleneck shifts downstream to the case company which now would not have enough capacity available to catch up with delayed orders on its normal production schedule.

[9] The blending of raw material can be considered both a preventive measure and an exploitation measure and is therefore mentioned in both sections.

6.3.6. Bottleneck Management: Elimination

6.3.6.1. Measures of Bottleneck Elimination

Bottleneck elimination describes the removal of the bottleneck, which conceptually is the same as pushing the bottleneck to another place with higher throughput limits. The measures described in this category "solve the problem" – different than exploitation measures which provide temporary remedy against the imminent risk of supply shortage and interruption of production processes without pushing the physical limits of the bottleneck. Bottleneck elimination goes after physical limits. It either pushes them in an attempt to increase physically possibly throughput at the bottleneck, or it reroutes the material stream so as to benefit from less rigid constraints at another place.

What measures are possible in this category to a good extent depends on the specific context of the focal firm. The ad hoc substitution of material, for instance, is not an option for many firms further downstream in the supply network. Likewise, in-house production of certain components may be constrained by technical ability or patents held by supplier firms. The switching of sources of supply, possibly the least surprising measure of all, is also the most dominant measure. It does require, however, that preventive measures were taken in due time and possible alternative or additional sources were prepared.

Switching of Supply Sources In the discussion of prevention measures it has been indicated that most case companies maintain multiple sources of supply, which decreases their dependence on one source and allows them to balance irregularities so they can avoid being affected by bottlenecks in the first place.

From the case companies' perspective, the use of multiple (parallel) sources is not only a preventive measure but can as well considered a measure of bottleneck elimination. The availability of multiple sources allows case companies not only to avoid bottlenecks in their inbound material stream but also to switch from one source of supply to another source of supply. The "bottleneck elimination character" is more obvious when the company maintains a set of alternative sources that are prepared and qualified for supply but remain passive until activated in case of a bottleneck in the main source. Activating suppliers which have been prepared as alternative sources eliminates the bottleneck in the company's inbound stream.

Switching between different sources of supply is the most dominant measure of bottleneck elimination identified in the interviews.

Substitution of Material Interviewees of four case companies explain that sometimes they are able substitute one material that is available for another one that is in short supply. For the raw material trading companies, substitution of material can be achieved, for instance, by offering customers material with higher (and sometimes even with lower) purity or from a different brand. For a production company, substitution can be used when quality tests confirm that the new material meets the same quality criteria as the material in short supply. A more expensive (and therefore not normally used) material can sometimes be used as a substitute for a less expensive material.

Validation of Promised Delivery Date Interviewees of three case companies suggest that when a bottleneck in supply emerges, one thing the case company should do is find out if a possible delay would actually create a problem both for (1.) the case company's ability to continue production on normal levels and (2.) for customers. When a supplier fails to deliver a particular component on time, it would not bother the case company unless changes in the production schedule are required. When the material in question is not scheduled for production before the actual, delayed delivery date, delays in supply can be accepted before costly exploitation or elimination measures are invoked. By the same token, customers may not actually need the material right on the originally agreed delivery date but might be comfortable with a postponed delivery date.

Although validation of delivery dates does not affect the existence of the causes for the bottleneck, it might eliminate the need to invoke costly emergence measures.

In-house Production In two case companies there is capacity available to take over production of certain components should suppliers be unable to deliver. Although in-house production requires some lead time and might be more expensive than sourcing the parts to suppliers, it is a feasible option in these companies which they can use to maintain their production output level and thus their service level with customers.

Buying from Competitor Interviewees of two raw material trading companies say their companies can buy material from competing traders should their normal suppliers be unable to deliver on schedule. In both cases, interviewees state that procurement cost would be higher and that their company might even lose money when they buy material from competitors in order to fulfill their customers' orders. According to the interviewees, fulfilling customer orders has higher priority than being profitable in these particular orders so that buying material from competitors is one of several options they can pursue.

Escalation to Management One interviewee explains that management is informed when no solution for a supply bottleneck can be found on a lower hierarchical level. Management of the case company then gets in touch with the supplier's management in order to discuss and negotiate possible solutions or remedies for the supply situation.

Escalation to management may initiate a variety of actions both on part of the case company as well as on part of the supplier that is causing the problem.[10]

Use of Contract Manufacturer (Internal) When the bottleneck in supply is resolved and shifts to the case companies' internal production, one case company makes use of a contract manufacturer with whose help the company is able to double its production capacity so that a backlog in production can be resolved.

[10] Obviously though, the escalation itself does not affect material flow, which is why the categorization under "bottleneck elimination" is somewhat arbitrary as it could be equally well categorized under "bottleneck exploitation".

Use of Production Capacity of Sister Plant (Internal) One case companies runs a production plant in Europe and one in China. The interviewee explains that in the past when significant delays could be expected due to insufficient capacity in the European plant, production capacity of the Chinese plant could be utilized to some extent to support the fulfillment of customer orders in Europe.

As with the use of contract manufacturers, tapping the sister plant's production capacity does not affect the availability of supply and the inbound material stream (although it could if the material in need were available in China but not in Europe). That is, this measure is only of value when the bottleneck shifts to internal production capacity – which is easily conceivable when a bottleneck in supply has created a backlog of orders for production.

6.3.7. Bottleneck Management: Placement

The concept of bottleneck placement was included in the interview questionnaire so as to probe if case companies employ activities that correspond to the concept in the context of supply networks. The responses received from interviewees suggest that while interviewees did comprehend the logic underlying bottleneck placement they were unable to name situations or activities from their companies' practice that reflected the concept. Without excluding the possibility that there are in fact organizations which do use this concept in their supply network, it can be inferred that bottleneck placement is not common a concept in the management of supply networks. The concept was thus removed from the tentative model as originally conceptualized in Section 4.6.

6.3.8. Limitations to Bottleneck Management

The case companies face a variety of different limitations to their ability to manage bottlenecks. Some of these limitations are specific to the respective company's industry or network setup whereas others are rather general; some limitations are imposed from the outside whereas others are self-inflicted. Such limitations hinder organizations from effectively achieving their goal – that is, from managing their bottlenecks.

One of the most prevalent limitations that were identified in the case study was the general shortage of the material in demand on the market, which was either directly or indirectly indicated by six case companies. In some cases, this shortage was natural; that is, the material is subject to natural scarcity on the planet (as compared to scarcity because of intense demand from industry). This problem is faced by some of the raw material traders (cases 4, 9, and 10) as well as the manufacturer of metal products (case 8). The problem refers both to rather rare materials such as lead with high purity and low radiation as well as to more “mundane” materials like tin, the demand for which is approaching global mining and smelting capacities. In case 1, scarcity of raw material is (occasionally) caused by the way suppliers organize their production process: certain qualities and types of glass are produced in large batches, put on stock, and sold from there, while production of another quality or type of glass is continued. When one specific type of glass is sold out, it can take weeks before production of this type can be commenced. In all of these cases, companies are severely limited in their actions once the bottleneck emerges.

Another important restriction is due to the properties of the raw material or product. Properties that were mentioned that represent limitations are weight and shelf life. Weight represents a limitation for it excludes fast transportation modes (air freight). Different types of metal are subject to this limitation. Such raw materials from overseas can only be economically transported by cargo vessels, which excludes expediting transportation via the selection of air freight as a means of bottleneck exploitation.

Shelf life, on the other hand, refers to the deterioration of product quality over time while the product or material is on stock. Fresh food may be the best-known example for products that are subject to this limitation, but industrial products, too, can deteriorate over time. Case company 1 has to cope with the shelf life of glass. As mentioned earlier, the company faces the problem that producers of raw glass produce in large batches of one type, and when one type of glass is sold out delays may occur until a new production batch of that type is run. Because the quality of glass deteriorates over time, the most obvious counter-measure to the limitation posed by this production logic – increasing production batches and putting more finished glass on stock – is not an option for producers. Likewise, the case company cannot sensibly buy up large amounts of raw glass to keep them on stock "just in case". The combination of shelf life, production logic (batches with significant lead time), and the trade-offs involved is which makes this a typical "newsvendor problem".

In five cases, interviewees express that they perceive their company's power position as relatively weak compared to at least some of their suppliers, to which they attribute supply-related problems in the past. The interviewee of case company 1 remarks that problems are more likely to emerge with powerful suppliers. Case company 3's interviewee states that suppliers openly admitted that other customers have higher priority in resource allocation decisions. While not admitted by suppliers, case company 6 experienced disadvantages in material allocation decisions, too. Case company 7 received delayed deliveries and quality of lower quality material at the time their long-term supplier acquired additional customers. The interviewee of case company 8 expresses concerns that some larger suppliers may cease supply for the amounts purchased by the case company are too small. That is, the entire sample of SMEs among the case companies is subject to perceived or actual disadvantages due to a weak relative power position.

The natural geographic distribution of raw material imposes limitations and requirements on those companies that demand such resources. On many occasions, industrial firms cannot choose a geographic region or a country to which they want to source raw material. Raw material traders – whose profession it is to make raw material available to industrial customers – thus tend to employ a broad variety of sources of supply on different continents, requiring long-haul transportation. The amounts and properties of the material requested (see example "weight" above) exclude air freight so that the only economically viable transportation mode remains sea freight. Sea freight is slow, vulnerable to weather conditions, and normally cannot be significantly expedited. That is, sea transportation tends to make the supply chain vulnerable, slow, and inflexible. Yet, the distribution of natural deposits of certain raw materials make it necessary.

Also, besides difficulties attached to physical transportation, European and American companies receiving raw material from overseas have to cope with diverse and often difficult political, natural, and social circumstances which are prevalent in some sourcing countries. The interviewee of one raw material trader describes difficulties related to sourcing from Kongo and the attempts of industry organizations to establish tracking systems for conflict-free resources.

Three case companies are financially constrained so that they cannot pursue all bottleneck management measures they would like to. One interviewee describes that his travel budget does not allow supplier audits which he thinks could have avoided some supply-related problems the company has faced. Another interviewee expresses that significant funds were necessary to grow the business and safeguard supply. One interviewee states that the case company's entire industry is going through difficult times and that additional measures to prevent bottlenecks in light of decreasing volumes may be perceived as inadequate or unnecessary by management, which leads to the next limitation two case companies face: low purchasing volume.

Low purchasing volume may render the use of multiple sources unfeasible so that companies may be forced to rely one one source of supply for certain materials. This is the situation faced by case company 3. Also, relatively low purchasing volume – as compared to other customers of the same supplier – may decrease the relative importance and power position of the company for the supplier, which may result in disadvantages.

In three cases, limitations are related to forecasts received from suppliers. The interviewee of case company 10 states that unreliable forecasts from customers pose a problem. Case company 7, on the other hand, receives forecasts with a horizon of only two weeks for some products, which provides little time to react and plan capacity usage. The customer providing the short-horizon forecast claims not to have available better data. Case company 3 attributed the low availability of usable forecast data to a lack of professionalism of sales partners who tend to be small craft business.

For three case companies, the reasons as to why bottlenecks emerge tend to lie outside their company's reach. Examples are weather conditions or political events in sourcing countries that can impede supply for raw material traders, but also fire outbreaks in supplier facilities. "Outside organizational reach" can thus be seen as a category of limitations rather than as a limitation itself.

Other limitations identified were more specific to the individual companies and did not apply to several cases at once. One interviewee mentions the case company's organizational culture as a reason why the company has mostly relied on long-term single sourcing and not pursued multiple sourcing to a greater extent. One interviewee states that high capital cost for raw material makes higher inventory levels as a means to buffer variability in supply and demand economically unfeasible. The same company has to cope with the fact that irregularities in the quality of the raw material received do not become visible until the lengthy production process is started, so that preventive quality control is not possible.

The conceptual model proposed in Section 4.6 contains references to supplier market, buyers' market, organizational factors (technology, strategy, product characteristics, ability), and competition as determinants, parameters or influencing factors for the selection of bottleneck management measures in each of the categories proposed. Limitations are but one type of parameters that influence decisions (requirements or needs are another), yet it might be worthwhile trying to relate the limitations discussed above to the conceptual model so as to find evidence for the model's categories' validity.

With one exception, all limitations could be sorted into the categories proposed in the conceptual model: Above it was mentioned that some companies stated that causes for bottleneck emergence lie outside their respective organizations' reach, which represents a limitation to the organizations' action and influence. Because this statement is so imprecise and could refer to anything that happens outside the narrow legal organizational boundaries of the case companies, it has been excluded from the categorization. The categorization is displayed in Figure 6.3.1.

Certain differences emerged concerning limitations to bottleneck management between organizations upstream and downstream in supply networks. Such

External			Internal
Supply Market	Buyers' Market	Competition	Organization (Product, Ability, Strategy, Technology)
• Shortage of material on supply market • Natural/geographic distribution of raw material • High purchasing price for raw material	• Lack of professionalism of sales partners • Short forecast horizon from customers • Unreliable forecasts from sales partners	• Company size / powerless / low importance for suppliers	• Properties of raw material (weight, size, shelf life…) • Financial constraints • Low volumes • Organizational culture • Quality problems technically difficult to detect • Technical properties of production process

Figure 6.3.1. – Categorization of Case Companies' Limitations to Bottleneck Management

difference revolve around the type of material they receive as supply, i.e., whether they receive natural raw material or manufactured goods. The analysis was supported by information from an expert interview. As described in Section 5.3, one interview was conducted with an expert for raw material markets at the German Raw Material Agency (DERA). The information provided in this interview can further augment the understanding of limitations in bottleneck management.

The interviewee (expert 3) mentioned the substitution of raw material as one rather common measure to eliminate bottlenecks at companies either receiving (natural) raw material, such as NF metals, or supplying it to customers. This points to a limitation that some manufacturing companies face. While companies which are receiving and manufacturing natural, mostly unprocessed and homogenous raw material often do have the ability to substitute the material (e.g., by choosing the same metal with a different level of purity or an entirely different metal with similar chemical characteristics), companies whose inbound material stream consists of manufactured, and thus "artificial", parts that are engineered to fit into, and represent one distinct part of, an assembled product, such as an engine, are unlikely to be able to do this for a variety of reasons:

- the supplier may use specifically designed tools to produce that part,
- the part may require extensive quality testing, especially if it is a complex assembly itself whose properties and behavior might not diverge from the original part in any obvious, but possibly in more subtle, ways and possibly only after a certain period of time in use,
- if unable to produce the original part, the supplier might not be able to produce an alternative part either, so switching the part may require switching supplier, who in many cases has to be audited and approved first, which, in turn, can take more time than is available when trying to prevent production processes from starvation.

Because the processing of natural raw materials is to be found upstream in supply networks rather than downstream, the limitations outlined above are more likely to be faced by organizations downstream in supply networks, i.e., in a later value-adding phase. While the limitation exists for obvious reasons, it does indicate that the vertical position in the supply network broadly correlates with limitations as to the substitutability of goods. This finding is worthwhile mentioning as the multiple-case study did not reveal many bottleneck management limitations that companies seem to be facing depending on their vertical position alone; it was often the influence of lateral, and often non-adjacent, relationships that was said to constitute an important parameter as, for example, in the discussion of power and dependency (cf. Section 6.4.2). In the example of substitutability, it is not the vertical position per se that causes the limitation but instead the fact that state and properties of supply depend on the vertical position in that companies upstream in the network receive supply that has not, or to a lower extent, been processed and thus is more natural and broader in its possible application, whereas manufactured and assembled products are customized to fit very specific requirements (unless they are standard parts, such as screws or bolts).

Another difference, albeit not as stark, between manufacturers of natural and of engineered products can be derived from the natural distribution and scarcity of raw material. There are monopolies in many branches of industry, partly based on patents, partly based on unique technical capabilities, and partly because of successful marketing. Generally, such monopolies were created by the companies which hold them. With natural raw material, however, companies may hold a natural monopoly if they possess the exploration license for the only one, or one of very few, profitable sources for that specific material that exist and are known. The exploration of such a raw material is often naturally limited by the magnitude of the deposit – by natural scarcity, that is. Thus, it is not only the monopolist exploration company's marketing strategy that determines price and availability of the good but also there mere natural limits of its deposit. While with an "artificial" monopoly, the manufacturer has the ability to scale up production, to invest in additional capacity, or to license production to a third party or to the customer itself, the natural monopoly may constitute natural, and possibly stricter, boundaries to production volumes. For a manufacturer, being dependent on a natural monopoly thus appears to be even less desirable than being dependent on an artificially created monopoly for supply.

Another limitation for receivers of natural raw material is based upon the market characteristics of such material. Raw material prices tend to be volatile for they are often strongly influenced by economic cycles. Many raw material are traded on spot markets, such as the LME. Since prices indicate scarcity, companies do face the immanent risk of not being able to continually receive large enough amounts of a specific material. Companies may be able to hedge against price fluctuation; they may also, in a way, hedge against unavailability of the material by closing long-term contracts with a supplier. As any hedging, long-term contracts come at a cost. The cost in this case is the price risk which consists of the chance of having to pay significantly higher prices, as determined in the contract, than the company would otherwise have to pay on the spot market.

Obviously, price fluctuation might also work in favor of the buying company that may benefit from lower than market prices. Depending on the prevalent power regime, though, suppliers in such cases may demand renegotiation of contract terms and conditions.

That is, receivers of natural raw material have to trade off price risk against supply risk. The situation is different for most manufacturing companies. Manufactured goods, too, depending on market supply and demand are subject to fluctuating market prices themselves, and because they consist of natural raw material, they also to a certain extent reflect its market prices. Possibly because they consist of several different components, each of which subject to individual price fluctuation, possibly because long-term contracts are more common, which may have a taming effect, the fluctuation of prices of manufactured goods downstream in the supply network often appears not to be as significant as for natural raw material. Hence, manufacturers downstream in supply networks closing long-term supply contracts with suppliers seem not to be as concerned about price risk as receivers of raw material further upstream in supply networks. Therefore, long-term contracts seem to represent an instrument of bottleneck prevention that is more suited for downstream than for upstream companies; the price risk is not as immanent for downstream companies.

Another notable difference between receivers of natural raw material and receives of manufactured goods is the ability of the former to tap another important source of supply: recycling. For some metals, the share of recycled material is quite significant. As an example, according to expert 3 and DERA (2012), 43% of all copper processed in Germany was recycled. Receivers of natural raw material may choose to invest in recycling capacity so as to be able to tap additional sources of supply whereas receivers of manufactured goods may have fewer options to do so.

6.3.9. Summary

This section drew together much of the information from the individual case companies and presented the in summarized form across all cases. This includes the causes of bottleneck emergence, the case companies' measures of bottleneck management, as well as the limitations they face when managing bottlenecks.

As with the first part of the data analysis, this section does not contain interpretation but description and categorization of information.

6.4. Analysis of Interview Data Phase III: Reference to Literature and Conceptual Model

6.4.1. Introduction

The third part of the data analysis relates the findings from the multiple-case study to the literature and to the conceptual model proposed in Chapter 4. It tries to explain the emergence of bottlenecks in some case companies' supply network by reference to non-adjacent power regimes. Moreover, it relates bottleneck management measures chosen by the case companies to the concepts of power, flexibility, and risk, all of which were identified in the literature review. It is asked if lack of power in supply relationships on part of a company can limit the company in its options for bottleneck management and if the case companies appear to aim for a more powerul stance in their supply relationships by selecting measures that may help them increase their relative power. These analyses address research questions 5 and 6.

Research question 7 is addressed in the last part of this section. It investigates into the terms supply chain and Supply Chain Management and extends the theoretical discussion that began in Section 2.4.4 with empirical evidence from the company exemplars.

6.4.2. Bottleneck Management, Power and Dependence

6.4.2.1. Power Regimes as a Cause of Bottleneck Emergence

In Section 6.3.2, three categories of causes of bottleneck emergence were discussed: physical, organizational, and operational. The data analysis suggests that organizational causes play an important role. Organizational causes of bottleneck emergence are related to *conscious* and *deliberate decisions* (mostly) made by the supplier. Power seems to have played an important role in the way some case companies were treated by suppliers. In this respect, power seems to determine to some extent what activities the case companies *can* pursue when attempting to manage bottlenecks their supply network. That is, the discussion that follows is likely to contribute to an answer to research questions 5 and 6.

Cox et al. (2001) point out that power is largely ignored in the SCM literature although it does represent an important factor in the way value is appropriated in supply networks. In their analysis of power regimes, they look at 16 different power setups in double-dyadic relationships (i.e., buyer – supplier – sub-supplier). Each of these actors can be either more powerful or less powerful than the other actors, independent of them, and interdependent with them (which causes power to be about equal). The authors refuse to adopt the notion of chains and they refuse to believe that supply networks are meant to provide customers with the greatest value. Instead, they suggest supply chains are really supply networks and that supply networks exist in order for the companies involved to create value for *themselves* (i.e., to make money).

Although these insights are refreshing because they are notably different and set the paper apart from the larger part of SCM literature, the authors fail to address some aspects. In their discussion of power regimes, they do not specify what constitutes power and how it allows companies to appropriate value. Presuming that power exists without specifying these two details might be acceptable; in this case, however, these details have implications for the authors' conclusions.

These points are addressed by Crook & Combs (2007). They derive the existence of power from the RDT notion of the possession of important resources. Furthermore, they use Thompson's (1967) conception of task interdependence to identify in what setting (pooled interdependence, reciprocal interdependence) power can be appropriated to what extent by the more powerful actor in the supply chain (cf. Section 2.5.5.2). It is this notion of interdependence that is missing in the paper by Cox et al. (2001), which results in an overly simplified model of value appropriation.

Different from either paper, however, the data analysis suggests that it is *not* the dyadic power regime within which the case companies are located but the power of a company *outside* the dyadic supply relationship of the case companies that has implications for the material or capacity allocation decisions of their suppliers. It is the lateral relationship of an organization in the network that is *not* directly connected to the focal case company but merely to its supplier. It is the relative power of the competing buyer in comparison to the case company that influences the supplier's capacity allocation decisions. Although interviewees repeatedly indicated that unfavorable allocation decisions were made by suppliers larger than the respective case company, the analysis suggests that it is the power (for which size is merely a proxy) of the competing buyer that seems to make the difference.

If power of the supplier is of relevance at all for such allocation decisions, then the opposite case might even be true: the larger the supplier, the less likely it will cause supply interruption of the smaller case company, the reason being that a larger supplier is more likely to be able to afford letting a larg (compared to the case company) customer carry part of the burden of insufficient total supply capacity which is then shared by the competing buyers instead of exclusively being carried by the smaller, less powerful firm.

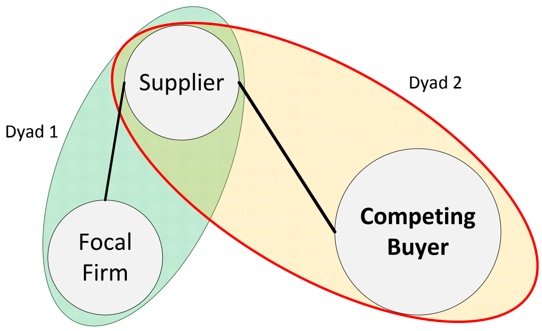

Figure 6.4.1. – Non-adjacent Power Regimes in a Supply Network

So the neglected point in existing literature is that many authors – sometimes in spite of their acknowledging the complex web-like structures of supply networks – base their analysis on a linear chain-like model. Some might do this for the sake of simplicity; and for questions of value appropriation it might actually be a valid approach. Yet they do miss the important fact that power regimes outside the direct dyadic supply relationship of the focal firm can influence the supply relationship of the focal firm. One contribution of this work therefore is that it emphasizes that the role of power regimes with firms that are not adjacent to the focal firm can have important implications for the focal firm – such as the interruption of the inbound material stream. Moreover, this emphasizes the importance of maintaining a mental model that actually allows for such relationships to exist, which is likely to be supported by the description of a supply *network* rather than supply *chain*.

Figure 6.4.1 illustrates the case. Both dyad 1 and dyad 2 are subject to separate power regimes. While existing literature as well as the perception of some interviewees at the individual case companies (represented by the focal firm in the illustration) attribute supply shortages to the power regime between their firm and the supplier (represented by dyad 1 in the illustration), there is reason to believe that the relation of a non-adjacent organization that is competing with the focal firm for resources or capacity at the supplier and the power regime resulting from the relation between that firm and the supplier is causing the adverse effect on the focal firm. The power regime of dyad 1 might not even function the way some interviewees suggest: it might, in fact, be the lack of power on part of the supplier and thus its dependence on the more powerful competing buyer rather than the relative power of the supplier over the focal firm that contributes to the situation.

Moreover, non-adjacent power regimes can be related to the discussion of network theory and its impact on performance in Sections 2.5.2 and 2.5.3. Density was one measure that was shortly discussed. Arguably, in networks of lower density – i.e., networks that contain more structural holes – indirect performance effects may be less likely to be transmitted than in dense, interwoven networks. More specifically, structural equivalence, or at least similarity, on the supply side of two or more firms is a precondition for non-adjacent power regimes to be able to impact on the supply relationship of the focal firm. In a supply network where the ties of interest are supply ties, structural equivalence, even partial, represents a risk factor for the stability of supply for a firm – and mostly for a firm that relative to its equivalents is less powerful with respect to, or is otherwise less important for, the suppliers they have in common.

Another possibility is that the firms that report to have been disadvantaged by suppliers' allocation decisions are outside of what was referred to as cohesive subgroups. In Section 2.5.3.2, cases were cited where embeddedness in a cohesive subgroup had advantages for the firm, such as better information sharing, trust, and quick collaboration to solve urgent problems. Higher prioritization might be another benefit of strong cohesion; accordingly, members of the cohesive subgroup would prioritize organizations outside that group lower when they have to make allocation decisions. It cannot be stated with any certainty that cohesion did have any impact on the outcome of supply allocation decisions for the case companies, yet this theorizing opens up additional worthwhile research venues where network theory can be applied to analyze the behavior of supply networks.

Similarly, the connection between the supplier and the competing buyer could be described as a *strong tie* (cf. Section 2.5.2.2), one that includes higher "emotional intensity" (e.g., because of cultural proximity) or which was built on "reciprocal services" (Granovetter 1973, p. 1361). The interviewee at case company 6 suggested that supplier in Eastern Europe tend to grant preferential treatment to other suppliers in Eastern Europe, which indicates that the cultural context may indeed be of influence.

In Section 2.5.3.1, some of the potential performance advantages attached to centrality were discussed. Among the advantages of different types of centrality are better capability to extract value from the network as well as higher power (e.g., due to control of information flows). It is conceivable that power advantages of competing customers, leading to non-adjacent power regimes, may to some extent be attributed to their central position in the wider supply network. In case of economic networks (supply networks are one type of economic networks) the centrality of a firm may correlate with its economic power as the firm does business with more companies and requests goods in larger amounts and from a more a diverse set of suppliers. Hence, the direction of causality may rather be such that high centrality follows from high economic power. Yet again, in-depth investigation into the network characteristics was not possible so that a possible link between power configurations observed in the case companies' network and centrality must be considered speculative and a starting point for further research.

The data set does not allow to draw convincing inferences about group cohesion, strength of ties or centrality; power has shown to be a prominent and repeatedly surfacing concept, however. Where power originates and why remains unclear and requires further investigation.

6.4.2.2. Bottleneck Management Measures as a Means to Alter Power Relations in Supply Networks

From the data analysis, it appears that the case companies have to deal with a broad variation of reasons for bottleneck emergence. In some cases, the differences are obvious: companies in whose supply network there is no transportation by cargo ship cannot be affected by the sinking ships. Likewise, companies that buy domestically do not have to deal with customs regulation and supply will not be held back by customs.

Other differences are less obvious and require further investigation. *Suppli-*

ers' material allocation decisions stand out as the single most-often mentioned cause of bottleneck emergence, affecting five out of ten case companies. At the same time, the other five case companies seem to be completely worry-free about allocation decisions of suppliers. At first sight, this bottleneck cause seems to have affected mostly small and medium-sized companies. Case companies 1, 3, 6, and 7 all fall into this category. Case company 2, however, does not fit here with revenue of several billion Euro (2013). For case company 2, the interviewee expresses that problems with reliable supply are more likely to emerge with larger, powerful suppliers than with smaller ones. Also, tires and engines stand out among the components that have caused problems in the past. Both, tires and engines, are supplied by powerful large suppliers which also supply other customers which are, in fact, even larger than the case company and thus are more important customers. That is, despite the large size of case company 2, its relative size as compared to competing customers is, although not insignificant, rather small.

At the same time, four out of five case companies which are not adversely affected by suppliers' material allocation decisions – case companies 4, 5, 9, and 10 – hold leading positions in their market or are even world market leaders. The interviewee at case company 8 does not mention suppliers' material allocation decision as a cause for supply shortage although there are competitors for most products the company offers. Reasons may be that case company 8 either receives parts from suppliers that are available in abundance so that limiting allocation decisions do not have to be made by suppliers, that parts received are customized so that finished parts cannot be diverted to other destinations, and that the case company despite its not being very large still is an important customer for its suppliers. Furthermore, supply shortages due to suppliers' material allocation decisions do not *have to* occur in each case, which does not mean that they *cannot* occur. Summarizing, the cases seem to provide evidence for a relationship between the *relative power position* of a firm in its network and suppliers' material allocation decisions. As emphasized in the previous section, the notion of non-adjacent power regimes might help explain the situation.

If the relative power of a firm as compared to its suppliers and to other customers of its suppliers plays an important role in suppliers' material allocation decisions, it is worthwhile investigating the factors that increase or reduce a firm's power, respectively. Some interviewees explicitly mention power as one factor for successful supply relationships (from the perspective of their firm). One case company (case 7) combines purchasing with a sister company in the same industrial group in order to improve their power position in the network. In another case company (case 3), the interviewee states that one supplier openly admitted to have preferred another customer over the case company in an allocation decision because of the other customer's higher importance for the supplier's business, which can be translated into the other customer having more power than the case company. That is, power is *recognized* as a factor by the case companies and some seem to try improve their supply situation by improving their power position. In case 7 which was just cited, power apparently is equated with *buying power*, (that is, purchasing volume) and thus relative importance for suppliers' revenue stream.

Another example for the limiting influence of (other organizations') power in the network is provided by case company 8. Case company 8 finds itself in something that could be roughly described as a "sandwich configuration" between large and powerful suppliers and large and powerful customers. The company produces anodes for customers. The anodes come with copper support rods of which there are many different types and which the company receives from its suppliers. The electrolysis at the customer site is a continuously running process; in many cases, this production process is interrupted for as few as three days per year for scheduled maintenance activities. The start up phase for the electrolysis usually lasts several days. Hence, enormous cost due to production loss is incurred if the production process is interrupted. The case company's customers maintain an inbound stock of about 300 anodes. The average consumption is ten anodes per day. That is, the inbound stock represents a buffer of 30 days of inventory. The case company's lead time for copper support rods often is more than three weeks and occasionally more than 30 days. Upon delivery of the copper support rod, the anode will be produced. That is, the order lead time for anodes tends to exceed customers' inventory buffer. Because there are so many different profiles for copper support rods, for cost reasons the case company cannot maintain large inventories of each type. Customers of the case company refuse to increase their inventory of finished anodes from the case company to prevent production outages and instead expect the case company to be reliable. Supply of copper support rods for anode production at the case company tends to be unreliable and lead time is long. Also, relatively high cost for copper make large inventories of different support rod profiles at the case company economically unfeasible. That is, the case company faces both high demands from its (more powerful) customers and little support from its (more powerful) suppliers at the same time while facing limitations with respect to measures it can take to make sure customers will always receive their anodes on time.

In Section 2.5.5.2, literature on power, (inter-) dependence, and coordination in organizational networks was reviewed. It appears that organizations pursue measures to decrease their dependency on individual suppliers or directly aim to increase their power. The review of literature suggests that buying power is not the only element that constitutes power in a supply relationship. Kumar (2005) distinguishes between *dependence-based* power and power due to *punitive capability*. Punitive capability can, in fact, be identified as one element of contract design in supply relationships in the form of penalty clauses for cases of non-compliance. Interviewees from three case companies state that penalty clauses are included in sourcing contracts at least in some cases; one interviewee expresses that he wants penalty clauses to be included in more sourcing contracts in the future. That is, some case companies apparently aim to increase their power by increasing their punitive capability. This suggests that the concept of power due to punitive capability has – at least implicitly – been recognized by some firms.

As to power based on dependence, Emerson (1962) describes dependence as the converse of power:

$$P_{ab} = D_{ba} \tag{6.4.1}$$

In fact, multiple sourcing is the single most-often employed measure for bottleneck prevention that could be identified in the case studies and it is a primary measure to reduce dependency on – and thus power disadvantage – compared to individual suppliers.

As indicated in Section 3.2, power configurations in the supply network are examined as one important part of the purchasing portfolio analysis (Kraljic 1983, Wildemann 2001). In the purchasing portfolio matrix, an analysis of the purchased material with respect to profit impact and supply risk is combined with a comparative analysis of supply market power and company power to deduce supply strategies. This implies that power (and dependency) relationships in supply networks play an important role in the assessment of supply reliability as well as in the creation of suitable strategies to prevent supply shortages (PPA is limited to the prevention aspect of bottleneck management) and that this has been recognized by some researchers .

It is possible to look at bottleneck management measures through power and dependency lenses and frame the measures in terms of power increase and dependency reduction. Preventive measures are likely to play a more important role than reactive measures for the mutual adjustment of power positions as they provide the actors with the time necessary to react and actually make adjustments. Table 6.4.1 provides an overview of preventive measures of bottleneck management and explanations as to how they can affect power and dependency.

Table 6.4.1. – Measures of Bottleneck Prevention and How They Can Affect Power Relations

Measure	Aims at Power / Dependency	Mechanism	Case References
Multiple sourcing	Decreases dependency, increases power (can decrease power)	Decreases dependency on reliability and goodwill of individual suppliers, increases negotiation power of focal firm. At the same time, however, if multiple sources are used in parallel, purchasing volume for each source is lower which might decrease power position compared to individual suppliers.	all
Multiple sourcing (alternative)	Decreases dependency	The preparation of alternative sources decreases dependency on individual suppliers.	unclear
Annual framework agreements	Decreases dependency	Decreases dependency on suppliers' market situation by providing information about needed capacity upfront.	1, 2, 3, 6, 7, 8

Long-term relationships	Levels power and dependency	Long-term relationships can increase asset specificity on either side which creates interdependence and thus reduces one-sided power advantage.	3, 4, 9, 10
High incoming goods inventory	Decreases dependency	Decreases dependency on supplier's service level and allocation decisions by allowing for some slack in delivery process.	3, 5, 6, 9
Penalty clauses for non-compliance	Increases power	Penalty clauses for non-compliance can be seen as an attempt to increase power based on punitive capability.	1, 3, 8
Sourcing to professional traders	Decreases dependency	Professional traders tend to maintain a broad portfolio of suppliers so that dependency on individual raw material suppliers can be reduced.	7, 8

Close relationship with LSP	Increases power (but can increase interdependence and thereby level power)	Consolidation of the portfolio of LSPs and close, long-term relationships may increase power of focal firm due to its funneling of additional business to selected LSPs. At the same time, there is a possibility that interdependence increases and power is levelled due to increasing asset specificity and switching cost.	2, 4
Combined purchasing	Increases power	Increases power by increasing purchasing volume and thus negotiation power and relative importance for the suppliers' business.	7, 8
Blending of raw material	Decreases dependency	Blending of raw material supports independence of raw material quality and thus of individual suppliers.	5

The geographic spread of sources is not mentioned in table 6.4.1 although it might be seen as a measure to lessen dependency. The dependency this measure can lessen is on geographic regions, which is important if the question is how geographically confined interruptions, such as natural disasters or political turmoil, can be avoided. It does not, however, address questions of power and dependency in relation to other organizations like suppliers beyond what is already covered by multiple sourcing as such.

Table 6.4.2. – Measures of Bottleneck Identification and How They Can Affect Power Relations

Measure	Aims at Power / Dependency	Mechanism	Case References
Networking for information acquisition	Decreases dependency	Each of these measures aims to improve the information available for the focal firm, thereby decreasing dependency on information provision by suppliers.	5, 6, 7, 9
Information about supplier capacity	Decreases dependency		4
Monitoring of supplier activity	Decreases dependency		8

Measures of bottleneck exploitation are reactive in nature and tend not alter the relative power position of a firm; the same is true for most measures of bottleneck elimination. Bottleneck identification provides some measures that aim to create advantages due to better availability of information which serves both preventive and reactive needs. An overview of measures of bottleneck identification and elimination and how they matter in terms of the relative power position of a firm is provided in tables 6.4.2 and 6.4.3, respectively.

6.4.2.3. Lack of Power and Low Importance as a Limiting Factor

After bottleneck management measures were described in terms of how they affect power and dependency, it seems worthwhile taking a closer look at the case studies in which company representatives state that a weak power position constitutes a limiting factor for their management and reliability of supply. More specifically, it can be asked whether these companies seek to improve their power position (or reduce their dependency, respectively) by employing effective measures as indicated above, and if so: to what extent. Moreover, if

Table 6.4.3. – Measures of Bottleneck Elimination and How They Can Affect Power Relations

Measure	Aims at Power / Dependency	Mechanism	Case References
Substitution of material	Decreases dependency	Decreases dependency on individual suppliers by tapping an alternative set of suppliers.	3, 4, 6, 8
Produce in-house	Decreases dependency	In-house production of components that are normally sourced to suppliers represent a contingency action that reduces the company's dependency on individual suppliers.	3, 8
Escalation to management	Increases power	Escalation does not alter power relations between two organizations but instead aims to make use of power relations within organizational hierarchies.	3

they do not attempt to alter power relations, it would be worthwhile speculating on the reasons why this is so.

Case companies 1 (manufacturer of glass-based products), 3 (producer of solar power based heating systems), 6 (raw material trader), 7 (producer of soldering powder), and 8 (producer of radiation shields and anodes) directly or indirectly express that their relatively weak power position has been a problem in the past. Each of these firms counts as a small or medium-sized company according to the definition provided by the European Union (European Commission 2005). For case company 8, the interviewee did not elaborate on the relatively weak power position as compared to its suppliers. The relative powerlessness was mostly mentioned in the context of the installation of consignment warehouses with larger suppliers. Therefore, case company 8 will not be part of the sample of companies with a relative lack of power as compared to suppliers and competitors. Table 6.4.4 provides an overview[11].

Case company 1 employs six preventive measures on a regular basis and plans to increase the use of a seventh measure (penalty clauses for non-compliance) in the future. Four out of seven preventive measures can serve to either increase power or reduce dependency. Other measures used by the company, for example those that fall into any of the categories identification, exploitation, and elimination, have not been associated with power or dependence. Most of these measures which case company 1 employs and which stand in relation to power or dependency aim to reduce the company's dependency on individual suppliers in general or on individual supplier's service level: Multiple sourcing reduces dependency on the individual supplier, and so does the preparation of alternative suppliers. Annual framework agreements reduce dependency on individual suppliers' current market situation as the purchase of a certain amount of supply normally is guaranteed by such agreements. Moreover, multiple sourcing can increase negotiation power while penalty clauses for non-compliance increase punitive power.

Five out of eight preventive measures which case company 3 employs have

[11] The total number is indicated excluding exploitation measures for reasons explained in Section 6.4.2.2.

Table 6.4.4. – Measures That Can Affect Power/Dependency Employed by Case Companies Which Appear to Hold Weak Power Positions

Case Company	Reference	Measures Affecting Power / Dependency	Share of Measures that Affect Power / Dependency
1 – manufacturer of glass-based products	Section 6.2.2 on page 225	Multiple sourcing, preparation of alternative suppliers, annual framework agreements, penalty clauses for non-compliance (planned)	Total: 4/11 Prevention: 4/7 Identification: 0/3 Elimination: 0/1
3 – producer of solar power-based heating systems	Section 6.2.4 on page 239	Multiple sourcing, high incoming goods inventory, annual framework agreements, long-term relationships, penalty clauses for non-compliance (infrequently used), substitution of material, in-house production	Total: 7/18 Prevention: 5/8 Identification: 0/4 Elimination: 2/6
6 – raw material trader	Section 6.2.7 on page 259	Multiple sourcing, high incoming goods inventory, annual framework agreements, networking for information acquisition, substitution of material	Total: 5/9 Prevention: 3/4 Identification: 1/2 Elimination: 1/3
7 – producer of soldering powder	Section 6.2.8 on page 266	Multiple sourcing, annual framework agreements, sourcing to professional traders, combined purchasing, networking for information acquisition	Total: 5/9 Prevention: 4/5 Identification: 1/1 Elimination: 0/3

been identified as affecting the company's relative power position. In addition to the measures explained above for case company 1, long-term relationships can level power relations. With substitution of material case company 3 also makes use of one bottleneck elimination measure which aims to decrease dependency on supply of particular material from a supplier.

Case company 6 makes use of three preventive measures which decrease dependency or increase power, out of four preventive measures in total. Also, this company uses social networking as a means to improve its information base by which the company reduces its dependency on information provision of individual suppliers. Moreover, in some cases the company would offer its customers alternative material if the material originally demanded is not available. Inhouse production capabilities reduce the company's dependency on supply of certain components from individual suppliers.

Four out of five preventive measures that are used by case company 7 either reduce dependency or increase power. Sourcing to professional traders – who tend to maintain a broad set of supply sources – reduces dependency on individual producers of raw material. Also, the company combines purchasing activities with a sister company in the same industrial conglomerate, which the interviewee describes as a means to increase purchasing power and negotiation weight.

The share of measures as presented in the right-hand column of table 6.4.4 on the preceding page is rather misleading, however, as it compares the number of measures that affect power or dependency with the total number of measures the company employs for each category of bottleneck management activities – although the number of measures in the categories identification and elimination is low in general. That it, the comparison might create the impression that the case companies tend not to employ many measures that will alter their relative power position. As tables 6.4.2 and 6.4.3 on page 355 show, however, only three out of 11 identification measures and three out of eight elimination measures affect power or dependency. That is, case company 3 employs two out of three possible elimination measures that affect power or dependency. Therefore, when trying to make a comparison of companies that state to be holding a

Table 6.4.5. – Measures That Affect Power/Dependency Employed by Case Companies Which Hold a Powerful Position

Case Company	Reference	Measures Affecting Power / Dependency	Total Number of Measures Affecting Power / Dependency
4 – raw material trader	Section 6.2.5 on page 247	Multiple sourcing, long-term relationships, close relationship with LSPs, information about supplier capacity, substitution of material	Total: 5 Prevention: 3 Identification: 1 Elimination: 1
5 – metal production	Section 6.2.6 on page 253	Multiple sourcing, high incoming goods inventory, blending of raw material, networking for information acquisition	Total: 4 Prevention: 3 Identification: 1 Elimination: 0
10 – raw material trader	Section 6.2.11 on page 290	Multiple sourcing, long-term relationships	Total: 2 Prevention: 2 Identification: 0 Elimination: 0

relatively weak power position with companies that hold a powerful position in their network, it seems more sensible to compare the absolute number of measures that affect power/dependency rather than the share of measures that affect power/dependency.

Case companies 4, 5, and 10 can be considered powerful companies due to both the absolute size in terms of revenue and their importance as key actors in their respective industry. Table 6.4.5 provides an overview of measures these companies employ which may affect their power position.

The number of measures employed that address power or dependency are higher for the sample of relatively powerless companies. The sample of case studies is too small to make valid statistical inferences. The purpose of this first comparison is to get an overview.

The comparison still seems too simplified though and thus needs additional refinement. A question that remained unaddressed until so far is the case companies' *intent* to employ a particular measure. Simply put: Does a case company employ a particular measure *in order* to alter its relative power position or for other reasons, with possible alteration of the relative power position merely being a side effect? To answer this question, each of the measures discussed above needs to be revisited with respect to its being a necessity, a deliberate choice to increase power (or decrease dependency), or a deliberate choice for other reasons than power. 11 preventive measures, three identification measures, and three elimination measures were identified in the case studies as possible levers for power relations in supply networks. Each measure shall be shortly revisited, in some cases separately for the sample of companies which are described as powerful and for the sample of companies that hold relatively weak positions in their network. As they were used above, the two samples were created from selected case companies so as to support the comparison of "powerful" and "less powerful" companies and the measures they pursue. Because no objective measure of power is available, the selection was made upon subjective yet careful assessment of each company's market position and purchasing volume as well as of statements made by interviews that relate to the respective company's power to suppliers or competitors. While it will be difficult to make any definite statement as to which company employs what measure for what reason, it seems worthwhile putting forth arguments for one choice or another to shed a light on some of the possible reasoning behind decisions to employ one particular measure or not.

Multiple Sourcing Multiple sourcing is the most prevalent measure identified in the study. Multiple sourcing can be either, a mere necessity for the case company or a deliberate choice. It is a necessity if one source of supply is unable to provide the focal company with the full amount of goods needed, so that additional sources of supply are required to meet the focal company's demand. Multiple sourcing can also be required by customers, as in the case of case company 7, some of whose customers make multiple sourcing mandatory for their suppliers. On the other hand, it can be a means to lessen dependency on one particular supplier and to improve negotiation power. For case company 3, this is the intent behind increasing the use of multiple sourcing in the future after it had been felt that some suppliers took advantage of their position as sole sources. That is, the role of multiple sourcing in this study has been three-fold: 1) to open up several channels so as to be able to receive enough supply to meet demand, 2) to meet customers' contractual requirements, and 3) to improve the company's negotiation position by decreasing dependency on individual suppliers. The reasoning behind the decision to make use of multiple sourcing might even consist of a combination of these reasons, or include all three reasons at once.

As to the preparation of alternative sources, it is unclear which of the case companies use this option – with exception of case company 1 for which the interviewee states that the company plans to increase the preparation of alternative suppliers which will remain passive until needed. At case company 4, the interviewees explain that their company often uses one primary source and some secondary sources in terms of purchasing volume, which is similar to the idea of maintaining a set of suppliers that are prepared to chime in as a contingency option.

Because it is unclear to what extent the other case companies are preparing alternative sources that remain passive, no inference can be drawn from this point.

Sample of Companies Holding a Powerful Position For raw material traders, the use of multiple sources comes rather naturally. Not every producer is able to deliver all different qualities of a particular raw material such as lead or tin, so that relationships with several suppliers exist at once, which, in turn, creates redundant sources for other qualities of the same raw material. Three of the four raw material trading firms that participate in the study are either large or even leading in their industry (two of them listed in table 6.4.5) whereas one firm (case company 6) is rather small and takes a niche role. The three larger firms are not likely to use multiple sourcing as a means to increase their negotiation power. They are important players in their field and maintain long-term relationships with a variety of suppliers. Furthermore, the price they pay suppliers for the raw material which they make available to their customers has barely any direct financial implication as it is passed through to their customers (with a "service charge" added). Much of the material these companies buy and sell is traded at the London Metal Exchange, so that information about price is publicly available. Therefore, attempts to increase negotiation power are unlikely to play an important role behind the raw material traders' decision to use multiple sources of supply.[12]

Similar reasoning can be applied to case company 5, the producer of metal. The company is one of one of the world's largest producers for that type of metal. Hence, the use of multiple sources of supply seems to be a logistical necessity rather than a means to improve the company's power position. Also, the sources used for the (primary) raw material the company receives are located according to the natural distribution of this material on the globe.

Therefore, if anything can be said at all about the sample of case companies which were labeled powerful and its the use of multiple sources, often located in diverse geographic areas, then it seems to be largely unrelated to questions of power and dependence and instead seems to be a necessity or a prudent business decision so as to receive the amounts of raw material needed for their day-to-day business. However, because of the industries the respective case companies from this sample are active in and because of the implication this has on the way they structure their supply network, a conclusion shall not be inferred.

[12]By the same token, geographic spread of sources – excluded from the set of measures that have the potential to influence power relations anyway – seems to be a natural consequence of the raw material traders' use of multiple sources rather than a deliberate choice to hedge against the risk of locally confined disruption of the supply chain. The use of raw material that is extracted from naturally distributed sources involves the use of suppliers from different places, often different continents. Moreover, some geographic areas are dominating the availability of supply to an extent that would render replacing these sources difficult or impossible. One example is tin from Indonesia.

Sample of Companies Holding a Relatively Weak Position One raw material trader – case company 6 – is part of the sample of companies that have been identified as holding a relatively weak power position in their network. Nonetheless, the arguments outlined above for the three more powerful raw material traders hold for this case company, too. The use of multiple sourcing is unlikely to represent a measure to increase power (or lower dependency) relative to the case company's suppliers.

Case company 1 is a manufacturer of glass-based products and as such faces limitations inherent to the production logic of glass producers as outlined in Section 6.2.2 (the "*newspaper vendor's problem*"). Maintaining more than one source of supply (and having some more sources prepared for contingency) thus appears like a prudent business decisions in order to increase reliability of supply. Indeed, the need to increase reliability of supply is emphasized by the interviewee. At the same time, the interviewee remarks that there is a tendency that it is the more powerful suppliers which let the case company down. Thus, multiple sourcing seems to fulfill a dual role: as a means to cope with the unpredictability of supply in the case company's industry as well as means to lessen dependency on powerful suppliers which occasionally let the case company feel its relative lack of importance as a customer.

Case company 3 has a tradition of using single sourcing with long-term suppliers. After the company experienced disappointment with suppliers which took advantage of their position as sole sources, the company plans to increase the number of sources for some components, according to the interviewee. Thus, for case company 3 the use of multiple sources seems to be clearly associated to questions of power and dependence.

For case company 7, the use of multiple (dual) sourcing in some cases is mandatory because of the requirements imposed by some customers. Hence, the use of multiple sourcing clearly is a necessity for this company. Because multiple sources are required by *some* customers, they are available to be used for production for *other* customers, too. The interviewee states that forecasts received by some customers only cover a period of two weeks starting from the day the forecast is received. This stresses the importance of flexibility on part of the case company, and thus underlines the need for multiple sources. The use of professional trading firms as source for raw material follows the same logic as trading firms tend to maintain a broad portfolio of sources.

Annual Framework Agreements Annual framework agreements include an estimated amount of parts or material the focal company will purchase from the supplier with whom it has signed the agreement. The commitment attached to such an agreement often is bidirectional. That is, the buying firm will expect the supplier to be able to provide the amounts stated in the agreement just like the supplier will expect the buying firm to call off roughly the amounts stated in the document. In practice, forecasts are often wrong and suppliers might build up production capacities that remain largely unused when the amounts forecasted and stated in the framework agreement were too optimistic. When actual call-offs significantly diverge from the amounts agreed upon, the relative power position and quality of the supply relationship become important. In an earlier study (Beer 2011), one interviewee from an automotive supplier described the large discrepancies that sometimes exist between framework agreements and actual call-offs. In many cases, car makers – as the usually more powerful entities – do not have to face consequences when demand estimations are far off.

One of the most important benefits of framework agreements is that they reduce surprises by fostering planning and communication about expected demand. Suppliers can thereby adjust their capacity (and possibly scale up production capacity) and customers do not have to fear that suppliers will be unprepared for orders that fluctuate around the agreed upon baseline. For the buying firm, this implies that it is less dependent on suppliers' goodwill since an agreement has already been reached.

Sample of Companies Holding a Powerful Position As outlined in the previous paragraph, framework agreements provide both entities with some security in their planning. Buying firms in particular reduce the significance of the "power element" from the relationship unless suppliers are willing to violate terms and conditions of the framework agreement. Accordingly, one would expect that framework agreements play a less important role for powerful companies. Indeed, none of the three case companies from the sample of powerful companies has stated to be using annual framework agreements with their suppliers. A study of the automotive industry (Beer 2011) reveals, however, that framework agreements are most common for car makers and their suppliers. One possible explanation for this discrepancy is that OEMs in the car industry make extensive use of single sourcing, whereas all three companies from the sample of powerful case companies use multiple sourcing extensively. With single sourcing, car makers are more dependent on each individual supplier's reliability so that they may try to make sure the supplier has had enough time to set up production capacities according to the OEM's needs, which such an agreement facilitates. Powerful companies with multiple parallel sources of supply are less dependent on each individual supplier's reliability. Moreover, two of the three case companies in this sample are raw material traders. While they have framework agreements with some of their customers (so that the amounts included in such agreements with customers can be "mirrored" into the agreements with their suppliers), they may receive orders from other (new) customers which they cannot foresee and which are more difficult to be considered within framework agreements with their suppliers.

It should be noted again, however, that just because interviewees from this sample of companies did not mention framework agreements with their suppliers it does not necessarily mean that they do not make use of them. It could be that interviewees did not consider framework agreements a measure of bottleneck management so that they remained unmentioned.

Sample of Companies Holding a Relatively Weak Position Based on the previous explanations, one would expect that companies with a relatively weak position as compared to their suppliers make use of framework agreements with their suppliers. In fact, within the sample of companies with a relatively weak position in their network, all four companies use framework agreements with their suppliers (whereas from the sample of powerful companies none of the three companies states to be using framework agreements). This stark division between the two samples could suggest that annual framework agreements are indeed understood as a means to alter, or at least to better cope with, unfavorable power relations. None of the interviewees, however, elaborated on the use of framework agreements, nor on the intent behind their use. That is, the intent remains unclear; accordingly, a causal relationship between the use of framework agreements and attempts to alter power position cannot be established for this sample.

Framework agreements indicate that supply relationships are not ad hoc and "arm-length" but will persist for an extended period of time. In the automotive sector, for instance, supply relationships often exceed the production life cycle of the car (often about seven years) as small amounts of parts are delivered during development and ramp-up of production and additional parts may be requested as replacement parts after the regular production life cycle has ended. That is, framework agreements often indicate long-term relationships, which may level power and dependency, as Cook (1977) points out with reference to Emerson (1972).

Long-term Relationships Four case companies have emphasized their effort to maintain long-term relationships with their suppliers. As pointed out previously, the implication of long-term relationships on power constellations is that they might level power differences to some extent. One reason why power differences may decrease over the long-term is that companies possibly increase their asset specificity. Asset specificity may lead to higher switching cost for either party, possibly contributing to either party's inclination towards stability and endurance of the relationship.

Sample of Companies Holding a Powerful Position Case companies 4 and 10 have emphasized good and long-term supply relationships as a key measure to the prevention of bottlenecks in their supply network. Both companies have considerable negotiation power due to their purchasing volume and the leading position they hold in their respective industry segment. Both, case company 4 and case company 10 are raw material traders. Also, case company 9 –

not part of this sample, but with considerable transaction volume nevertheless – has stressed the importance of long-term relationships. This suggests that long-term relationships may play a particularly important role for companies active in raw material trade. One possible explanation is that the number of suppliers of certain raw materials is limited by the natural distribution of such resources and by the exploitation licenses granted by the governments of the respective countries. Some suppliers thus hold a natural monopoly for a particular material. Hence, long-term relationships might indeed be a means to secure access to (sometimes scarce) resources, thus indeed addressing aspects of power and dependence – in spite of the case companies' impressive size and transaction volumes.

Sample of Companies Holding a Relatively Weak Position The only company from this sample that emphasizes the importance of long-term relationships is case company 3. The interviewee at case company 3 explains that long-term relationships with suppliers are an important part of the company's culture as sustainable and long-term thinking has been one of the pillars the company was founded on. Hence, the choice to maintain long-term relationships seems not to be primarily motivated by aspects of power and dependency.

High Incoming Goods Inventory Incoming goods inventory provides a buffer against irregularities in supply. At the same time, such a buffer incurs capital cost. Value of the material thus is one of several factors that are normally taken into consideration when deciding about the level of incoming goods inventory. By buffering irregularities in supply through inventory (instead of time), firms increase their resilience. Although the power configuration in the network as such is not altered, the buying firm reduces its vulnerability to supply glitches and thus its dependency on the reliability of the supplier. The buying firm becomes less vulnerable to problems resulting from power disadvantages in the supply relationship.

Sample of Companies Holding a Powerful Position From the sample of powerful firms, only case company 5 uses high incoming goods inventory. Case company 10 does not keep any significant inventory. Case company 4 keeps enough inventory to bridge irregularities such as delayed arrival of overseas shipments. Because case company 4 offers a broad variety of brands it cannot keep high inventory levels of many of them. Case company 5 uses an external service provider to take care of incoming material, which includes blending of material from different sources so that consistent quality is ensured when the material is fed to the production process. An association to power or dependence is not known to play a role for case company 5 in its decision to keep high inventory.

Sample of Companies Holding a Relatively Weak Position Among this sample, two companies state to be keeping high inventory levels of incoming goods.

For case company 6, keeping relatively high inventory levels is part of the business model as it allows the company to react quickly to customer orders. The capital cost incurred is considered in the pricing of the company's services, and customers seem to be willing to pay the premium in exchange for almost immediate access to the products they need. Hence, power or dependency seem not to be important drivers for the decision of case company 6 to keep high levels of incoming goods inventory.

The situation is different for case company 3. The company has a tradition of single sourcing and experienced that individual suppliers took advantage of their position as sole sources, leading to higher prices they charged for supply as well as to irregularities in delivery. The interviewee mentions that in one case a supplier admitted that another customer was prioritized higher so that delivery of the material ordered by the case company were be delayed. In order to deal with irregularities in supply, the company has kept high levels of incoming goods inventory, according to the interviewee. Thus, it can be concluded that power disadvantages led to the decision to keep high levels of incoming goods inventory.

Penalty Clauses for Non-Compliance Kumar (2005) mentions punitive capability as one type of power. Penalty clauses for non-compliance can be considered one way to formalize punitive capability in supply contracts. Non-compliance can refer to the supplier's inability to deliver according to the framework agreement, e.g., too low amounts, insufficient quality, or too late. By the terms of the contract, suppliers could be held responsible for financial losses that the buying firm has to bear because of the supplier's performance.

In some cases, penalty clauses for non-compliance exist but are not actively enforced. In the automobile industry, car manufacturers tend to include penalty clauses in contracts with suppliers. If automotive suppliers had to bear the (often enormously high) cost for production interruptions at car makers, however, they might be forced to file for bankruptcy, which would cause even more severe irregularities in supply. Also, interviewees in an earlier study suggested that in spite of penalty clauses in contracts, the buying firm might rather seek a "cooperative" solution with the supplier (Beer 2011).

The interviewee at case company 8 (not part of either sample) raises the point that buying firms dealing with much larger suppliers might not be able to include penalty clauses in supply contracts against the will of the supplier. That is, companies might have to possess a certain amount of power in the first place so as to be able to include penalty clauses; the power gap must not be too large. On the other hand, the power advantage, e.g., due to company size and turnover, must not be too large, either, so as to not risking the supplier survival. Accordingly, penalty clauses seem to be an effective instrument only in network configurations where buying firm and supplier are of comparable size and power.

Sample of Companies Holding a Powerful Position None of the companies from this sample (nor any larger company not part of the sample) has stated to be using penalty clauses in supply contracts. As in other cases, it does not mean that penalty clauses are never used but merely that they remained unmentioned by the interviewees. One possible explanation is that two of the case companies from this sample are raw material traders and the third company, too, receives raw material directly from mines. Possibly, it might not be common to have penalty clauses in such supply relations. None of the other raw material traders that are not part of this sample states to be using penalty clauses, either.

Sample of Companies Holding a Relatively Weak Position Two companies from this sample state to be using penalty clauses for non-compliance in supply contracts.

The interviewee at case company 1 emphasizes that he would like to expand the use of penalty clauses and include them in a greater number of new supply contracts. At case company 3, the interviewee says that 90% of all supply contracts do not include penalty clauses, which may be explained with the company's emphasis on good and long-term supply relations which would probably not be supported by punitive action. This is in spite of the fact that the company was adversely affected by suppliers' material allocation decisions in the past (cf. Section 6.2.4).

Hence, it is not possible to draw any clear conclusion about the use of penalty clauses in supply contracts by companies with a relatively weak position in their network. One company plans to increase the use of penalty clauses while the other company uses them only infrequently (and does not indicate that this about to be changed).

Sourcing to Professional Traders By sourcing to professional traders, companies tap the ability of such suppliers to ensure reliable supply from a broad variety of sources. Also, as the interviews with four raw material traders suggest, professional traders tend to maintain a very high service level with their customers for this is one key requirement to be successful in their business. The strategies the traders employ differ with respect to inventory they keep. Two traders maintain extensive inventory so as to be able to serve customer orders from stock at short notice. One trader does serve orders from stock, too, but notes that the inventory level is not particularly high and serves to bridge irregularities in supply. One trader does not keep any significant amounts of material on stock but passes through material from suppliers to customers (with higher order lead time than the other traders). In either case, interviewees emphasize that reliable order fulfillment is key in their business so that customers can be sure to receive the material on schedule as ordered.

Sample of Companies Holding a Powerful Position Two of the three companies from the subset of powerful companies are professional traders themselves and receive their material directly from producers of that material. Case company 5, the one remaining company in this set, has not mentioned sourcing to professional traders. That is, the data base for this sample is not suited to make any inference about the relationship between sourcing to professional traders and the intent to alter power relations in the network.

Sample of Companies Holding a Relatively Weak Position Sourcing to professional traders was mentioned by two companies from the total set of companies and by one company – case company 7 – from the subset of companies with a relatively weak position in their network.

For many products, case company 7 receives demand forecasts only for a very short time period. Some of the company's customers stress the importance of reliable supply, which is why they make sourcing to at least two suppliers (which they will have to approve prior to contract closure) mandatory for the case company. Professional raw material traders – at least those which keep much of their material on stock so as to be able to meet customer orders at short notice – provide flexibility and a high service level which the case company is dependent on. Moreover, the amounts of material the case company receives from its suppliers are likely to be considered "insignificant" by some larger suppliers, which might make sourcing to professional traders necessary for smaller amounts can be ordered. Though the latter argument is rather speculative and inferred by analogy to case company 8, it seems likely that case company 7 has made the decision to use professional traders out of necessity or prudence rather than with respect to alter power relations.

Close Relationship with LSP Two case companies stressed the importance of good relationships with logistics service providers (LSPs). The underlying logic as to why a close relationships with an LSP may alter power relations is analogous to framework agreements and long-term relationships. The parties become invested with each other so that power differences may decrease.

Sample of Companies Holding a Powerful Position One firm from the sample of powerful companies emphasizes good relationships with their LSPs as being important for their business. In addition, case company 2 which is not part of this sample but also of considerable size points out that they take care of the contract with LSPs even for their supply – and do not leave this to their suppliers.

There is no clearly visible evidence, however, that the decision to maintain a close relationship with an LSP has to do with attempts to increase power or lower dependency.

Sample of Companies Holding a Relatively Weak Position None of the case companies from this sample mentions close relationships with LSPs as an important instrument. This creates the appearance that close relationships with LSPs are not considered a common measure to elevate the power position of the firm as compared to their LSPs or even suppliers.

Combined Purchasing Combined purchasing was mentioned by two case companies (one of which within the sample of weak companies) and was described as a direct attempt to increase the company's negotiation power as compared to its suppliers by increasing the purchasing volume at stake.

Sample of Companies Holding a Powerful Position None of the interviewees at companies from the sample of powerful companies mentions the use of combined purchasing, e.g., with other companies of the same conglomerate. The most obvious possible explanation is that companies which are already powerful and purchase large volumes do not need to further increase the purchasing volumes by combining the purchasing process with other entities.

It can be noted, however, that there are cases where even powerful companies teamed up for combined purchasing. There are cooperation projects for combined purchasing between large car makers, which are usually limited, however, to certain components (such as hybrid batteries) or regions (e.g., NAFTA region or China) (Beer 2011).

Nonetheless, there is no evidence that such a strategy is pursued by any of the powerful case companies in the sample as a means to increase power.

Sample of Companies Holding a Relatively Weak Position Case company 7 is combining some of its purchasing activities with a sister company from within the same industrial conglomerate. As the interviewee explains, the declared goal is to increase negotiation power as compared to suppliers through higher purchasing volumes at stake. Therefore, this is a clear case of a company with a relatively weak position in the network making an attempt to decrease the power disadvantage to suppliers by combining purchasing activities with a third party.

Blending of Raw Material The blending of raw material prior to its feeding to the production process is a measure with very limited application outside a range of chemical processes and companies, which is why the discussion of this point is not further divided into the sample of powerful and relatively weakly positioned companies.

When raw material from different sources is blended – whether it is vine grapes, olives, or copper concentrate – the operator is able to create a standardized quality that lets him run the actual production operation without much variation of the parameters he would otherwise have to adjust if the quality of the raw material varied. At the same time, it makes the company more independent of any specific source of its raw material. Theoretically, the company would then be able to use greater amounts from a supplier with more beneficial terms or better pricing.

Although it cannot be stated with certainty that greater independence has not been one aspect, it is much more likely that the decision to blend raw material from different sources prior to the production process of case company 5 is to support stability in the – somewhat inflexible – production process so that production parameters do not have to be varied.

Measures of Bottleneck Identification (Networking, Information About Supplier Capacity, Monitoring) Three bottleneck identification measures were identified which can be associated with the altering of power configurations in the supply network. Generally, all such measures aim to improve information access and thereby create an information surplus for the case company. Good and actionable information provide advantages for decision-making at the companies – regardless of possible advantages for the configuration of power that might be attached. It might be too far a stretch to argue that any of the actions that fall into the category of bottleneck identification and that were associated with potential power advantages – networking activities for information acquisition, collecting information about supplier capacity, and monitoring of supplier activity – are selected for reasons of gaining power advantage. There is no evidence from the interviews with the case companies that increase of power or decrease of dependency have been important aspects behind the decision to put such measures into action.

Measures of Bottleneck Elimination (Substitution of Material, In-house Production, Escalation to Management) The substitution of material is a bottleneck elimination measure that is chosen by four of the case companies, one from the sample of powerful companies, two from the sample of companies with a relative weak position in their network, and one company from outside either sample. The underlying mechanism is that another component or raw material replaces the component or raw material originally demanded when for some reason these are not available (in sufficient amounts). Raw material (such as different types of metal) of lower purity, for instance, can often be replaced by raw material of higher purity which would normally not be chosen for the higher purity tends to come at higher (purchasing) cost and might not provide an advantage for the particular application. Companies can thereby reduce their dependency on an particular supplier or a particular raw material.

The substitution of material does usually not come for free. New material might have to be approved for production by quality auditors, the company may not have time for extensive testing and thus runs the risk of disappointing customers should the material turn out not fulfill quality expectations, and – in case of purchase of raw material – material of higher purity tends to be more expensive than material of lower purity Therefore, material substitution can be considered a contingency measure that under most circumstances would be avoided and becomes only reasonably applicable should the material or component originally demanded be unavailable in sufficient amounts, i.e., should the original material be subject to a supply bottleneck. It is clearly a reactive measure; it does not alter power configurations upfront so as to prevent supply bottlenecks in the first place. Instead, the substitution of material is a reaction and aims to resolve bottlenecks. As such, although it does reduce the company's dependency on the availability of supply from one or more particular source(s), power and dependency appear to be secondary rather than primary aspects. Moreover, the ability to substitute material seems to be influenced too much by the industry the respective company is operating in: Three of the four case companies that state to be using substitution of material in bottleneck situations are purchasing raw material (as opposed to manufacture/assembled goods); homogenous material – arguably – is easier to replace with another homogenous material with similar characteristics than assembled or manufactured components to whose shape and configuration often many different companies have contributed and which might stand in complex interdependency with other components to which they will be mounted, welded, or otherwise attached.

Therefore, it must be concluded that based upon the data from this study no evidence can be found that the substitution of material is – consciously – associated to questions of power by the firms employing this measure. This does not exclude the possibility that in other cases, firms may choose to develop contingency options such as the substitution of material so as to increase their independence from particular suppliers or particular types of raw material – and thereby reduce possible disadvantages that result from a "power gap" to suppliers or “competing” customers of the same suppliers. For the case data at hand, however, such a causal connection cannot be established for the substitution of material.

The same applies to the two other bottleneck elimination measures that were found to have a possible relation to power or dependency, in-house production of components that are normally produced and delivered by suppliers, and escalation to management.

In many cases, production firms are able to produce a component in-house that for reasons of efficiency was outsourced to an external supplier. The production of material in-house – as opposed to receiving the same material from a supplier – can be considered a special case of “switching sources”, with the specialty being that the new source of supply is internal. Also, it is similar to the substitution of material in that it allows the company concerned to continue production and sales. In-house production was mentioned by two case companies as an option that can be pursued in case of insufficient supply, one of which is part of the sample of companies with a relatively weak position in their network. As with the previous measure, the two samples of companies are not suited well to draw any conclusion as to a possible causal relation between thinking in terms of power and maintaining the capability to produce in-house. For one thing, two of the three case companies from the sample of powerful companies and one company from the sample of companies with a relatively weak position in their network are raw material traders and do not possess any production capacity – they buy and sell. For another thing, the third company from the sample of powerful companies receives natural raw material from its suppliers as input to the production process which has to be mined and thus cannot be produced in-house. Therefore, a clear statement as to a possible relationship between power or dependence and in-house production cannot be made based upon the case data.

As to the escalation to management, it is clearly a way to harness the power of hierarchy and to improve the organization’s negotiation position as compared to the counterpart. It is merely leveraging the power the organization already has, however, rather than improving its power position as a whole. The relative power of the organization as such is not altered. The interviewee at case company 3 – from the sample of companies with a relatively weak position in their network – mentions this options as a way to increase pressure on the negotiation counter-part at the supplier so as to achieve higher prioritization of the case company's needs on the supplier's "agenda". It can be speculated as to whether companies with a weak power position in their network would need to involve management to increase pressure in negotiations about the continuation of supply more often than powerful companies would. Though it would appeal to reason, the data won through the interviews in this study do not provide enough evidence for a clear answer. While there is only one company in this study that explicitly mentioned that management sometimes is involved to resolve problems that are impossible to solve or take too much time to solve on a lower hierarchical level, in an earlier study (Beer 2011) it became evident that even large car manufacturers with high reputation and market power retreat to involving higher management hierarchies to resolve problems with suppliers should the situation be such that critical parts cannot be delivered on time and there is explicit risk of production line stoppage at the car manufacturer due to lack of supply. That is, even company's possessing a high power position in their network "escalate" problems to management to accelerate the development of a solution when negotiation with suppliers.

Summary and Critical Review The review of bottleneck management measures with respect to their meaning for power and dependence was intended to shed light on the question as to whether a causal connection can be established between a company's relative power position in its supply network and measures of bottleneck management it employs. The results of this review are mixed.

The review suffers from a variety of constraints, so that the conclusion has to be formulated with caution. The overall number of companies involved in the case study is small, and so are the numbers of companies selected for each of the two samples. Hence, valid statistical inferences are impossible. The approach has therefore been to look at the situation of each individual case company within the samples so as to better understand the reasoning or intent behind choosing to perform a certain measure. More specifically, the question was whether the intent behind choosing a measure was (1.) merely a business necessity (or at least a prudent business decision), (2.) an attempt to improve the case company's power position in the network, or (3.) deliberate for other reasons than power.

For some of the measures, a light could be shed on the intention by separately analyzing and then comparing the two samples of companies. For other measures, this was not possible because other factors or properties of the entities were likely to influence the outcome too much so that an isolated analysis of aspects of power would have lead to distorted results. Two of the most powerful case companies, for instance, are both active in raw material trade, while the third one is also purchasing raw material (as opposed to manufactured or assembled components) as input to its production process. This makes the sample unsuitable for the analysis of measures such as "sourcing to professional traders". By the same token, no statements about a causal relationship between "blending of raw material" and power or dependence can sensibly be made since this is an option that companies that purchase assembled or otherwise manufactured components (as opposed to homogenous raw material) cannot pursue. Other factors that inhibited the analysis of bottleneck management measures and their relationships to power and dependence are incomplete information about bottleneck management activities (not every interviewee responded with the same level of detail; not every interviewee was aware of all measures – or might not consider certain activities as related to bottleneck management) as well as the lack of an objective measure of power, so that the creation of the samples of powerful and less powerful companies was based on the researcher's subjective assessment won through the interviews. The review is summarized in Table 6.4.6.

Table 6.4.6. – Summary: Review of Bottleneck Management Measures That Seem to be Chosen for Reasons of Power

Measure	[A] Sample of Firms with Powerful Network Position	[B] Sample of Firms with Relatively Weak Network Position	Summary
Multiple Sourcing	Necessity: 4, 5, 10 For power: – Other reasons: – Unclear: –	Necessity: 1, 6, 7 For power: 1, 3 Other reasons: – Unclear: –	Sample [B] provides evidence that firms with low power in their supply network choose multiple sourcing to reduce dependency. No conclusion can be drawn about sample [A], however.
Annual Framework Agreements	Necessity: – For power: – Other reasons: – Unclear: –	Necessity: – For power: – Other reasons: – Unclear: 1, 3, 6, 7	Framework agreements were not mentioned in sample [A] while all interviewees from sample [B] state to be using framework agreements. This division might suggest that a company's power position and its decision to use framework agreements are not independent of each other. More detailed information could not be obtained, so that a clear conclusion can be drawn with certainty.

Long-Term Relationships	Necessity: 4, 10 For power: – Other reasons: – Unclear: –	Necessity: – For power: – Other reasons: 3 Unclear: –	That no entity of sample [B] associates this measure with power suggests that relationships are not normally maintained over the long term for reasons of power. For the two entities of sample [A] that emphasize long-term relationships they seem to be mostly a business necessity.
High Incoming Goods Inventory	Necessity: – For power: – Other reasons: 5 Unclear: –	Necessity: 6 For power: 3 Other reasons: – Unclear: –	The interviewee at case company 3 indicated that high inventory levels have been a measure that was used to cope with irregularities in supply. For case company 3, irregularities in supply are at least partly related to power disadvantage. Thus, there is evidence that the use of this measure was motivated by reasons of power.
Penalty Clauses for Non-Compliance	Necessity: – For power: – Other reasons: – Unclear: –	Necessity: – For power: – Other reasons: – Unclear: 1, 3	No conclusion can be drawn about the use of penalty clauses and its relationship to power and dependence.

Sourcing to Professional Traders	Necessity: – For power: – Other reasons: – Unclear: –	Necessity: 7 For power: – Other reasons: – Unclear: –	Because two of the three companies from sample [A] are professional traders themselves, the sample is not suited to draw any conclusion about a possible causal relationships between sourcing to professional traders and power. For sample [B], too, the data does not allow any clear conclusion.
Close Relationship to LSPs	Necessity: – For power: – Other reasons: 4 Unclear: –	Necessity: – For power: – Other reasons: – Unclear: –	The data does not provide any evidence as to a possible causal relationship between the power position of a firm in its supply network and its maintaining a close relationship to LSPs.

Combined Purchasing	Necessity: – For power: – Other reasons: – Unclear: –	Necessity: – For power: 7 Other reasons: – Unclear: –	For case company 7, the interviewee made clear that the intent behind the use of combined purchasing with a sister company is to increase the companies' negotiation power. While other reasons are certainly conceivable, too, to combine purchasing functions, increased power may well be among the dominant reasons.
Blending of Raw Material	Necessity: 5 For power: – Other reasons: – Unclear: –	Necessity: – For power: – Other reasons: – Unclear: –	Only one case company blends the raw material prior to using it in the production process. In this case, it seems to be a prudent business decisions rather than primarily an attempt to alter power relationships.
Measures of Bottleneck Identification	Necessity: – For power: – Other reasons: – Unclear: –	Necessity: – For power: – Other reasons: – Unclear: –	No evidence can be found to establish a causal relationship between the three measures of bottleneck identification priorly identified in this context and the intent to alter power relations.

Measures of Bottleneck Elimination	Necessity: – For power: – Other reasons: – Unclear: –	Necessity: – For power: – Other reasons: – Unclear: –	The samples are not suited to establish a possible causal relationship between the intent to use these measures and power/dependency.

In short, the proposition which was discussed – and which continues to be up for testing – is as follows: A relatively weak power position in supply network leads a buying firm to the selection of bottleneck management measures that improve its relative power as compared to, or lessen its dependency on, suppliers.

Some evidence for this proposition could be identified from the case study data, yet the data set is too sparse and the samples are less than optimal. The analysis of the intent behind chosing specific bottleneck management measures does, however, provide a fruitful basis for further study of this proposition.

6.4.2.4. Summary

The preceding discussion demonstrates that many measures of bottleneck management, especially those that are preventive in nature, *can* serve to alter existing power relations in supply networks in favor of the focal firm and in some cases are recognized and employed by case companies for this purpose. This implies that power relations play a more important role in supply networks than the body of literature on Supply Chain Management suggests. Non-adjacent power regimes were identified as important constructs that can influence the outcome of the focal firm. Literature on SCM still tends to emphasize the primacy of cooperation while many measures firms employ in practice to make their supply situation work in fact aim to increase their power or reduce their dependency, respectively.

6.4.3. Bottleneck Management and Risk

6.4.3.1. How Bottleneck Management Aims to Control Risk Factors

In Section 3.6, risk was defined as “uncertainty about and severity of the consequences of an activity” (Aven 2010). The bottleneck management activities identified in this thesis can be related to this definition of risk.

As it is apparent from the definition chosen for this thesis, risk consists of two main factors. The first factor is uncertainty. Uncertainty in this context refers to the incomplete information an organization has with regard to the possible emergence of a bottleneck. The second factor is the severity of the consequences. Provided a bottleneck emerges, the consequences may be severe or not, depending on contingency plans, the measures the organization has taken, chance, et cetera. Organizations can choose to tackle each of the two factors with their bottleneck management activities, so as to reduce the uncertainty as well as the severity of bottlenecks in their supply. The data analysis has shown that organizations indeed tackle both factors. Table 6.4.7 provides an overview of preventive bottleneck management measures and how they affect each of the two constituting factors of risk.

Table 6.4.7. – Preventive Bottleneck Management Measures and How They Affect Risk

Measure	Risk Factor (Uncertainty / Consequences)	Explanation	Case References
Multiple sourcing (parallel)	Uncertainty	Use of multiple sources in parallel decreases the chance that supply interruptions will occur and affect production capability.	all

Multiple sourcing (alternative)	Consequence	Preparation of alternative sources allows the firm to switch sources at short notice and thereby mitigates adverse effects of supply bottleneck at original source.	unclear
Annual framework agreements	Uncertainty	Framework agreements prepare suppliers for estimated demand and thereby reduce uncertainty concerning production capacity reserves.	1, 2, 3, 6, 7, 8
High incoming goods inventory	Consequence	Incoming goods inventory allows the firm to continue production for some time should supply interruptions emerge.	3, 4, 5, 6, 9
Supplier audits	Uncertainty	Supplier audits reveal potential shortcomings at suppliers' production sites and provide the basis for improvement measures that will help avoid emergence of bottlenecks. Awareness both of suppliers and focal firms is increased.	1, 2, 7, 8

Long-term relationships	Uncertainty	Long-term relationships support trust, mutual understanding of, and communication between the parties involved, thereby decreasing the chance of interruptions.	3, 4, 9, 10
Standardized sourcing criteria	Uncertainty	Standardized sourcing criteria are meant to define a proven standard for sourcing decisions that will help reduce the chance of supply interruptions.	1, 2, 8, 9
Buying power and reputation	Uncertainty	Suppliers seem to be less likely to let down customers who are considered important.	4, 5, 10
Consignment warehouse	Uncertainty	Consignment warehouses provide transparency as to actual height of inventory at the customer's site and thus decrease the chance of understocking.	6, 8
PCF agreement	Uncertainty	PCF agreements help cope with variations in demand and thereby help avoid physical bottlenecks.	1, 3

Sourcing to professional traders	Uncertainty	Professional traders maintain a broad supplier portfolio and thus are less likely to be unable to deliver as promised.	7, 8
Suppliers receive forecast data	Uncertainty	Providing suppliers with forecast data reduces uncertainty and thus the chance of irregularities in supply.	2, 3
Supplier development programs	Uncertainty	Supplier development and training aims to improve suppliers' operational capabilities and thereby contributes to decreased chance of supply interruptions.	2, 8
Close relationships with LSPs	Both	Close relationships foster communication and cooperation with LSPs and there reduce the chance of irregularities in delivery. At the same time, close relationships open up the venue for improved options for recovery in case of contingencies.	2, 4

Preference for suppliers with short lead time	Both	Short lead time facilitates catching up with production and delivery schedule should irregularities arise and decreases the chance of irregularities in the first place.	3
Suppliers maintain safety stock	Consequence	Safety stock at supplier sites provides a buffer against slipping supply schedules.	2
Information about supplier capacity	Uncertainty	Information about capacity available at suppliers' production sites helps firms plan for contingencies and thereby reduces uncertainty.	4
Combined purchasing	Uncertainty	Higher buying/negotiation power increases customer's importance for the supplier and supports preferred treatment.	7
Suppliers belong to same corporation	Both	Choosing suppliers which belong to the same organization is likely to enable the focal firm to exploit the strong ties and thereby reduce chance of irregularities and invoke preferred treatment should irregularities arise.	10

Blending of raw material	Consequence	Blending of raw material from different sources enables the firm to compensate the loss of one source of supply by increasing the share of supply it sources to another supplier, which increases resilience against production interruptions.	5
Scenario planning	Uncertainty	Scenario planning increases the awareness of the firm for possible sources of interruptions and thus supports the identification of suitable measures to prevent unfavourable incidents.	5

The table shows that among preventive measures there is a strong focus on reduction of uncertainty while mitigation of consequences plays a rather marginal role. Mitigation measures can be found instead in the bottleneck exploitation and elimination categories: all measures of these categories aim to mitigate the adverse effect of bottlenecks once they have emerged or eliminate bottlenecks, respectively, which is only logical given that exploitation and elimination measures can only be employed reactively – once the bottleneck is already there. Bottleneck identification as such does neither affect uncertainty nor consequence but rather provides the basis for exploitation and elimination measures. Table 6.4.8 provides a short summary.

Table 6.4.8. – Summary: Bottleneck Management Activities and Risk Factors

Bottleneck Management Activity	Risk Factor (Uncertainty / Consequence)
Bottleneck Prevention	Mostly reduction of uncertainty, partly mitigation of consequences
Bottleneck Identification	Provides information base for mitigation of consequences (exploitation or elimination)
Bottleneck Exploitation	Mitigation of consequences
Bottleneck Elimination	Mitigation of consequences

6.4.3.2. Summary

The short analysis of the relationship between bottleneck management measures and risk suggests that bottleneck management measures as identified in the multiple-case study provide the means to tackle both of the factors that constitute risk: uncertainty and severity of consequences. Bottleneck management thus can represent a valuable building block to risk management in supply networks, often referred to as Supply Chain Risk Management (SCRM). Measures of bottleneck prevention predominantly aim to reduce uncertainty. As explained in Section 3.6, uncertainty includes – but is not limited to – probability. Several bottleneck prevention measures aim to reduce the probability of the emergence of unplanned bottlenecks. Bottleneck exploitation and bottleneck elimination address the second factor of risk which is severity of consequences. These measures aim to decrease the severity of supply bottlenecks. Bottleneck identification provides the information basis therefor.

Hence, risk management and bottleneck management are not exclusive. Instead, each discipline approaches an overlapping set of objectives from different angles and with different conceptual foci. A bottleneck management perspective is likely to provide value to and augments risk management as it introduces additional viewpoints. By the same token, research on risk management is likely to add additional value on bottleneck management.

6.4.4. Bottleneck Management and Flexibility

6.4.4.1. How Bottleneck Management Increases Flexibility or Reduces Variability

Lean, agile, and leagile supply setups for supply networks were discussed in sections 3.3 and 3.5, respectively. *Reduction* has been said to be one core concept of Lean. To make a system lean, reduction efforts are directed towards, for instance, complexity, variability, batch size, inventory and – more generally, but maybe most importantly – *waste*. What is considered *slack* in a more conventional production paradigm, or *flexibility* in an Agile paradigm, is seen as *waste* in a Lean system. The absence of capacity and inventory buffers makes Lean systems more likely to retreat to using a time buffer should irregularities arise. Using time as a buffer is a more elegant way to express that production and delivery are delayed.

From the analysis of the case studies it appears that buffering through time is not favored by the companies participating in this study. This inference is made based upon the number of bottleneck management measures that aim to increase flexibility as a means to cope with variability and irregularities. This does not imply that companies do not aim to reduce variability at the same time. It becomes clear from the data analysis, however, that the case companies in this study do not rely on a stable environment but instead seem to anticipate variability and prepare for it. Table 6.4.9 provides an overview. The table shows that the case companies employ a variety of preventive measures that directly or indirectly aim to decrease variability whereas some measures seem to emphasize flexibility.

Table 6.4.9. – Preventive Measures of Bottleneck Management That Aim to Increase Flexibility or to Reduce Variability

Measure	Increases Flexibility / Reduces Variability	Explanation	Case References
Multiple sourcing	Increases flexibility	The use of multiple sources in parallel as well as the preparation of one or several alternative sources is a measure to cope with variability for it increases flexibility.	all
Annual framework agreements	Reduces variability	Annual framework agreements provide suppliers with information about demand and requirements they can expect from their customers, which enables them to be prepared and smoothen operations.	1, 2, 3, 6, 7, 8
High incoming goods inventory	Increases flexibility	High incoming goods inventory allows the company to react to unexpected surge in demand which suppliers might have difficulties to be responsive to.	3, 4, 5, 6, 9

Supplier audits	Reduces variability	Supplier audits as a preventive measure are to increase the likelihood that the supplier meets requirements as demanded by the customer.	1, 2, 7, 8
Long-term relationships	Reduces variability	Long-term relationships support trust and facilitate communication, thereby improving information transmission which stabilizes supply relationships.	3, 4, 9, 10
Standardized sourcing criteria	Reduces variability	Use of proven, standardized sourcing criteria helps avoid “surprises” in sourcing decisions and support stability, thereby reducing variability.	1, 2, 8, 9
Consignment warehouse	Reduces variability	By supporting transparency as to actual inventory levels consignment warehouse contribute to smoother, less variable material flow.	6, 8
PCF agreement	Increases flexibility	PCF agreements include flexibility requirements for suppliers.	1, 3

Sourcing to professional traders	Increases flexibility	By sourcing to traders who maintain multiple sources of supply the focal firms makes use of traders' flexibility.	7, 8
Suppliers receive forecast data	Reduces variability	Forecast data enables suppliers to plan their capacities so that variability in the process can be reduced.	2, 3
Supplier development program	Reduces variability	Supplier development and training aims to improve suppliers' operational capabilities and thereby reduce variability in operations.	2, 8
Close relationships with LSPs	Increases flexibility	Close relationships with LSPs support finding solutions in case of contingencies.	2, 4
Preference for suppliers with short lead time	Increases flexibility	Short lead time enables suppliers to respond quickly to fluctuations, e.g., in demand, and the selection of suppliers with short lead time thereby increases the focal firm's flexibility.	3
Suppliers maintain safety stock	Increases flexibility	Inventory of finished goods can provide additional flexibility in case of fluctuating order call-offs.	2

Information about supplier capacity	Reduces variability	Availability of information about supplier capacity prepares the focal firm for possible delays in the supply process so that contingency plans can be devised well in advance and variability can be reduced, e.g., by tapping additional sources of supply.	4
Blending of raw material	Increases flexibility	Blending of raw material increases flexibility as to the exact proportions of raw material received from the individual suppliers.	5

From the discussion above, it can be inferred that none of the case companies relies on Lean/JiT as the dominant paradigm in their supply network. Eight measures that aim to reduce variability are accompanied by nine measures that aim to increase flexibility. Flexibility is normally created by some sort of redundancy, slack, or extra capacity, each of which would be considered waste in a Lean environment. What could be shown is that instead of confining themselves to measures that aim to reduce variability, the case companies seem to seek a balance between decreasing variability and improving their ability to cope with variability, that is, to increase flexibility.

Either way, the implications are worthwhile noting. In the literature review of Chapter 2, different types of manufacturing systems (Section 2.2) as well as different types of supply networks (Section 2.5.6), and how they match, were discussed. In Chapter 3, the concepts of Lean (Section 3.3), Agile, and Leagile (both Section 3.5) were reviewed. Flexibility and variability are key concepts and parameters to both production strategies and supply network strategies. It appears that the selection of bottleneck management measures, through their addressing of flexibility or variability, respectively, can shape the organization's profile in a way that influences its match with both the internal production as well as with the supply network. It shall not be inferred that case companies have chosen particular meausures for that purpose, yet it can be said that bottleneck management measures provide another lever to improve an organization's strategic fit with management of production and supply.

6.4.4.2. Summary

This section illustrated the use of bottleneck management measures in their role of either increasing flexibility in order to cope with variability – or of decreasing variability in the first place. That is, by framing the discussion of bottleneck management measures in terms of flexibility and variability, another dual role can be identified in addition to the two identified in previous sections (addressing power or dependency and addressing uncertainty or severity of outcome). Relating bottleneck management to flexibility enhances the literary discourse on supply network strategies and their fit with manufacturing system paradigms.

6.4.5. Summary: Roles of Bottleneck Management Measures

The preceding discussion demonstrates that companies can make a variety of decisions when they design and maintain their supply network and manage bottlenecks. Among these decisions, three different choices companies have to make could be distilled from the case study data and were related to the relevant literature. Preventive measures appear to *fulfill different roles*, each of which is dual in nature. They can *increase the focal company's power* in a supply relationship (or *reduce its dependency*), *reduce uncertainty* (or *increase mitigation capability*), and *increase the company's flexibility* (or *reduce variability*). Some measures fulfill multiple roles at once, others affect only one parameter. Table 6.4.10 provides an overview. These different roles make certain measures suitable for some environments rather than for others. The discussion of different types of manufacturing systems in Section 2.2, of different types of supply networks in Section 2.5.6, as well as of Lean and Agile in Sections 3.3and 3.5, respectively, indicate different requirements for bottleneck management which measures with certain roles can meet better than others. Agile environments, for instance, may invoke the use of measures that increase flexibility, whereas measures that reduce variability would be favored in lean environments.

The table also shows that the most popular measures that could be identified among the case studies tend to serve different purposes at once. They do, for instance, at the same time decrease dependency on individual suppliers, reduce uncertainty in the process, and increase the focal company's flexibility.

Table 6.4.10. – Summary: Roles of Preventive Bottleneck Management Measures

Measure	Power Relations: Increases Power or Reduces Dependency	Risk: Reduce Uncertainty or Cope with Consequences	Increase Flexibility or Reduce Variability	Case References
Multiple sourcing (parallel)	Decreases dependency, increases power (can decrease power)	Reduces uncertainty	Increases flexibility	all
Multiple sourcing (alternative)	Decreases dependency	Helps cope with consequences	Increases flexibility	unclear

Annual framework agreements	Decreases dependency	Reduces uncertainty	Reduces variability	1, 2, 3, 6, 7, 8
Geographic spread of sources	Decreases dependency	Reduces uncertainty	Increases flexibility	4, 6, 8, 9, 10
High incoming goods inventory	Decreases dependency	Helps cope with consequences	Increases flexibility	3, 4, 5, 6, 9
Supplier audits		Reduces uncertainty	Reduces variability	1, 2, 7, 8
Long-term relationships	Levels power and dependency	Reduces uncertainty	Reduces variability	3, 4, 9, 10
Standardized sourcing criteria		Reduces uncertainty	Reduces variability	1, 2, 8, 9
Buying power and reputation		Reduces uncertainty		4, 5, 10
Penalty clauses for non-compliance	Increases power			1, 3, 8
Consignment warehouse		Reduces uncertainty	Reduces variability	6, 8

PCF agreement		Reduces uncertainty	Increases flexibility	1, 3
Sourcing to professional traders	Decreases dependency	Reduces uncertainty	Increases flexibility	7, 8
Suppliers receive forecast data		Reduces uncertainty	Reduces variability	2, 3
Supplier development programs		Reduces uncertainty	Reduces variability	2, 8
Close relationships with LSPs	Increases power (can increase inter-dependence and thereby level power)	Both	Increases flexibility	2, 4
Preference for suppliers with short lead time		Both	Increases flexibility	3
Suppliers maintain safety stock		Helps cope with consequences	Increases flexibility	2

Combined purchasing for higher buying power	Increases power	Reduces uncertainty		7
Information about supplier capacity			Reduces variability	4
Blending of raw material	Decreases dependency		Increases flexibility	5
Scenario Planning		Reduces uncertainty		5

6.4.6. About the Validity of the Supply Chain Model and Supply Chain Management

The last (three-parted) research question relates to the discussion in Section 2.4.4 where the validity of the notion of supply chains as well as the related and popular field of Supply Chain Management was questioned. The proposition was that the mental model generated by the name supply chain does not adequately reflect the interorganizational structure that is created based on the requirements of buying (receiving) and selling (supplying) companies.

Research question 7a was: *Is the notion of supply chains (as opposed to supply networks) useful and does it represent interorganizational structures which the case companies are part of?*

A tentative claim was put forth in Section 2.5.4 that negates this research question. The data analysis following the case study interviews has provided additional evidence that support this claim. In particular, the fact that case companies experienced supply shortages because suppliers prioritized other customers higher speaks to the importance of the notion and the understanding of networks:

> "[Suppliers tell us] sometimes that we are too small as a customer so that we are not of high importance and that orders for larger customers have to be finished first" (interviewee at case company 3).
>
> "So several times we had to stop our machines because of lack of material and after we had a problem with the quality. (...) What I understood is that they found new customers. Not really competitors of us, but using the same material. And in order to supply them, they did some change on our supply" (interviewee at case company 7).
>
> "If a furnace breaks down those that order higher quantities will be preferred over us as a small customer" (interviewee at case company 6).

The quotes clearly indicate that organizations from *outside* the direct supply relationships of the case companies potentially influence the availability of supply for the case companies and in extreme cases cause supply shortages. This finding confirms the proposition made earlier that the notion of supply chains does not adequately represent the interorganizational structures of demand and supply. Concepts identified in this project, such as non-adjacent power regimes, are alien to SCM and supply chain thinking. The notion of supply chains seems not to be useful and, in fact, appears to be detrimental to the understanding of the processes and events in such networks, possibly leading to supply shortages, the causes of which should not even exist – and therefore cannot be understood – within a supply chain paradigm.

Research question 7b was: *Is Supply Chain Management a pointed description of the activities organizations perform or seek to perform in order to ensure the stability of their inbound material streams?*

SCM has been called a "simplistic method" and "means of selling management consultancy" (Johnsen et al. 2008, p. 71). The close cooperation and integration it proposes require somewhat stable requirements which many researchers in SCM in the introductions to their papers suggest do hardly exist in "today's constantly changing economy". In fact, the very notion of the *management* of supply chain can be questioned as many firms might *cope* with their network rather than manage it (Harland & Knight 2001) – quite besides the fact that it was concluded in the previous paragraph that the notion of supply *chains* seems to be mostly inadequate.[13] Therefore, it was tried to understand to what extent the case companies that were interviewed pursue activities that could be roughly described as "managing" their supply chain/network. Given the previous findings, the question could therefore be rephrased as: *To what extent can the activities organizations perform or seek to perform in order to ensure the stability of their inbound material streams be described as managing?*

The fact that definitions of SCM are numerous and often divergent (cf. Mentzer et al. 2001) suggests that a common understanding has not evolved. Chopra & Meindl (2010), for instance, suggest "effective supply chain management involves the management of supply chain assets and product, information, and fund flows *to maximize total supply chain surplus*" (p. 23, emphasis added). If that definition were adopted, it could be stated that the case studies provided no evidence that SCM exists at all as the interviews did not suggest in any way that maximizing supply chain surplus was on the agenda of either the case companies or their suppliers. There appears to be a tendency that authors in SCM insinuate an altruistic intent of SCM for which empirical evidence seems to be scarce. The quotes that were brought in the discussion of research question 7a underline this notion. Another interviewee remarks:

> "The whole idea, the whole concept of the supply network is for me a bit more theoretical than I can see in practice. So I'm just starting

[13] Even the *Supply* part of *Supply* Chain Management is, in fact, not unambiguous (but of course, this applies to *supply* networks, too). While the buying firm does care about the supply for its production, it is, in most cases, the *demand* that triggers all actions along the chains or networks. Hence, more suitable terms would arguably be *demand* chain and *Demand* Chain Management which would allow to better distinguish chains and networks where demand (customer order) is the trigger for action from chains or networks where material is pushed into the system because supply is the trigger, as it is the case with waste management and wind or solar power. Such systems have been coined *supply-driven* chains (see, for instance, Hull 2005).

> with Martin Christopher[14] and Cranfield and the theory behind it, but I still miss, at least in my real experience, just to see any kind of application" (interviewee at case company 5)

The quote indicates that the interviewee – who is the head of external logistics at his company and not unfamiliar with the essential processes of supply and logistics – perceives SCM as a rather abstract, theoretical concept.

Some of the concepts discussed in this thesis suggest that the general notion of *managing* a supply network is only applicable in very specific situations. Managing in general has multiple meanings; management in the context of supply chains or networks is poorly defined, and the answer to the research question may suffer from this limitation. Authors who discuss the term Supply Chain Management often attest ambiguity (Bechtel & Jayaram 1997, Tan 2001) and "considerable confusion as to its meaning" (Mentzer et al. 2001). Also, existing definitions are often so vague that they could easily be applied to anything, which indicates they do not provide much new insight. These definitions often state that SCM "deals with" (Jones & Riley 1985) or "integrates" (Council of Supply Chain Management Professionals (CSCMP) 2010) the flow of goods, without really specifying what activities this would involve.

Accordingly, the vague nature of the term renders any statement as to whether a firm conducts activities that could be described as SCM almost arbitrary. Any firm that receives material from suppliers has to *manage* "assets, product information, and fund flows" (Chopra & Meindl 2010). Likewise, any firm "[plans] and [manages] activities in sourcing, procurement, conversion, and logistics" (Council of Supply Chain Management Professionals (CSCMP) 2010). What sets traditional purchasing and supply management apart from SCM? High-level terms such as "integration" (of demand and supply) and "management" do not contribute to clarity unless these terms are defined as well. One may state that many definitions of SCM do seem fail to meet the definition of definition (cf.

[14] Martin Christopher is professor emeritus at Cranfield University and the author of many articles and textbooks on Supply Chain Management, some of which have become very popular. The interviewee uses the term supply network most likely because it was used by the interviewer throughout the interview. The mentioning of Martin Christopher makes clear that the interviewee really refers to Supply Chain Management.

Fowler et al. 1995). They are simply imprecise as to the meaning or the nature of the activities they aim to define.

Two approaches could be followed to find an answer to the research question.

Following a comprehensive review of definitions of SCM one could aim to identify repeatedly surfacing elements in these definitions and compare them to the activities that were identified in the case studies (*top-down* approach). This approach suffers from the limitations outlined above, in particular from the vagueness and general character of the terms used in those definitions (such as *planning* and *integration*).

The second approach would be to analyze the interviewees' responses to selected questions that were designed as a probe into existence of and information about activities, techniques, and tools that demonstrate a high level of understanding of supply-related processes and caution about supply-related risks. This approach can be characterized as *bottom-up*. It seems more promising than the first one and will be followed.

Several questions aimed at activities commonly associated with SCM, such as tier-n management, supplier audits and training, and delivery modes. The responses from the interviewees indicate that most case companies – with the notable exception of case company 2 – do not have an elaborate plan, let alone a strategy, as to how they can improve the stability of their inbound material stream. This does not imply, however, that they do "nothing"; the individual case analyses in Phase I of the data analysis demonstrate that each case company performs several bottleneck management activities. The case analyses also demonstrate significant differences between the firms, though.

When it comes to the management of supply, firms seem to operate on different *layers*. The existence of these layers also provide an additional explanation as to why both terms, supply management and supply network (or chain) management, appear to suffer from some vagueness – neither term addresses all layers at once.

All organizations seem to be able to fully *control* and *adjust* the way they respond internally – i.e., within their organizational boundaries – to the inbound material stream and to possible irregularities. The *internal response* represents the first layer of activities.

On the next layer, organizations *influence* the inbound material stream itself. They can, for instance, *aim* to adjust the frequency of deliveries, the delivery mode, or packaging. It is important to note that they *influence* on this layer, they *do not* fully *control*. Any change on this layer requires consensus with direct suppliers for both echelons are involved. That is, change on this layer require communication and possibly involve compromise.

On the third layer, the organization *influences* the characteristics of its supply network as such. Again, this includes communication and – probably to an even greater extent than before – compromise. It is on this layer that influencing factors such as the existence of relative power differences or power regimes make most difference.

The description of these three layers help understand the management of supply networks (or Supply Chain Management), and it enables us to address the research question.

Figure 6.4.2 illustrates the three-layer model.

Starting from the presumption – derived from the empirical data gathered in the ten case studies – that SCM, however vaguely defined a term it is in the literature, addresses these three layers, it is possible to answer research question 7b by stating that each case company performs activities that can be related to at least one layer of this three-layer model. Addressing the different layers involves a set of requirements that not all organizations meet to the same extent. The most dominant example is the existence of power regimes, both adjacent and non-adjacent , that enable organizations to exert – or prevent them from exerting – influence on more "distant" layers. The term Supply Chain Management suffers from a severe lack of conceptual clarity, which would make it easy to argue that most of the case companies – and arguably most other companies, too – do not perform activities that neither could nor should be described as SCM. If we, however, let loose of this rather rigid interpretation and look at the activities organizations perform on the three different conceptual layers outlined above, then it can be concluded that these activities which they perform and which have been subsumed under *bottleneck management* in this thesis, can

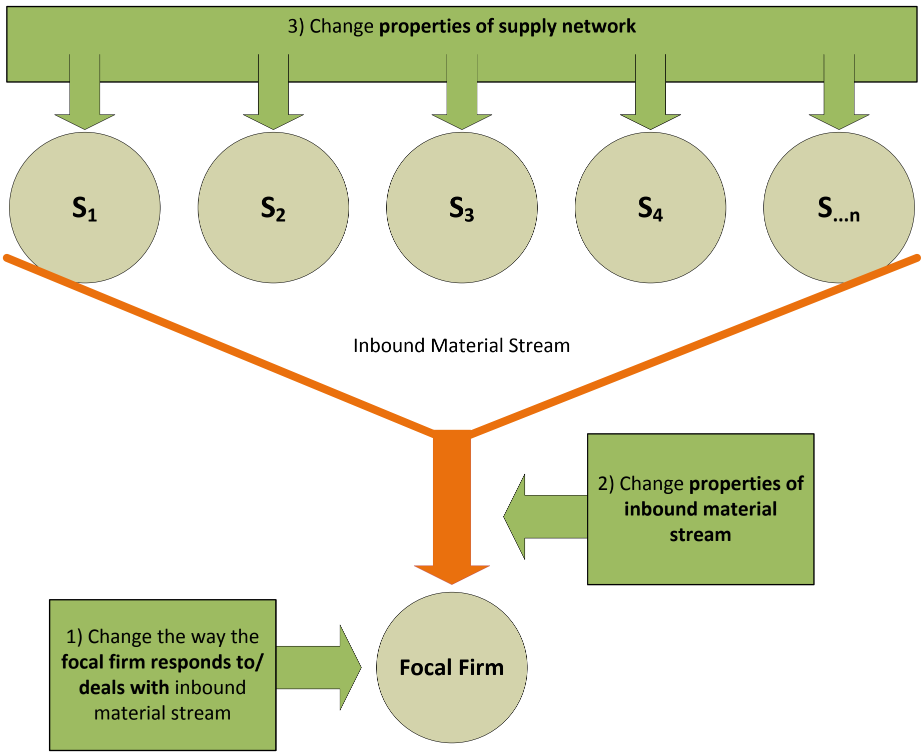

Figure 6.4.2. – Three Layers of Supply Network Management

indeed be considered to be adequately described by what is commonly referred to as Supply Chain Management and, in this thesis, is referred to as supply network management, as bottleneck management can be seen as representing a more specific set of activities which are part of this broader concept.

The three-layer model defined above for supply network management can also serve to put the different roles of bottleneck management measures (cf. Section 6.4.5) in perspective. The different roles that emerged from the data analysis are related to power (increase power/decrease dependency), risk (decrease uncertainty/increase mitigation capability), and flexibility (increase flexibility/reduce variability). Each role is *dual* in character, i.e., it addresses a concept and its converse (power/dependency), or problem cause and mitigation (variability/flexibility and uncertainty/mitigation capability). The three dual roles thus include six distinct strategies. These strategies address different layers of the three-layer model, as illustrated in Figure 6.4.3. How they relate can be best derived from Table 6.4.10.

The third sub-question (7c) was: *How does the understanding of supply relationships change if the notion of supply networks (as opposed to supply chains) is adopted?*

The point that supply network is a better description of the interorganizational structure from where the focal firm's inbound material flow originates was made by several authors (e.g., Harland et al. 2001) and was stressed in this thesis with references to both theoretical concepts as well as empirical data. This last research question provides the opportunity to wrap up some of the arguments made before and to present some additional arguments that will point to new venues that can be explored if the notion of supply networks is adopted and replaces the faulty metaphor of the chain.

One of the prominent themes that emerged from both the review of literature and the data analysis is the concept of *power*. As was pointed out earlier, power can arise from different circumstances, such as the possession of important resources (e.g., Crook & Combs 2007), a central position in the network (e.g., Gulati et al. 2002, Kim et al. 2011) or the ability to punish (e.g., Kumar 2005). Power seems not to be a very prominent concept in the field of SCM

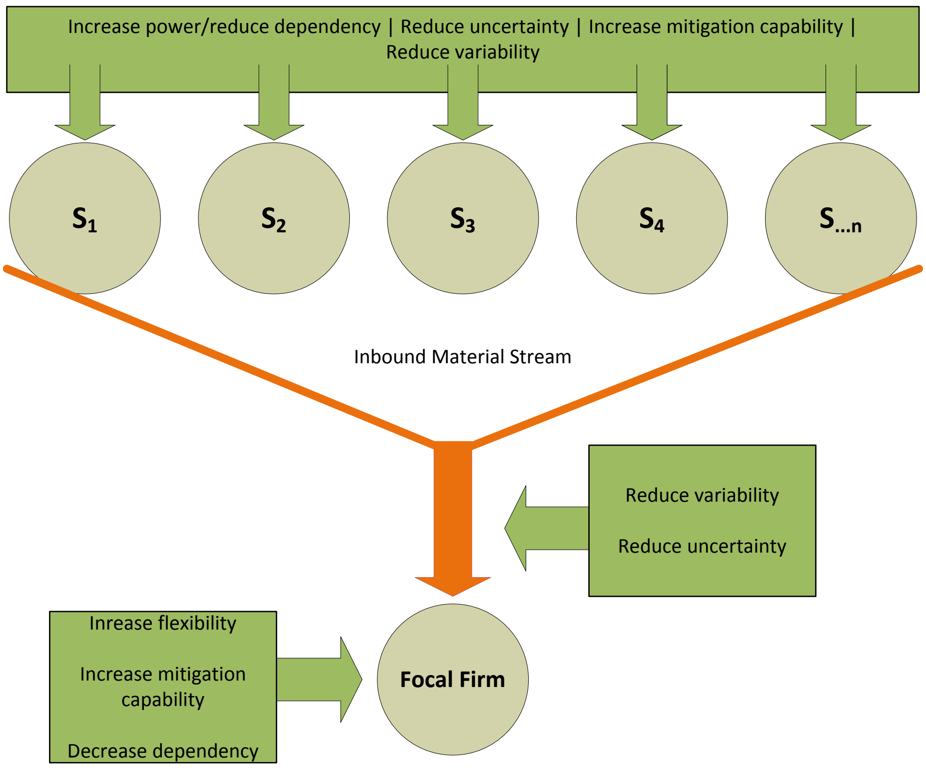

Figure 6.4.3. – Roles of Bottleneck Management in the Three-layer Model of Supply Network Management

(Cox et al. 2001), which is understandable given that many writers in this field emphasize the imperative of cooperation and holistic optimization rather than optimization of individual organizations (e.g., Lockamy III & Draman 1998, Simatupang et al. 2004, dos Santos et al. 2010, Chopra & Meindl 2010, , to name just a few), as is recognized and criticized by again others e.g., (e.g., Lonsdale 2001). Also, interviewees at case companies 1, 2, 3, 6, and 7 referred to power differences between their companies and suppliers or to such differences between their companies and competitors (i.e., competing customers of the same supplier) to explain occurrences of supply interruptions. Power is an enormously wide concept, and was merely touched upon in this thesis. And yet, it has become obvious that its implications are significant for the supply relationships of some firms. The network perspective helps embrace and supports understanding of the significance of power and of its impact in supply relationships. The concept of non-adjacent power regimes was discovered and discussed. Such non-adjacent constructs seem to have had adverse impact for the stability of some case companies' inbound material stream. Such concepts can only exist if a wider, and somewhat more complex, network perspective is adopted.

Another important concept that was discussed in the literature review but remained largely unaddressed later in the empirical data analysis is *complexity*.[15] The implications of complexity have to be understood in the context of the discussion of *networks* that preceded this section. As it could be shown that the interorganizational structures behind a given firm's inbound material stream can be best described as a network – not a chain – the question about possible impli-

[15] The interview questionnaire used at the case companies did not address complexity. One reason why the concept was omitted in the data collection is that complexity has become so ubiquitous a term – while its use tends to be only remotely connected to its meaning in the scientific context – that it would have required much effort to explain the concept to interviewees. One could argue the concept could be probed for in the interviews without explicitly mentioning it, thereby avoiding any hassle with definition and conceptual clarification. It was expected, however, that organizations tend not to be aware of many of the properties that indicate complexity in, or induce complexity into, a system, mostly because supply networks are not even recognized as a system but most commonly conceived of as linear relationships (if at all) or merely as independent dyadic relationships with suppliers, decoupled from the wider context of networks.

cations give rise to the importance of concepts such as complexity that are most relevant in such interconnected environments. Also, it is more intuitive to refer to networks as systems rather than to chains which by the nature of their structure show only limited interaction, involve fewer agents, and arguably contain fewer feedback loops – some of the defining properties of Complex Adaptive Systems.

Some authors were cited who suggest that supply networks should be understood as CAS (Choi et al. 2001, Pathak et al. 2007). One property of CAS is emergence, i.e., the ability of the system to bring about effects that can neither be explained with the properties of any individual part of the system nor with their sum. The existence of emergence, however, runs counter to the ability to predict outcomes of the system. Predictability, however, has been argued to be a core assumption underlying the ability to *manage* a system; lack of predictability of a system's outcomes thus questions the possibility of it to be managed (Stacey et al. 2000). Obviously, this is an important aspect that adds to the discussion of research question 7b, too. A discussion of complexity and its implications for the management of supply networks in general and of bottlenecks in particular would not be possible without understanding and acknowledging the existence of supply networks.

Even if the idea is rejected that supply networks are Complex Adaptive Systems, a subgroup of systems with special properties, they are nevertheless systems. A conceptual system comparison between supply networks and factory systems was conducted in Section 3.7. There, it was argued that supply networks are open systems: they receive energy and matter and they release energy and matter. And very much so, as they often span over long distances and therefore are subject to impact from a variety of sources external to the system. Arguably, there is a big difference between the impact a network of organizations, with both vertical and lateral relations inside as well as across system borders, can experience and the impact to which a simple chain, spanning over the tiers in a linear fashion, is subject. Again, acknowledging the existence of lateral – and cross-border – relationships provides a richer perspective on the management of supply.

Another field of research that can be tapped if the network model is accepted is network theory. Network theory provides tools for the conceptual description of networks in terms of nodes and ties. It allows to describe a firm's position in a network relative to other firms' positions and it allows to describe properties of ties as well as of the network as a whole. The conceptual description of the network levels the way to its analysis (as, for instance, in the branch of Social Network Analysis).

The structure of a network and the type of ties between organizations can have implications for the outcome of the individual organizations directly involved – but also for non-adjacent entities, as it was concluded from the data analysis. Concepts such as centrality provide a useful angle to look at potential consequences for the event of irregularities. Authors have already applied it to the identification of bottlenecks in supply networks (e.g., Mizgier et al. 2013).

Network theory provides a toolbox so rich that it could not possibly be treated in all its facets in this work. Nonetheless, it shall be emphasized that it does open up venues that are likely to yield new insights into the management of supply, and it shall be stressed that it its application is most promising if the conception of complex interorganizational structures on higher echelons is not trimmed to a "supply chain". Borgatti & Li (2009) point out that it is "a fundamental axiom in network analysis that actors are not independent but rather influence each other" (p. 9). Hence, network analysis explicitly allows for such concepts as non-adjacent power regimes whereas the notion of indirect influence remains largely disguised in SCM.

It can be concluded that replacing the notion of supply chains with supply networks comes with a host of implications, both practical and theoretical. Conceiving of the interorganizational structures behind the supply of goods and services as a network provides opportunities to better understand and analyze these structures as well as potential and actual events, such as the interruption of the supply stream. It enables the practitioner to act upon information about the network that hitherto remained disguised by the widely accepted management textbook parlance of Supply Chain Management. For researchers, it opens up additional venues that seem to have remained overlooked by many, as judged by the number of publications covering topics like network analysis or complexity in supply networks. Therefore, the general understanding of supply relationships is likely to change a lot if it is acknowledged and understood that these relationships represent only the periphery of much wider and more complex networks.

6.4.7. Summary

This section represented the interpretive and explanatory part of the data analysis. Information from the multiple-case study was related to elements of the conceptual model created in Section 4.6 and, more generally, to the literature reviewed in Chapters 2 and 3.

First, the information was related to power. Power and dependence were discussed in Section 2.5.5.2 and power has also been found to be an important component of the purchasing portfolio analysis (Section 3.2). It was inferred that a triadic network setup with power imbalance to the advantage of another buying company can increase the chance of bottleneck emergence for the focal buying firm if the common supplier has to make capacity allocation decisions. This setup was termed non-adjacent power regimes.

Next, an inquiry into bottleneck management measures as a means to alter such power relations followed. For all relevant measures of bottleneck management, it was outlined how they can possibly affect power and dependency in a supply network. It was then investigated if some of the case companies are making use of measures that affect power and dependency for this purpose – or if possible influence on power and dependence are merely side-effects that were not intended by the case companies which used them. The analysis compared a sample of relatively powerful case companies with a sample of relatively powerless case companies and discussed their selection of measures. Indications that certain measures are, in fact, employed for the purpose of altering power relations were provided by case study interviewees. Some corroborative evidence could be found in the analysis while no evidence could be found that would have lead to refutation of the idea. The limited number of companies which participated in the multiple-case study created some limitations, however, for the composition of the two samples that were compared, so that for several measures of bottleneck management a meaningful conclusion could not be drawn as to the intent behind their selection. Inductive statements cannot be proven right through corroboration. Hence, the proposition implicitly made when investigating into case companies' reasoning behind the selection of certain measures – that weak companies choose to employ certain bottleneck management measures in order improve their power position in the network – remains a theoretical proposition and not a fact. While the proposition is appealing to common sense, it is easily conceivable that some companies, both within the set of case companies as well as outside, employ measures that were said to be able to alter their power position for entirely different reasons unrelated power. If such evidence were found in future studies, it would enable refinement of the theory's boundary conditions.[16]

Also, the selection of bottleneck management measures was framed in terms of risk. The concept of risk was discussed in Section 3.6. It was found that two components of definitions of risk stand out: uncertainty and severity of the consequences of something happening. Bottleneck management measures were described in terms of how they address either factor. Different than the previous analysis of bottleneck management measures and their relation to power, this analysis did not aim to establish a proposition about the existence of a causal relationship between the selection of particular measures and its addressing of either factor of risk. Instead, it was argued that certain measures do have certain effects, the case companies' actual reasoning behind their selection notwithstanding.

The same applies to the following discussion of bottleneck management measures and flexibility. Measures were said to be able to either increase a focal company's flexibility and thus its means to cope with variability, or to decrease variability in the first place. Relating to the discussion of manufacturing systems in Section 2.2 and the classification and match of supply networks in Section 2.5.6, it can be seen that the portfolio of bottleneck management measures

[16]In fact, the discussions of the roles of risk and flexibility that followed the discussion of power already make clear that intent different from power can influence the decision whether or not to adopt a particular measure.

a production company employs can be matched with the type of production and the supply network strategy so as to improve fit. The consideration of flexibility increasing or variability decreasing, respectively, through the conscious selection and use of particular bottleneck management measures thus is not merely an intellectual exercise but is, in fact, very practical and supports organizations' means to shape their profile and improve strategic fit.

The discussion of bottleneck management in terms of power, risk, and flexibility were summarized as a conception of three distinct roles of bottleneck management measures. Some measures have only one role whereas other measures can have two or three roles. The conception of three roles emphasizes an organization's ability to manage bottlenecks in supply consistent with its production and supply strategies.

The section ended with a discussion of the validity of the supply chain model and the term Supply Chain Management. The supply chain model and the notion of Supply Chain Management was first discussed in Section 2.5.4 before the critique was enhanced in this section with empirical data from the case companies. It was concluded that the supply chain model does not adequately represent the interconnected, and often interdependent, structures of firms to which the focal firm is connected by supply relationships.

In response to the last research question, it was argued that supply network is a better model than supply chain as it allows for concepts which, according to both relevant literature as well as case study data, do have important implications for production companies. Among these concepts are power and complexity. Also, the entire toolbox of network theory can be used if the notion of networks is accepted.

Also, it was pointed out that the term Supply Chain Management is too vague to even tell whether a firm does SCM or not. Hence, it was tried to give the term meaning by pointing out possible levers of the firm and the requirements attached to using them. The result was a three-layer model of Supply Chain Management which can represent the activities the participating companies in the study pursue.

6.5. Critical Evaluation of Research Approach

6.5.1. Introduction

It might remain unclear throughput a large part of a research project if the particular research approach chosen for the project is the best one. In particular the mode chosen for data collection might face criticism since most decisions involve at least one trade-off (e.g., number of respondents vs. depth of inquiry). Therefore it seems reasonable to reflect on the data collection mode chosen and how it seems to have met expectations after the data collection has been completed. Moreover, validity and limitations of the study shall be shortly addressed.

6.5.2. Semi-structured Interviews as Primary Data Collection Method

6.5.2.1. General Impression

A qualitative approach had been selected for this project. Accordingly, statistical evidence was not aimed for in this research which removes the necessity for a "high" number of respondents. At the same time, however, one objective of this research was to identify patterns both in bottleneck emergence and in bottleneck management. Therefore, one or very few in-depth case studies would have provided too particularistic a view on the issues at hand. Due to the widely varying circumstances in different industries and for companies of different size and market power any attempt to analytically generalize findings might have become difficult had the number of cases been very small. Semi-structured interviews represent a compromise between the two extreme poles for breadth and depth as they can be conducted with reasonable effort and at reasonable cost with a broader sample of cases than in-depth case study research while allowing interaction of researcher and interviewee, thus bearing the chance of creating deeper insights than a survey could. This trade-off was known in advance and was one reason why semi-structured interviews were selected as data collection method.

Possibly one of the strongest arguments against a survey or structured interviews is the exploratory nature of the data collection. Therefore, it was necessary that the data collection method allowed for unexpected and new responses that can be captured and followed up in the discussion. A rigid survey design with closed questions would require that all, or at least most, answers that would be given by respondents are known in advance and can be presented as possible choices in the survey.

Quality of data is another concern when conducting surveys. During the interview process in this project it became clear that interviewees sometimes did have difficulties answering questions with confidence. The fact that additional explanation as well as examples for facilitation could be provided improved the quality of responses in the interviews. The chance to interact with interviewees enabled the researcher to ask questions that are less straightforward to understand. This does not mean that questions were made more difficult to understand on purpose, but it does mean that subtle differences could be asked for without providing lengthy explanations in written form which the respondant should have studied in advance. Subtle differences are, for instance, the distinction between bottleneck exploitation and bottleneck elimination which in a survey would not have been feasible without detailed explanation. Even in the interviews responses to the two different sections were sometimes confused. While this could be expected and did not provide a problem as in the data analysis the data was structured along the categories originally intended, it did by times invoke additional explanation, repeated questioning, and the mentioning of examples for facilitation. Explanations that could be given verbally and visually (e.g., with a drawing appended to the interview questionnaire) in the interviews would have required careful reading prior to the response had a survey been used as an instrument for data collection, which respondents are unlikely to commit to in a remote survey. Accordingly, the quality of data collected via interviews is likely to be higher than it could be expected from a survey.

In the interview process answers sometimes were given in “unexpected moments”. It happened, for instance, that one measure that serves to prevent bottlenecks (asked for in questionnaire section “Bottleneck Prevention”) was only mentioned when discussing production capacity flexibility (questionnaire section "Bottleneck Placement"). On other occasions, individual causes of bottleneck emergence were confirmed when explicitly addressed but remained unmentioned when generally asked for causes of bottleneck emergence (e.g., when interviewee was asked if bottlenecks in the past occurred because of supplier bankruptcies).

Also, the interviews allowed to create a personal relationship with the interviewee and several times it had been offered to the researcher to answer additional questions on the phone should the need arise. This level of support cannot be expected from survey respondents. In some cases, the interview was conducted with more than one participant from the companies at once (up to three). The reason was that sometimes specialist knowledge was available that the primary interviewee did not possess. Involving more than one person in the interviews was neither intended nor asked for by the researcher but was made possible by the primary interviewees in the respective companies. In such cases, it was possible to ask more detailed question than with only one interviewee. Again, this access to knowledge is unlikely to be made available by respondents of a written survey.

The main difficulty with semi-structured interviews as data collection method was the low approval rate by companies in the first place. Several interview requests were turned down. It is speculated that two main factors have contributed to this result:

1. People can he held responsible by peers or superiors for providing internal and possibly confidential information to people external to the organization. Depending on company policies and organizational culture this may involve personal risk for the interviewee.

2. The interview process takes time of the interviewee which people tend to claim not to have enough of. Accordingly, a reason frequently given when interview requests were refused was that people were "too busy".

Notably, the situation changed and access to interviewees improved immediately when the researcher became part of an organization that referred the researcher to its suppliers. In this setting, concerns about confidentiality seemed to play a less important role and time was made available. Though there is no certainty as to why this was the case, one probable explanation is that it is common practice for many suppliers to share information with their customers so that an interview request coming from a customer was not considered unusual, in particular since the scope of the research project overlapped with information interests of the customer firm.

6.5.2.2. Strengths and Weaknesses of Semi-structured Interviews

Some of the strengths of semi-structured interviews were mentioned in the preceding text. These advantages, that were partly anticipated and partly unanticipated yet experienced include

- interaction between researcher and interviewee reduces the chance of misunderstood questions so that responses are likely to yield higher quality data,
- finer differentiation between questions allows to focus on more subtle aspects,
- compromise between depth and width of data so that more companies could be interviewed at reasonable expenditure of time and cost,
- interaction between researcher and interviewee can build trust; enduring relationship allows quality check of case description and follow-up questions.

Yin (2009) mentions two additional advantages (p. 102):

- "targeted – focuses directly on case study topics,
- insightful – provides perceived causal inferences and explanations".

Obviously, interviews do have weaknesses, too. Yin (2009) mentions four weaknesses:

- “bias due to poorly articulated questions,
- response bias
- inaccuracies due to poor recall
- reflexivity – interviewee gives what interviewer wants to hear”

These four weaknesses shall be shortly addressed.

Bias due to poorly articulated questions (or poor understanding for other reasons) cannot be excluded; however, chances can be minimized. All interviewees were sent a short description of the research project prior to the interview data. Moreover, all interviews began with a short introduction of the research project. Generally, all interviewees were experienced in their position and – with the exception of the interviewee at case company 5 – the position they held was directly or indirectly concerned with inbound material flow. The interviewee at case company 5 holds a senior position in external logistics but is less concerned with the supply side of the business. So the interviewees were generally familiar with potential problems posed by supply and with counter measures, which reduces the chance of bias due to poorly articulated (and thus poorly understood) questions. Furthermore, the same questions were used at all case companies without this researcher getting the impression that questions generally were unclear or misunderstood on several occasions. Also, additional explanations were provided throughout the interview process. Therefore it can be concluded that this potential weakness, while it cannot be completely excluded, is unlikely to have affected the quality of data gathered in any significant way.

Response bias may exist for several reasons. One reason are secrecy requirements on side of the organization. Interviewees at the case companies may not be willing to give away certain information. The fact that some of the interviews were conducted within one supply network of one focal firm (case company 8) may have caused reservations on side of some the suppliers as they might have feared that other, competing suppliers might also participate in the study and gain useful insights that would provide them with a certain competitive advantage. Although the questions asked in the interviews did not aim at generally confidential information, such a bias might have existed nonetheless.

Another possible reason for response bias might be that interviewees do not like the interviewer and thus might have little motivation to support him in his research. Although this option cannot be excluded with certainty, the general impression of the atmosphere during the interviews was friendly and supportive.

In order to reduce response bias, all interviewees and their companies were guaranteed anonymity. In order to make sure a satisfying level of anonymity is ensured, case descriptions (as presented in Phase I of the data analysis) were sent to interviewees for approval. In some cases, information that would have facilitated the identification of the company name for industry insiders were removed in this process. Nonetheless, response bias might have existed.

Inaccuracies due to poor recall pose a problem particularly for those studies were the researcher interviews individuals to learn about events in the past. This is partly the case for this study. Although the focus clearly is on recurring, present, and very recent activities and events, interviewees did recall incidents in the past to illustrate certain problems and make their point. It cannot be excluded that details about events from the past were inaccurately recalled. Because the past events of interest – bottlenecks that led to supply shortages – can lead to critical situations in internal production processes and order fulfillment, such events are somewhat likely to be remembered by the people directly concerned with the situation.

Reflexivity refers to the possible desire of interviewees to please the researcher by giving responses he would likely be fond of. The subject discussed with interviewees can be characterized as emotionally neutral, and the researcher would not have felt happier with interviewees' responses that indicated, for instance, a large number of supply related problems than with responses that indicated trouble-free supply processes. Moreover, the existence of measures in organizations in order to stabilize inbound material flow is not subject to interpretation; measures either exist or they do not. Therefore, reflexivity is unlikely to have affected the quality of interview data in a negative way.

Table 6.5.1 summarizes the preceding discussion and presents in a short form the four weaknesses and the researcher's subjective assessment of their impact on the data quality in this research project.

Table 6.5.1. – Summary: Weaknesses of the Interviews According to Yin (2009) and How They Might Affect the Data Quality of this Study

Weakness	Subjective Assessment
Bias due to poorly articulated questions	Little or no impact on data quality
Response bias	Possible impact on data quality
Inaccuracies due to poor recall	Possible (yet low) impact on data quality
Reflexivity	Little or no impact on data quality

6.5.3. Rival Explanations

In Sections 6.4.2,6.4.3, and 6.4.3 the selection of bottleneck management measures was discussed. It was proposed that buying firms choose particular measures, and decide not to choose other measures, for a reason. Among the many parameters that can frame the decision process for a firm, some were selected which appeared to stand out and are which seemed to be backed by the body of literature reviewed in the earlier part of the thesis. The decisions were framed within three dual roles that measures of bottleneck management can fulfill: increase power or lessen dependency, reduce uncertainty or improve mitigation capability, and increase flexibility or reduce variability. The individual measures of bottleneck management were analyzed with respect to these dual roles; this analysis concerned mostly preventive measures. A summary was provided in Table 6.4.10.

Obviously, it is not clear beyond doubt that any organization has chosen its particular activities and measures for the reasons suggested in this analysis. Accordingly, there are rival explanations which are worthwhile considering. Table 6.5.2 presents an overview. The terminology used in this table is borrowed from Yin (2000, p. 249).

Firstly, the selection of the measures could be a product of chance only (*null hypothesis*). If this had been the case, no in-depth reasoning about the effects

Table 6.5.2. – Rival Explanations for the Selection of Bottleneck Management Measures

Rival Explanation	Description
Null Hypothesis	The effect observed is due to chance only.
Direct Rival	Other reasons and intentions have led to the effect observed.
Commingled Rival	Both other reasons and the reasons cited have led to the effect observed.

and side-effects of certain measures had occurred. As long as a measure made the appearance of being able to solve the problem at hand, it could have either been selected or completely ignored in favor of another measure that made the impression that it would do just as well. The decision-maker had been indifferent.

Secondly, the effect observed – the selection of particular bottleneck management measures – could be due to other reasoning than has been suggested (*direct rival*). It is conceivable, for instance, that decision-makers at the case companies had simply followed organizational policies that remained unmentioned in the interviews, or just gut feeling based on years of experience, when they made decisions to employ certain measures.

Thirdly, the decisions to employ particular measures might have been influenced by the reasoning outlined in this thesis, yet not completely, and other factors and reasoning that remained unaddressed in this project might have influenced the decision, too (*commingled rival*).

None of these rival explanations can be rejected with full confidence. The null hypothesis appears to be the least probable explanation as decisions as the ones discussed in this thesis generally require consciousness. It seems rather unlikely that decisions just happen to happen when people can be held accountable for these decisions.

Neither direct rival explanations nor commingled rival explanations are unlikely, however. In fact, it can be assumed – as it was stated in Section 6.4.2.2 – that some measures were a mere requirement for a lack of better options rather than the product of thoughtful and lengthy reasoning. This does not weaken the value of this analysis, however. The purpose was to augment the understanding of bottleneck management; and the context within which the individual case companies operate and the decisions they make were related to derive theory as to what purpose particular decisions *can* serve, which includes both explanatory as well as a predictive power.

The existence of possible rival explanations shall thus be seen as an invitation to further investigate the topic and to refine and complement the theory.

6.5.4. Validity and Reliability

In social science there are four common tests to judge the quality of the research design (Yin 2009, pp. 40 et seq.):

- construct validity,
- internal validity,
- external validity, and
- reliability.

While this research project is not located within social science, it does use the case study method – which is popular in social science – so that the four tests may contribute to the validity of this project nonetheless. There are many other types of validity that could be considered (see, for instance, Cronbach & Meehl 1955), yet the ones cited by Yin (2009) appear to be sufficient as they cover the most important aspects: if the present study is valid and reliable according to the definitions put forth below, the desire to demonstrate its validity shall be satisfied.

Construct validity refers to

> "the vertical correspondence between a construct which is at an unobservable, conceptual level and a purported measure of it which is at an operational level. In an ideal sense, the term means that a measure assesses the magnitude and direction of (1) all of the characteristics and (2) only the characteristics of the construct it is purported to assess" (Peter 1981, p. 134).

It can also refer to the "usefulness of the construct as a tool for describing or explaining some aspect of nature" (ibid).

Construct validity may potentially be a weakness in some aspects of this project. In Phase III of the data analysis, constructs such as power and dependence or flexibility were used. Such concepts are somewhat vague and their meaning depends to a large extent on the very specific content in which they are used. At the same time, these concepts emerged from the data analysis so that definite operational measures to describe them were not developed during the data collection phase. However, the several incidents that hinted at concepts such as power are prominent in the case descriptions of Phase I. The case descriptions, in turn, were sent to all case companies for correction and approval. In fact, this is one tactic Yin (2009) suggests as a means to strengthen construct validity. That is, the database from which the emergent themes such as power and dependency were derived were indeed reviewed. Moreover, power was explicitly and directly or indirectly mentioned on some occasions (e.g., in cases 2, 3, 7 and 8) when adverse effects on the case companies due to suppliers' material allocation decisions were discussed. In the third phase of the data analysis, power was then approximated with the relative importance of a buying company for its suppliers (and dependence was defined as the converse of power). The importance results from purchasing volumes and possible sanctions of the focal firm and their significance relative to the same measures at other buying firms. Although no exact operational data in terms of purchasing volume were obtained, interviewees subjective assessment of their company's importance in contrast to other companies' importance for a particular supplier can be counted as a valid measure provided that the interviewees can be assumed to have industry expertise, which is true for every case. Moreover, a description of the postion of each case company in the market was requested from interviewees, which helps understand and assess the companies' relative importance.

Flexibility is another construct that was used and for which there is no exact operational measure available. It was defined as a company's means to cope with variability and irregularities. This understanding of flexibility is based on, and in accordance with, the vast literature on agile and leagile in production environments and supply networks (cf. Section 3.5).

The preceding discussion does not imply that construct validity is not a potential weakness of the study at hand, yet it demonstrates that validation of the constructs used was sought even in cases were no exact operational measure was available.

Internal validity is "mainly a concern for explanatory cases" (Yin 2009, p. 42). Phase III of the data analysis (pp. 341 et seq.) is mostly explanatory and as such seeks to provide explanation for the selection of actions the case companies take in their effort to stabilize their inbound material flow. In other words, causal relationships are proposed and they can be considered valid if the researcher has demonstrated effort to provide evidence that the events that are supposedly caused by a particular factor are indeed caused by that factor and not by another. The purpose of ensuring internal validity is not to prove propositions but to make such propositions as clear and likely as reasonably can be expected at the given level of abstraction and quality. The most important measure in this project to address internal validity was the replication of interviews in order to find convergent evidence. Interviews were conducted at ten different case companies. Not only were the companies different, but also the industries the companies were operating in and the positions the interviewees held in their respective company. The evidence from the various interviews converged to a surprisingly large extent so that several themes emerged that were taken up in the data analysis (e.g., the implications of relative power positions in supply networks).

External validity refers to the degree to which results from a case study "are generalizable beyond the immediate case study" (ibid., p. 43). To strengthen external validity, Yin proposes to follow a *replication logic* which, he emphasizes, is different from obtaining additional respondents in a survey. The generalizations made in CSR are *analytic* whereas survey data are used as a base for *statistic generalization*. If statistic generalization of survey results were the benchmark, case studies would hardly be able to provide any valid theoretical contribution as the "sample size" tends to be one or very few. Although the multiple-case study in this project included ten cases, generalizing statistically would still not be an option. The multiple-case design does, however, allow to compare results from several cases to assess their consistency (cross-case comparison; cf. Phase II of the data analysis). Yin (2009) discusses different types of replication logic, such as *literal replication* (the case is expected to yield similar or identical results) and theoretical replication (the case is predicted to yield contrasting results). The case study design can be planned accordingly to include such replication logic. It is important to note that this thesis is partly *exploratory* and thus by its nature did *not* (because it *could* not) involve prediction about expected results. Importantly, though, in the selection of case studies (cf. Section 5.4) it was aimed to include companies with different contexts, such as industries with different characteristics, different company size, different production patterns, or different supply network structures. Because hardly any organization equals a second one in all these respects, the aim to identify case companies that would meet these requirements was relatively easy to achieve. At the same time, it was tried not to change too many variables at once so that valid inferences would not require an even higher number of cases to be involved in the replication logic. That is, the replication logic followed resembles best, though not completely for the reasons explained above, what Yin describes as *theoretical replication* (ibid, p. 54).

Reliability refers to the degree to which the same results can be obtained by repeating the study. A study is reliable if a researcher would be able to reach the same findings and conclusions if she followed the procedures described in the research. According to Yin (2009), the reliability of the study can be improved by maintaining a case study protocol and by creating a case study database. For this project, a database was created. The database was created and maintained in Microsoft Access 2013. The tables include

- the list of case companies (including pseudonyms and descriptions),
- causes of bottleneck emergence,
- bottleneck prevention measures,
- bottleneck identification measures,
- bottleneck exploitation measures,
- bottleneck elimination measures
- limitations to bottleneck management.

Several junction tables and queries were created so as to be able to retrieve the relevant information at ease and without the possibility of incorrect operation that otherwise could possibly lead to distorted analyses. Moreover, the tables include columns for description, comments, and categorization. The existence of the database and its use support the possible replication of results independent of the researcher.

6.5.5. Limitations of the Empirical Study

In spite of all serious effort to strengthen the validity of this study there are limitations, some of which were externally imposed whereas others are consequences of decisions made by the researcher throughout the project.

The most prominent limitation throughout the empirical data collection was the difficulty to get access to case companies. A greater number of case companies might have led to additional insights or to the rejection of some of the propositions or claims made in this thesis. Owing to the support of one particular case company, access could be gained to several other companies which were in trustful supply relationships with that case company. Yet even where access was granted it was still not unlimited; in fact, that some of the case companies knew about each other might potentially have let to bias on part of the interviewees, although there have been no indications that this was the case. Nonetheless, the limited access to case companies let to strong reliance on semi-structured interviews as primary and – more often than not – sole method for data collection. Triangulation with additional data sources was difficult or impossible to obtain and in some cases not explicitly attempted. One of the reasons that made triangulation difficult was that much of the information sought after tends not to be codified or documented. In fact, some interview question aimed to find out about the existence of standardized and codified measures and the response was generally negative.[17] Instead, as indicated in the previous section validity was tried to strengthen by increasing the number of interviews with different companies. It shall be acknowledged, however, that replication cannot make up for lack of triangulation. Yet it was the decision that seemed most adequate on the trade-off between exploitation and exploration.

This study has been inductive and thus proposes *theory* inferred from literature and empirical data. Therefore, all statements made in this document must be seen as propositions and possible explanations of reality. The critical realist perspective adopted prohibits claims of absolute truth. It has been tried to approximate truth, yet it is acknowledged that reality is much more complicated than the theory proposed in this project can represent.

6.6. Summary

This chapter presented the analysis of the data gathered in the course of the multiple-case study. For each case, an individual case description was created that related that presented the data in ways consistent with the conceptual model. The case descriptions were created from the interview transcripts by coding with key words and sorting the relevant data into the categorizes derived in the conceptual model (and used in the interview questionnaire). This first step of data analysis, the results of which are presented in Phase I, turned the case study data into information.

In Phase II of the data analysis, the information previously presented indi-

[17] Such as the following: "Is there a standardized action plan in place for (1) supply network design, (2) sourcing options (selection, redundancy, location), and (3) supplier training?" and "Is there a standardized procedure according to which suppliers will notify you when a bottleneck has emerged or chances are it will emerge?"

vidually for each company exemplar were summarized along the same categories but across all cases. The result is a comprehensive overview of all causes of bottleneck emergence, all bottleneck management measures (categorized in four distinct types of bottleneck management activities), and all limitations to bottleneck management that could be identified at the case companies.

The first two phases of the data analysis are descriptive and present the information won through the individual exploratory case studies in uninterpreted form. The only operation on the data applied in order to create usable information was their relation to some of the relevant categories from the conceptual model and their subsequent categorization.

Interpretation of the information created was performed in Phase III of the data analysis. In this phase, key concepts and ideas from the literature, some of which part of the conceptual model, were related to the case study information. Bottleneck management was related to power and dependency, the risk factors uncertainty and severity of consequences, and flexibility and variability. Also, case study information were used for an analysis of the supply chain model and Supply Chain Management, which resulted not only in a detailed critique of the two notions but also in a model of Suppy Chain Management that can adequately represent the activities the participating case companies perform.

The chapter ended with a critical posteriori evaluation of the research approach. The data collection mode and its strengths and weaknesses were discussed. Rival explanations were touched upon and validity and reliability of the study, and how these were strengthened, were explained. The evaluation was closed with the mentioning of the study method's limitations.

7. Synthesis: Results

7.1. Introduction

This section draws together the findings of the project. In Section 4, a conceptual model for bottleneck management in supply networks was defined based upon a review of relevant literature. The model served to guide the multiple-case study. At the end of this section, the model will be reviewed and modified with respect to the findings from the multiple case study (Section 6).

For the most part, this section refers to the findings from the analysis of the empirical part of the study. Valuable concepts have been worked out, however, in the theoretical part as well. These shall also be shortly wrapped up, too. While the review of literature served as a basis for the data collection and analysis, it does already include original contributions – and represents an original and valuable contribution it itself by providing a comprehensive and detailed overview of relevant literature which often remains unaddressed in the research of supply networks.

7.2. Conceptual Contributions in the Theory Part

7.2.1. The Concept of Bottlenecks

Before the data analysis began, the concept of bottlenecks was introduced and investigated. It was found that, in spite of its being widely used in various branches of research, a satisfying definition that would suit the aims of this project had not evolved. Therefore, a definition of bottleneck was provided in Section 2.3.2. The concept of bottlenecks was then further refined with a categorizations of bottlenecks (Figure 2.3.1 on page 46) as well as of conceivable states of a bottleneck (Figure 2.3.2 on page 47). These categorizations were not used in the later (empirical) part of the thesis, yet it is believed that such refinements of the concepts do represent original and valuable contributions to the body of knowledge as they add to conceptual clarity. As was pointed out in the introduction to the review of bottleneck litrerature (Section 2.3.1), categories of bottlenecks surfaced repeatedly throughout on several occasions throughout the thesis. The categorization provides a point of reference for the use of such specifications throughout the document.

7.2.2. Complexity and Complex Adaptive Systems

The concepts of complexity and Complex Adaptive Systems were introduced (Section 2.4 on page 48). It was discussed how these concepts relate to supply networks and their management. It was concluded that some supply networks show characteristics of CAS to a greater extent than others, but that a general statement as to supply networks being CAS is probably invalid, in spite of some authors' having suggested otherwise.

Types of complexity were categorized based on the literature reviewed and an additional category was proposed (*systemic* vs. *induced* complexity) (cf. Figure 2.4.5 on page 65). This review of types of complexity provide a solid starting point for further investigation into this area of research.

7.2.3. Supply Networks and System Archetypes

System archetypes were introduced and discussed in Section 2.4.6. It was tried to identify and describe system archetypes in supply network settings. Apart from the well-known works on the bullwhip effect (Forrester 1958, Lee et al. 1997), there seems to have been little effort to make use of system archetypes in supply networks, although their recognition would provide great benefits to those having to cope with such situations and looking for a potential lever to break out. Therefore, the value of the discussion lies in the acknowledgment that system archetypes may well have relevance in the management of supply networks; it is hoped for that this section will spark further research, both conceptual and empirical.

7.2.4. Flow of Agents and Degree of Freedom

Based on the discussion of systems and of networks, those lines of thinking were combined into a discussion of variable and static components of systems in Section 2.5.5.3. Again, these thoughts were not followed up explicitly in the empirical part of the work, yet they remain valuable as they add clarity and refinement to the conception of networks as a system, which was built on in many different places in this thesis.

7.3. Causes of Bottleneck Emergence and Categorization

This section refers to the first and the second research question: "*What are some of the reasons why supply shortages occur in supply networks?*" and "*Can the causes of bottleneck emergence be structured in a useful way?*"

The interview findings with respect to the causes of bottleneck emergence were listed and described in Section 6.3.2 and the reader is referred to this section for a complete overview and thus for a comprehensive answer to the first research question. While the causes of bottleneck emergence identified are certainly not complete and other organizations may experience different or additional reasons for supply shortages, the list does represent a good sample for two reasons: the companies which participated in the study partly have very different profiles and the causes identified can be structured into several meaningful categories.

The definition of bottlenecks proposed in Section 2.3.2 already hints at a first possible categorization of bottlenecks:

- physical,
- organizational, and
- operational.

Essentially, this categorization refers to whether supply is interrupted for (1.) actual physical reasons, for (2.) reasons of policies or rules, or (3.) accidentally, because of inability or malice. The value of this categorization is obvious: It can provide guidance for a prioritization of resources for bottleneck management. More specifically, it can suggest whether an actual increase of physical capacity is necessary or not; possibly, a more stable inbound material flow can be achieved at lower cost – for instance, with a modification of organizational rules.

Other categorizations are conceivable, too. Attempts to create different categories in the course of this study ended up as a refinement of the three previous categories rather than new and independent categories.[1] It can therefore be concluded that the categorization of causes of bottleneck emergence as hinted at in the definition of bottlenecks early in this thesis provides a good foundation for further work and that it can remain a useful constituent of the resulting theory.

7.4. Bottleneck Management Activities Performed at the Case Companies

This section refers to the third and the fourth research question: "*What do organizations do about bottlenecks in their supply networks?*" and "*Can the bottleneck management measures of organizations be structured in a useful way?*"

Section 6.2 provides an analysis of all measures or activities each individual case company performs in order to manage bottlenecks in its respective supply network. Section 6.3 provides a cross-case overview about the measures, structured along four general categories of bottleneck management activities.

Five categories of bottleneck management activities were initially defined in the conceptual model: prevention, identification, exploitation, elimination, and placement. The analysis of the multiple case study has confirmed the usefulness

[1] It had been tried, for instance, to make use of these categories: market conditions, environmental conditions, technical/technological reasons, human error, variability, and legislature. While certain causes of bottleneck emergence could certainly be described as related to market conditions or legislature, these categories merely represent additional – more detailed – information rather than independent information.

of four of the five categories – prevention, identification, exploitation, and elimination – whereas no empirical evidence could be found for the practical use of bottleneck placement. The concept of *bottleneck placement* was explained to each of the interviewees and examples were provided for the use of bottleneck placement in a factory environment. In spite of the conceptual similarities between material flow in factories and supply networks (cf. Section 3.7) it was not possible to identify or construct situations that would fit into the category of bottleneck placement. Therefore this category has been removed from the revised model, which should not limit its validity in other contexts, such as production planning and control in a factory.

Most bottleneck measures identified in the individual case studies fall under the category of *bottleneck prevention*. All case companies use preventive measures in order to avoid supply shortages. In some cases, the emphasis on prevention was particularly strong as compared to other measures.

Some type of *bottleneck identification* measures is employed by all of the case companies. It became apparent, however, that bottleneck identification, more often than not, is not part of a systematic process but tends to be comprised of a combination of informal communication with suppliers and with other members of the industry network. Little technical support is used; there is no (online, live) tracking of deliveries or similar activities. In some cases, it might not be technologically feasible to introduce advanced identification measures, in other cases it might not be feasible for other reasons (lack of support from supplier) or it might simply be unnecessary because communication with suppliers is well established and reliable.

Bottleneck *exploitation* has been shown to be a useful concept for companies with production capacity. Four case companies in the sample are raw material traders. For them, bottleneck exploitation is of limited use, as indicated by the number of measures they employ which fall into this category.

The options for *bottleneck elimination* often depend on the preventive measures the company employs. In many cases, the case company uses alternative or parallel sources so that one elimination measure is to switch to an alternative source or increase the share of material sourced to a parallel source. In other cases, elimination measures depend more on “ad-hoc” availability of options, such as the possibility to substitute a particular material or buy from a competing company.

Because the four remaining categories of bottleneck management activities enhance clarity and facilitate discussion of actions to secure and stabilize supply, it can be concluded that the four categories identified will represent a useful element of the theory.

7.5. Decision Variables for Bottleneck Management at the Case Companies

This section refers to the fifth and to the sixth research question: “*What* can *organizations do about bottlenecks in their supply networks?*” and “*Are there parameters that influence or determine what organizations can do in order to stabilize inbound material flow? How do organizations choose their measures? And what seem to be the parameters*?”

It is not possible to determine with any certainty all the activities any one organization could perform to manage bottlenecks in its supply network, nor would such a hypothetical setup in practice exclude the chance of interruptions due to supply bottlenecks. Moreover, because most companies face a rather unique combination of internal and external parameters and determinants, it seems unlikely that a one-size-fits-all approach exists and suffices all requirements. Simply put: organizations have reasons to perform the differentiated activities they chose to perform.

This does not imply, however, that gaps do not exist in companies’ portfolio of activities. If parameters could be identified that make certain action suitable or unsuitable for a specific company in a specific situation, this would allow us to tell whether there is gap in a specific organization’s plan and how it could be closed.

In Section 4.6, a conceptual model was proposed that includes four broad areas of influence: the supply market, the buyers’ market, competition, and internal organizational parameters such as strategy, ability, technology, and product characteristics. These areas of influence were derived from the literature.

Because there are so many factors that can determine the appropriateness of specific bottleneck management measures, it might be too difficult a goal to identify all individual parameters, especially since the time that could be spent with each case company was limited. In some cases, limitations were explicitly named by interviewees, in other cases limitations could be derived from the information available. The limitations that could be identified in the process of the multiple-case study interviews were categorized according to the areas of influence in the conceptual model and the result is displayed in Figure 6.3.1 on page 337.

Limitations are not the only type of parameters and not all decisions for or against certain actions can be explained with limitations. It has been tried in Section 6.4 to refer the interview data to the literature reviewed in the first part of the thesis. Particular emphasis was put on power and dependency since it was – directly or indirectly – mentioned by five of the case companies. In Section 6.4.2 on page 342, the relationship between causes of bottleneck emergence and power/dependency as well as the relationship between the selection of particular measures of bottleneck management and power/dependency was investigated. Although the investigation suffered from a variety of constraints, the conclusion can be carefully drawn that an organization's power position relative to its suppliers and relative to other customers of the same suppliers does play a role for the selection of the portfolio of bottleneck management measures. Moreover, n*on-adjacent power regimes* were introduced and it was explained how they potentially impact on the focal firm's supply relationship.

In Section 6.4.3, measures of bottleneck management were related to risk management in supply networks. It was shown that bottleneck management addresses both factors of risk: uncertainty and severity of consequences. It was concluded that risk management and bottleneck management have an overlapping set of objectives which they approach from different conceptual angles, so that bottleneck management is likely to augment risk management (and vice versa). The discussion and conceptualization of bottleneck management can therefore add to theory and the body of knowledge in risk management.

In Section 6.4.4, the discussion of Lean, Agile, and Leagile from Sections 3.3 and 3.5 was picked up and related to the bottleneck management measures from the case studies. Variability is at the heart of the problems Lean, Agile, or Leagile approaches deal with. Unintended variability tends to "complicate things" and as such can be considered a detriment to the management of inbound material flow. It was shown that some of the measures companies employ have the potential to decrease variability in the supply network while others enable the case companies to increase their flexibility and thus cope with variability.

The research questions asked at the begin of this section refer to the measures organizations can employ and inquire into the reasons as to why they choose the measures they choose. It could be shown that measures of bottleneck management can fulfill multiple roles and serve multiple purposes. This finding suggests that when bottleneck management measures are selected one should be aware of the implications of each measure. The different roles of bottleneck management measures represent *decision variables* that influence the efficacy of each measure for the purpose it is intended to serve and thus represent an important part of the theory. Together with the limitations organizations face such parameters can account for the differences between the actions different organizations pursue. That is, the discussion of limitations and variables is intended to provide both guidance as to what measures ought to be chosen as well as an explanation as to why differences exist in the portfolio of bottleneck management measures of different companies.

7.6. Supply Chains and Supply Chain Management

Also in Phase III of the data analysis, the adequacy of the terms supply chain and Supply Chain Management was discussed in Section 6.4.6. The research question was three-parted:

Concerning the adequacy of the terms supply chain and Supply Chain Management:

- *Is the notion of supply chains (as opposed to supply networks) useful and does it represent interorganizational structures which the case companies* *are part of?*

- *Is Supply Chain Management a pointed description of the activities organizations perform or seek to perform in order to ensure the stability of their inbound material streams?*
- *How does the understanding of supply relationships change if the notion of supply networks (as opposed to supply chains) is adopted?*

It was concluded that the term supply chain is likely to create a mental model that inhibits the understanding of the vertical and lateral relationships between organizations that create the inbound material stream for the focal firm. The term *Supply Chain Management* obviously suffers from the conceptual weakness of *supply chains*. Even if we, in our minds, replace “chain” by “network” (so it becomes Supply *Network* Management), there remains a problem attached to the term *management*. It was argued that concepts such as power regimes and complexity provide natural impediments to anyone’s ability to *manage* a network. The concept of management was further dissected and a three-layer model of supply network management was defined, initially solely as an auxiliary so as to be able to find an answer to the research question. The model turned out to complement well the concepts identified and discussed hitherto, so that the different roles of bottleneck management measures could be related to it (Figure 6.4.3 on page 408).

Finally, it was discussed how a network perspective opens up several venues for better understanding and analysis of supply. Several concepts discussed in the course of this thesis were referred to as having the potential to provide benefits if – and only if – a network perspective is embraced.

7.7. Summary: Bottleneck Management in Supply Networks

The various findings from the review of literature and the three phases of case study analysis were drawn together in the previous sections and will be shortly summarized here.

Original contributions from the theoretical part of the thesis were shortly recapitulated. These contributions relate to a thorough development of the concept of bottlenecks and bottleneck management in supply networks (later complemented by empirical data), complexity, complex adaptive systems, system archetypes, and degrees of freedom in system setup.

The bottleneck of a system was defined in Section 2.3 as "the element (node or edge) that limits the system in attaining higher throughput beyond a certain threshold. This threshold is determined by the bottleneck's physical throughput capacity, organizational rules, or operational practices." This definition served as the foundation for the categorization of causes of bottleneck emergence. Causes of bottleneck emergence were categorized into physical, organizational, and operational causes. All causes of bottleneck emergence that were identified in the course of the multiple-case study could be sorted into these categories. A classification of causes provides first indication as to what levers are available to the organization to improve or stabilize the supply situation.

The multiple-case study helped create a comprehensive list of bottleneck management measures which are pursued by the case companies. These measures can be categorized into four distinct types of activities: bottleneck prevention, bottleneck identification, bottleneck exploitation, and bottleneck elimination. These categories – and one additional category that was dropped in the course of the data analysis – were derived from a review of various streams of literature and they provided the structure for the case study interviews.

Limitations and parameters for the selection of bottleneck management measures were analyzed and discussed. Limitations to the case companies' bottleneck management were identified in the case interviews. The limitations were structured along the same categories that were suggested as general areas of influence on the selection of bottleneck management measures in the conceptual model: supply market, buyers' market, competition, and organizational factors. In addition, different parameters were identified based on the case data. The analysis of parameters suggested that bottleneck management measures can serve multiple purposes. Bottleneck management measures were related to power and dependency, reduction of uncertainty and mitigation of contingencies, as well as increase of flexibility and reduction of variability. These parameters and limitations help explain the differences between the bottleneck management portfolio of different organizations and they provide guidance for the selection of an organization's right bottleneck management measures.

Taken together, all the contributions mentioned above provide the basis for a theory of bottleneck management in supply networks. The theory adds to the body of knowledge in the wider field of supply network management, often referred to as Supply Chain Management (SCM), and to other branches of research at its interface. Moreover, it has the potential to support organizations concerned with the stabilization of their supply with a useful and rich perspective in which to frame their problems and potential solutions. The explanations of causes of bottleneck emergence as well as the discussion of specific bottleneck management measures and how they relate to different roles provides guidance for organizations seeking to select the right course of action to prevent and alleviate supply-related problems.

Figure 7.7.1 displays an overview of the most relevant contributions related to bottlenecks and bottleneck management. It is not a representation of the entire theory but illustrates some of its important concepts discussed up to now that were supported by the empirical assessment.

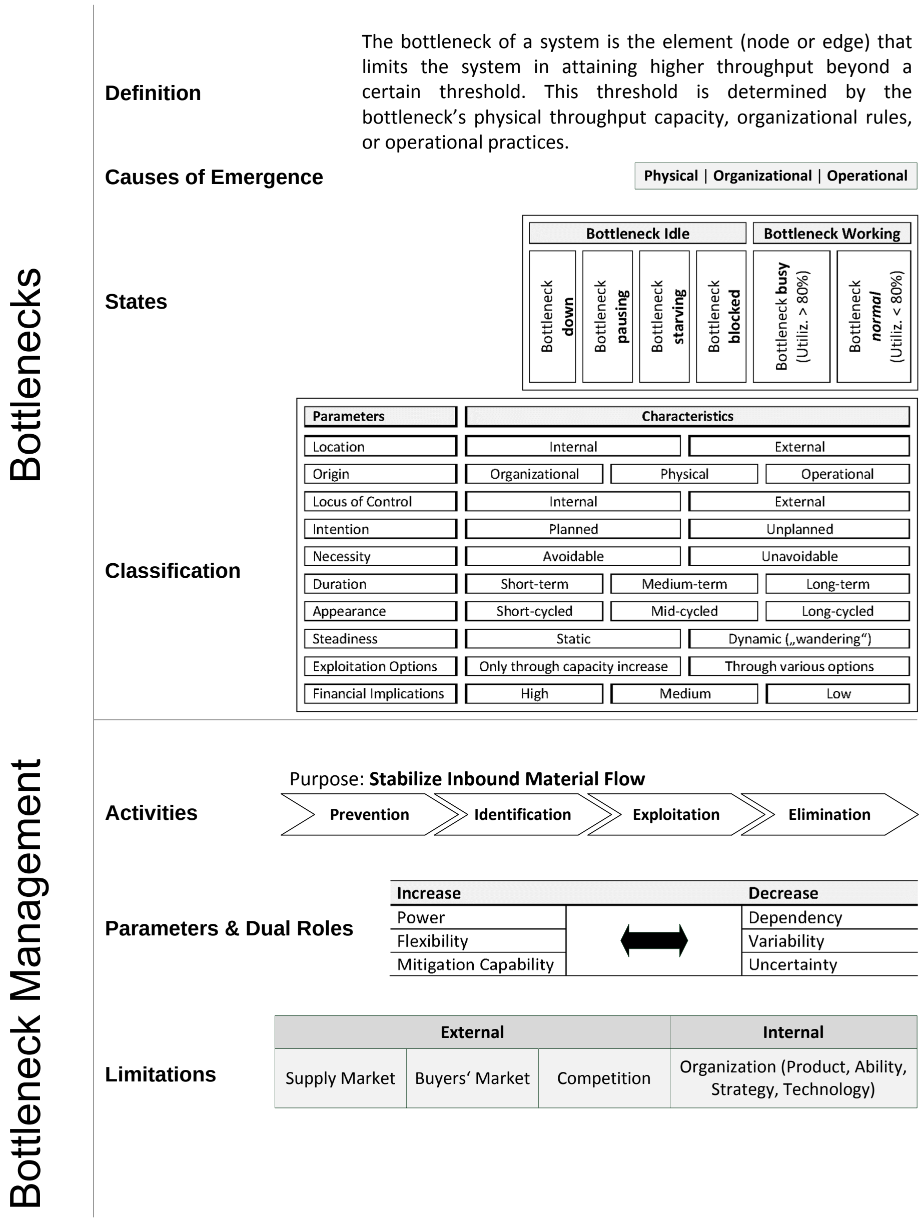

Figure 7.7.1. – Overview of Conceptual Contributions to Bottleneck Management in Supply Networks

8. Conclusion

8.1. Introduction

In Section 1.2, the general aim of this thesis was defined as follows:

> The general aim of this PhD dissertation is (1) to complement and enrich the knowledge on and understanding of bottlenecks in general and of bottlenecks in supply networks in particular, (2) to lay the groundwork for a theory of bottlenecks in supply networks, (3) to create structured and methodological access to the management of bottlenecks in supply networks, (4) thereby facilitating access to this field for industrial organizations.

Various streams of literature were reviewed with respect to relevant contributions to bottleneck management in supply networks. From the review of literature, a conceptual model was derived in Chapter 4 that provided the structure for the collection of empirical data. The data were collected through a multiple-case study consisting of ten individual cases. The primary data collection tool were semi-structured interviews with qualified personnel.

The literature review and the resulting conceptual model also served as a basis for the research questions. The research questions were defined as follows (cf. Section 4.7):

1. What are some of the reasons why supply shortages occur in supply networks?
2. Can the causes of bottleneck emergence be structured in a useful way?
3. What do organizations do about bottlenecks in their supply networks?

4. Can the bottleneck management measures of organizations be structured in a useful way?

5. What *can* organizations do about bottlenecks in their supply networks?

6. Are there parameters that influence or determine what organizations can do in order to stabilize inbound material flow? How do organizations choose their measures? And what seem to be the parameters?

7. Concerning the adequacy of the terms supply chain and Supply Chain Management:

    a) Is the notion of supply chains (as opposed to supply networks) useful and does it represent interorganizational structures which the case companies are part of?

    b) Is Supply Chain Management a pointed description of the activities organizations perform or seek to perform in order to ensure the stability of their inbound material streams?

    c) How does the understanding of supply relationships change if the notion of supply networks (as opposed to supply chains) is adopted?

The data analysis in Chapter 6 was conducted in three phases: First, each individual case was analyzed separately (cf. Section 6.2). In the second phase, the interviewees' responses were compared across the cases (cf. Section 6.3). In the third phase of analysis, selected parameters that can influence the selection of bottleneck management measures were analyzed and discussed (cf. Section 6.4). Moreover, the third phase related the case study data to the terms supply chain and Supply Chain Management. It was discussed how the data match the concepts behind the terms and what follows both for theory and practice of the management of supply networks.

In Chapter 7, the results of the project were drawn together and summarized. Together, they represent the foundation of a theory of bottleneck management in supply networks, which has been one of the aims stated at the outset of this project.

8.2. Contribution to Theory

This section is to explain the contribution to the literary discourse on the management of supply and interorganizational material flow. In spite of the vast amount of literature in the field of supply (chain) management and procurement, a consistent body of knowledge on the management of supply bottlenecks has not evolved. One of the aims of this research project has been to introduce the foundation of a theory of bottleneck management to the academic discourse. In Section 1.4.1, it has been said that a theory requires four constituents: *What*, *How*, *Why*, and *boundary definitions*. These constituents could be defined in the course of this project.

As to the constituent *What*, strategies, measures, and limitations in the management of inbound material flow as well as the causes of bottleneck emergence were defined as the units of analysis. These units of analysis were extracted from the multiple-case studies and useful structures were worked out for these elements.

The discussion of the units of analysis not only concerned the constituent *What*, but also the constituent *How*. For each of the elements, it was elaborated on *how* exactly it functions and thus, more specifically, how certain events lead to irregularities in supply, how the organizations analyzed achieve their objective of stable supply by the means of the measures they employ, and how certain limitations may prevent them from doing so. The elements *What* and *How* were addressed predominantly in research questions 1 through 5.

The third constituent, *Why*, was addressed in the analysis of decision variables. It was tried to explain *why* organizations chose the measures they employ (and not others) and why some organizations are subject to limitations other organizations are free of. This analysis also involved certain contextual information which represent the *boundary definitions*. The constituent *Why* as well as boundary definitions were addressed predominantly in research question 6, although some facets of the latter were addressed also in previous research questions.

It can be concluded that the elements that constitute theory were addressed.

They are not complete; the theory proposed in this thesis is intended to represent a base frame for further research. It is believed, however, that it does have reasonable explanatory power and the potential to make useful predictions.

The definitions of the elements of the theory raised questions about some core concepts of the wider theoretical setting which were addressed in research question 7. While the scope of research question 7 is covered by the general research aim defined at the outset of the thesis, it was recognized with some surprise that both the review of literature and the data analysis downright invoked a critique of widely accepted conceptions, which is now believed to represent a valuable corollary to the theory defined hitherto.

Some of the conceptual contributions that were made in the theoretical part of the thesis include a classification of bottlenecks and of bottleneck states. These elements provide the basis for a taxonomy, which enriches the clarity and explanatory power of the theory.

The most relevant individual contributions this research provides can be summarized as follows:

- A consistent definition of bottlenecks that meets both practical and academic requirements was provided as the review of relevant literature revealed that such a definition had not evolved to date.
- Types of bottlenecks and bottleneck states were categorized.
- The concept of bottleneck management in supply networks was introduced.
- Three categories of causes of bottleneck emergence were derived from the literature and validated through empirical study.
- Five categories of bottleneck management activities were derived from relevant literature. Four of these categories could be empirically validated through case studies.
- Specific measures of bottleneck management were identified in the analysis of the ten case exemplars.

- The individual measures of bottleneck management were related to literature on power, Lean/Agile, Supply Chain Management, manufacturing systems, and risk management. Roles were identified that specified the effect specific measures have and which make them suitable for specific taks and environments.

- Together, the definition and categorization of bottlenecks, the categorization of causes of bottleneck causes, the four general bottleneck management activities, the specific bottleneck management measures, and the attribution of measures according to their distinct roles constitute a taxonomy of bottleneck management in supply networks.

- An empirically grounded contribution to the ongoing discussion as to whether it is more appropriate to refer to supply networks rather than to supply chains was provided.

- A critique, rooted in a review of relevant literature as well as in empirical data, of the field of Supply Chain Management was formulated.

- The study tested the adoption of concepts from bottleneck management in factory systems in supply networks and outlined the commonalities and differences.

- The study created structured, methodological access to valuable knowledge for the management of bottlenecks in supply networks.

- In essence, this research introduced new aspects to and a new perspective on the management of supply and laid the groundwork for a theory of bottlenecks in supply networks.

According to Mills et al. (2004), the field of SCM contains only very limited original theory. Most theoretical concepts have emerged outside SCM and are applied not to describe or to solve “chain” or “network” problems but for organizational problems or problems in a dyad. SCM, however, is said to be much more. A core claim is that SCM takes into account the entire chain or network and not merely a small portion of it. Mills et al. (2004) claim that there are “only two theories of supply chains or networks": the bullwhip effect (Forrester 1958, Lee et al. 1997) and postponement strategies for differentiation of products as a means for more efficient marketing [1].

A theory of bottleneck management in supply networks augments existing concept and contributes to the body of theory in Supply Chain Management research. It provides a different angle from which to look at problems of the management of supply.

8.3. Contribution to Practice

This study has taken up the concept of bottlenecks and contributed to the clarity, the understanding, and the applicability of the bottleneck metaphor in the context of supply networks. The bottleneck metaphor is a powerful aid and facilitates both the selection of appropriate measures for the management of inbound material flow as well as the communication of material flow-related problems.

Moreover, the management of inbound material flow is methodologically supported by the categorization of bottlenecks, bottleneck states, causes of bottleneck emergence, activities for bottleneck management, limitations to bottleneck management, and roles of bottleneck management measures, each of which contributing to a better understanding and methodological access to the management of supply.

The categorization of causes of bottleneck emergence helps organizations understand the source of their supply-related problems. The understanding of the causes enables them to better choose the most appropriate counter-measures.

A comprehensive list of bottleneck management measures was derived from ten company exemplars in a multiple-case study. Although the list is by no means complete or representative, it is rich in detail and together with contextual information about the case companies can serve as the basis for interorganizational benchmark. The list of measures and their description can help organizations evaluate their own set of measures.

[1] Bucklin (1965) credits Alderson (1950) for his early work on postponement of product differentiation.

The measures identified in the case studies were categorized according to four general bottleneck management activities. Such categories provide a quick overview and access to the measures available so that potential gaps in an organization's portfolio of measures can be identified more easily.

Additionally, measures of bottleneck management were related to important concepts from both, theory and organizational practice, such as risk (probability and consequences), Lean (efficiency and flexibility), and interorganizational power relations. In the discussion of these concepts and how they relate to the empirical data gathered from the ten case companies, it was explained how bottleneck management measures can serve multiple purposes at once. This requires careful selection of the right measures, which is supported by the analyses in this thesis.

The discussion of the popular yet imprecise notions of supply chain and Supply Chain Management has emphasized the need to alter the understanding of supply-related interorganizational structures. It provides an aid for organizations aiming for better control of their inbound material streams by pointing out possible sources of disturbance from outside the direct contractual relationships so as to enable decision makers to take appropriate preventive measures in due time.

Finally, a theory of bottlenecks in supply networks provides a point of reference for organizations aiming for improved management of supply. This project provides the basis for additional research in this field, both in theory and in practice, hopefully providing more tools, concepts, and methodological access for organizations.

8.4. Research Limitations

This research project is subject to a variety of limitations, some of which necessarily follow from the choice of research approach. The limitations shall be shortly addressed in this section.

The time spent with each case company was limited, and it was difficult to get access to companies that would cooperate with the researcher in the first place.

More time with each case company, analysis of archival data, participation in meetings with suppliers, observation, and additional interviews with the same as well as with other members of the respective organization would support the strength of the claims made in this document. Such in-depth investigation might have been possible with one or very few case companies; instead it was decided to go for breadth and talk to more different organizations. While it is believed this was the right approach for this project, it had to be traded off against depth of investigation, which certainly is one limitation.

The analytic generalizations made in this thesis could be improved with an even greater number of cases in different industrial settings. There are, for instance, additional measures of bottleneck management that are known to the researcher but remained unmentioned by the case study participants. Likewise, a multitude of additional situations is conceivable that would lead to interruptions of supply. Additional cases could thus have enriched the theory proposed by suggesting, for instance, additional parameters and conditions for the selection of certain activities and measures (that is, additional cases would support more elaborate boundary conditions of the theory).

Because the study involved ten case companies with partly overlapping, yet partly also very different industrial background, it is conceivable that a replication of this study with different companies from different backgrounds would lead to partly differing propositions. It is believed that the core of the theory can suite a wide variety of different industrial settings, yet emphasis on a different set of particular measures might result.

The study is qualitative. Data sets (e.g., from the International Manufacturing Strategy Survey) exist that could be used to add a quantitative component to the project. Because it had put a strain on the scope of this project, quantitative data was not included. It is encouraged, however, to complement this work with analysis of quantitative data.

This study is inductive in nature. That is, it does not present validation of facts but theory. While a consequence of the research approach, it must be acknowledged that all claims made in this thesis represent propositions rather than facts and that this thesis is subject to the general limitations of induction.

Obviously, the entire research project is subject to the limitations inherent to a PhD project, such as rigid time frame and financial constraints. Research approach and scope were defined accordingly, yet more time and funding would have provided the means to investigate certain aspects in greater detail.

8.5. Need for Further Research

In this project, an entirely different perspective on the management of inbound material streams was adopted than is generally taken in the relevant literature. This different perspective on well-known problems may stir up some research fields – and if it does indeed this will be considered a success. The material flow or bottleneck perspective on the management of supply has implications for adjacent and overlapping research fields.

In Section 6.4.2, the relationship of power, dependency and bottleneck management measures was investigated. The number of data points limited the ability to draw strong conclusions from the analysis. Additional research that includes and compares larger samples of firms so as to derive more definite conclusions about, for instance, the relation of relative power (or lack thereof) and how it enables (or limits, respectively) the use of certain bottleneck management measures could provide valuable insights and extend the theory put forth in this project.

One adjacent field of research and practice is *supplier management*. More specifically, it can be asked what follows from the insights into bottleneck management methodology and power relations for the selection of suppliers, supplier training, supplier audits, and the design of supply contracts. All other things being equal, should a firm prefer to choose a less powerful supplier rather than a more powerful supplier? Should a supplier be preferred that does not supply more powerful firms that compete in the same segment as the buying firm? How can supply contracts be designed to cover potential supply shortages arising from preferential treatment of the supplier's other customers? How would scripts and questionnaires for supplier audits need to be modified to account for increased demands on bottleneck prevention or bottleneck exploitation? Can opportunities for bottleneck exploitation replace the need for alternative or parallel sources? Can possible organizational causes of bottlenecks be identified in supplier audits and changes be demanded prior to contract closing?

Another adjacent field is *transportation and logistics*. How do transportation networks need to be designed so as to enable firms to quickly change transportation modes and get maximum throughput at bottlenecks? How do decisions regarding local or global sourcing change given that global sourcing excludes quicker transportation and thus bottleneck exploitation, as it happens to be the case for some of the companies of the empirical study? What are the implications for the selection of the right production location?

Risk management was mentioned before as being a research field that can benefit from the conceptual work on bottleneck management. How should power relations be considered in risk prevention and mitigation strategies? Should business with powerful suppliers be considered risky? Can the four categories of bottleneck management activities enhance risk management methodology? Where are bottleneck management, as presented in this thesis, and risk management are at odds and where is overlap? In practice, will there be a need for both concepts in parallel at the same organization or will one be sufficient (provided risk management is mostly concerned with the risk of supply and production outages)?

There are also some more subtle relations to other topics. One example is *maintenance*. With regard to opportunities for bottleneck exploitation (and possibly bottleneck placement, although this category was removed in the course of the study), how should maintenance activities be prioritized? What are the implications for the maintenance budget? Does reactive maintenance still suffice the organization's needs or do the insights from this study suggest that preventive maintenance should be considered mandatory? In supplier audits, what maintenance documentation should be checked at the supplier's production site? Should a maintenance strategy be mandatory for a supplier to be granted the contract? What if the supplier is actually too powerful to accept these conditions and rejects any such demands?

In Section 2.5.2, it was touched upon concepts from *network theory* to conceptually describe networks between organizations. The empirical investigation carried out in this thesis did not include a complete analysis of the network structures of the case companies. Such an analysis could, however, provide additional insight if related to both causes of bottleneck emergence and concepts of bottleneck management. First attempts to advance these directions have already been made (cf. Cox et al. 2001, Craighead et al. 2007, Choi & Kim 2008, Mizgier et al. 2013), yet is clear that more work needs to be done in order to be able to derive reliable conclusions.

In Section 7.5, it was stated that the identification of *parameters* influencing the *selection of viable bottleneck management measures* was limited in this project. Additional research on the selection of the appropriate measures for bottleneck management is encouraged. It seems likely that value can be derived from a better understanding of the relation between an organization's internal and external parameters and limitations and the selection of the right bottleneck management measures.

Generally, the entire theory of bottleneck management in supply networks developed in this thesis is open to additional testing, extension, and modification. The inductive nature of this project makes it likely that the theory will not fit to every organization in every context. Additional context-specific refinement of the theory may enhance its value and its validity.

8.6. Summary

Only limited literature exists on bottlenecks in supply networks. This thesis aims to fill gaps in theory and to address industrial needs.

Different streams of literature were analyzed and useful concepts extracted so as to derive a structure of bottleneck management in supply networks.

An empirical data collection served to explore concepts used in practice. Data from the multiple-case study was related to theoretical concepts extracted from the literature review. The data analysis supported the concepts devised earlier and helped refine them. Moreover, it suggested the existence of three dual roles of bottleneck management measures, providing a framework for the selection of measures in different contexts.

Based on the literature review, commonly accepted concepts such as supply chains and Supply Chain Management were subjected to scrutiny. The notion of their misrepresentation of industrial practice was supported by the data analysis.

In summation, this project brings forth the foundation of a theory of bottleneck management in supply networks, thereby enriching both the literary and the non-literary discourse, and providing insights and guidance for decision-makers in the management of supply of industrial organizations.

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Appendix

A. Literature Review: Definition of Bottleneck

The literature referenced in the review below is listed in the bibliography.

Literature Review: Definition of Bottleneck

Reference	Scientific Discipline/ Subject Area	Definition or Statement Point to Definition
Suri (1986)	Production planning and control, Lean, Kanban	No explicit definition
Lawrence & Buss (1995)	Production planning and control, bottleneck analysis, economic analysis of bottlenecks	"A survey of the research and pedagogical literature finds that there exists no clear consensus as to the definition of a "bottleneck" resource." (p. 342) "Summarizing, there appear to be three principal definitions for bottleneck resources currently in use: A bottleneck resource is one for which (1) short-term demand exceeds capacity; (2) work-in-process (WIP) inventory is maximum; or (3) production capacity is minimum, relative to demand (i.e., capacity utilization is maximal). (…) Since none of these definitions considers costs, revenues, or profitability of the firm, but focuses solely on the output of the process, we will refer to them as production bottlenecks." (pp. 342-343) "[A]n economic bottleneck [is] defined to be that workstation which most severely increases costs or limits profits." (p. 355)
Ivens & Lambrecht (1996)	Production planning and control, production job scheduling	"The bottleneck m is the resource with the largest makespan for problem $P(k, M_0)$, i.e. the resource m for which $P(m, M_0) = \max_{k \in M \ M_0} P(k, M_0)$.
Kuo et al. (1996, p. 234)	Production planning and control, bottleneck identification in serial production lines	"[A] machine that impedes system performance (…) in the strongest manner (…) is typically referred to as the bottleneck (BN)."
Bergamaschi et al. (1997)	Production planning and control, order release strategies	No explicit definition
Chiang et al. (1998)	Production planning and control, bottleneck identification in production systems	Intuitively, bottleneck (BN) of a production line is understood as a machine that impedes the system performance in the strongest manner." (p. 352)

Reference	Scientific Discipline/ Subject Area	Definition or Statement Point to Definition
		"Even the definition of BN is unclear" (p. 352) "A machine is a UT-BN (or DT-BN) if an increase of its uptime (respectively, a decrease of its down-time) leads to the largest increase of the system production rate. (…) A machine is the BN if both its up time and its down-time are the most critical for the system performancProduction planning and control, bottleneck identification in production systemse." (p. 353) "Bottlenecks in Markovian production lines can be defined as partial derivatives of the system production rate with resp machines' up- and down-time." (p. 355) ect to
Hopp & Roof (1998, p. 871)	Production planning and control	In a production line, the bottleneck is the slowest station the capacity of which is below targeted throughput.
Hendry et al. (1998)	Production planning and control, simulation of workload control	No explicit definition
Laure (1999)	Production planning and control, semiconductor production	No explicit definition
Nakata et al. (1999)	Production planning and control, semiconductor production	No explicit definition
Jain et al. (2000)	Supply chain planning, semiconductor production	Workstation with highest utilization
Chiang et al. (2000, p. 567)	Production planning and control, bottleneck identification in production systems	„The bottleneck of a production line is the machine that impedes the system performance in the strongest manner".
Chiang et al. (2001, p. 543)	Production planning and control, bottleneck identification in production systems	"The bottleneck of a production line is the machine that impedes the system performance in the strongest manner".
Roser et al. (2002, p. 1079)	Production planning and control, bottleneck detection methods	"There are numerous definitions as to what constitutes a bottleneck (Lawrence and Buss 1995). Within this paper, we define a bottleneck as a stage in a

Reference	Scientific Discipline/ Subject Area	Definition or Statement Point to Definition
		production system that has the largest effect on slowing down or stopping the entire system.”
Lee et al. (2002)	Production planning and control, semiconductor production	No expicit definition
Roser et al. (2003, p. 1192)	Bottleneck detection, AGV systems	“We define a bottleneck as a machine whose throughput affects the overall system throughput, and the magnitude of the bottleneck as the magnitude of the effect of the machine throughput onto the system throughput. In summary, the sensitivity of the system throughput to the machine throughput determines the level of constraint of the machine.” (adapted from Kuo et al. 1996)
Haller (2003, p. 185)	Production planning and control, semiconductor production	A bottleneck is a process step (i.e., a machine) that limits over-all throughput.
Goldratt & Cox (2004, p. 139)	Production planning and control, Theory of Constraints	“A bottleneck is any resource whose capacity is equal to or less than the demand placed upon it.”
Wang et al. (2005, p. 3)	Production planning and control, bottleneck detection methods	“Bottlenecks are generally recognized as some resources or utilities, which heavily limit the performances of a production system” “[T]here is still not a consensus definition of bottlenecks.” “A common sense of bottleneck is 'something' that limits system’s production rate.”
Lu et al. (2006)	Production planning and control, study of shifting bottlenecks	“So far, there is no uniform bottleneck definition in academe.”
Li et al. (2007, p. 76)	Production planning and control, Markovian statistics	“Bottleneck is a machine that impedes the system performance in the strongest manner.”
Aske et al. (2007, p. 65)	Production planning and control	“A unit is a bottleneck if maximum throughput (maximum network flow for the system) is obtained by operating this unit at maximum flow (with no available capacity left). In some cases the bottleneck

Reference	**Scientific Discipline/ Subject Area**	**Definition or Statement Point to Definition**
		can not be located to a specific unit, but rather to a system of units ("system bottleneck")."
Hopp & Spearman (2008, p. 486)	Production planning and control, manufacturing principles	A bottleneck is the process with the highest long-term utilization.
Malkowski et al. (2009, p. 119)	E-Commerce, computer system performance analysis	"The common understanding of a system bottleneck (or bottleneck for short) can intuitively be derived from its literal meaning as the key limiting factor for achieving higher system throughput."
Stevenson et al. (2011)	Production planning and control	No explicit definition
Liu (2011, p. 39)	Production planning and control	"Hence, bottlenecks are defined as the most prominent, physical hindrances (e.g., workstations, production systems and customer orders) that impede achievement of target performance measures of a manufacturing system (i.e. primary bottlenecks)."
Mizgier et al. (2013, p. 1477)	Supply chain risk management, network theory	"[F]irms that induce high losses due to supply chain disruptions in a focal firm or the supply chain network as a whole."

B. Project Exposé

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Bottlenecks in Supply Networks:

A Systematic Approach to Prevention, Detection, and Management of Bottlenecks

Background to the Project

This research is part of a PhD project being undertaken at the Centre for Industrial Asset Management at the University of Stavanger, Norway. The research project involves several in-depth case studies that are intended to augment the theoretical research conducted in this project.

Project Description

Reliable supply is imperative for manufacturing firms; interruptions have posed major challenges in the past. A workable methodology to deal with bottlenecks in supply networks has not evolved, however. This PhD project seeks to provide a reference for thorough understanding of the emergence of bottlenecks in supply networks, their impact on manufacturing, their prevention, detection and management.

Empirical data are necessary to identify relevant problem sets as well as to validate theoretical propositions. The case studies conducted in the course of this project thus serve multiple purposes: to extend the knowledge base provided by the relevant literature, to identify the most urging problems for industrial supply networks, and to discuss, test, and validate solutions with professionals from industry. Desired output of the case studies is of qualitative nature.

Format & Procedures

Semi-structured interviews have been chosen as main method for data collection. The interviews will be conducted preferably on-site or, if not possible otherwise, on the phone. The settings chosen for the case studies include automotive, agricultural machinery, oil & gas, and food production.

Confidentiality

The use of the data collected in the case studies is subject to the following terms and conditions:

- Participating companies will not be mentioned in the dissertation nor in other publications of any kind if not agreed on otherwise, i.e., all participants remain anonymous.
- The dissertation as main outcome of the PhD project will be disclosed to public.
- Besides in the monograph that is to be released by September 2014, findings may be published through scientific journals and conferences under the same conditions as stated for the dissertation, i.e., participants remain anonymous if not agreed on otherwise.
- Field data and interim findings are not to be made available to other participating companies beyond what is going to be published anonymously.
- Field data and interim findings are not made available to other researchers before official publication through scientific journals, conferences, and the dissertation with exception of the PhD researcher's primary and secondary supervisors who are involved in the study.

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C. Interview Questionnaire

Interview Questionnaire: Bottlenecks in Supply Networks

This interview questionnaire aims to identify causes for bottlenecks as well as approaches to manage them. To make the analysis consistent, it may be necessary to select some of the company's most *important* or most *critical* products, respectively. *Importance* refers to significance the product has for the company's current or future bottom line. *Criticality* refers to the product's propensity to be subject to supply shortages (bottlenecks).

The information provided in this interview will be treated confidential. All information will be used only anonymously and the company name will not be mentioned to other case study participants nor will it be used in publications of any kind.

The outcome of the case study and the research project as a whole are likely to include useful guidance for all participants. The goal is to assemble state-of-the-art knowledge and best practices to provide industrial companies with practical solutions and remedy for supply-related problems.

This research project is funded by the European Union's 7th Framework Program.

Part I: Industry Characteristics, Firm Characteristics, and Product Characteristics

1. Do you have direct competitors for a significant share of your products? If so, how many?

2. How would you describe your industry in terms of dynamics/routine?

3. How would you describe your products in terms of complexity?

4. How would you describe your production process in terms of complexity?

Part II: Bottlenecks in the Supply Network: General

1. **As how severe do you perceive the problem of bottlenecks in your supply network in terms of frequency and impact?**

2. **Do you think your perception of bottleneck severity is generally shared by management and those concerned with material management?**

3. **Where in your supply network do bottlenecks normally emerge for your most important/most critical products?**

4. **What are the most common reasons for bottlenecks emerging in your supply network? (mention examples for facilitation)**

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Part III: Bottlenecks in Supply Networks: **Prevention**

1. **What actions does your company take in order to prevent the emergence of unplanned bottlenecks?**

2. **Is there a standardized action plan in place for (1) supply network design, (2) sourcing options (selection, redundancy, location), and (3) supplier training?**

3. **In your opinion, what actions *should* be taken (which are currently *not* being taken) in order to prevent the emergence of unplanned bottlenecks?**
   (If there is a mismatch between what is being done and what should be done: why?)

4. **Does your company engage in tier-n management? If so, to what extent? If not, why not?**

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Part IV: Bottlenecks in Supply Networks: Detection

1. **How does your company normally learn about bottlenecks emerging in your supply network?**

2. **Is there a standardized procedure according to which suppliers will notify you when a bottleneck has emerged or chances are it will emerge?**

3. **How long in advance (i.e., before supply shortage starved your production) does your company normally learn about bottlenecks emerging?**

Part V: Bottlenecks in Supply Networks: Exploitation

1. **In case a bottleneck has emerged, what actions does your company take in order to *exploit* it (i.e., get maximum throughput out of it)?**

2. **Do you have employees trained in exploitation of bottlenecks?**

3. **In your opinion, what actions *should* your company take in order to exploit bottlenecks?**

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Part VI: Bottlenecks in Supply Networks: Elimination

1. **In case of a bottleneck has emerged, what actions does your company take in order to *eliminate* it?**

2. **What actions to eliminate bottlenecks in supply networks can you think of? Which *should* your company take?**

Part VII: Bottlenecks in Supply Networks: Placement

1. **Can you make sense of the concept of *planned bottlenecks*?**

2. **Do you know – or have an idea about – how much flexibility your company maintains in production capacity?**

3. **Do you know – or have an idea about – how much flexibility your company expects suppliers to maintain in production capacity?**

Part VIII: Supply Network Characteristics

1. How many direct suppliers do you (approximately) have for your most important and most critical products?

2. What is the most common delivery mode for material you receive from suppliers? (JiT, JiS, conventional warehouse, consignment warehouse)

3. In your opinion, does the delivery mode seem to make a difference for severity (frequency and impact) of bottlenecks emerging?

4. As compared to the most critical suppliers (in terms of bottleneck frequency), how do you perceive your company’s power (in terms of influence on suppliers’ management decisions, negotiation power…)?

5. In your opinion, how important is your company as a customer for your most critical suppliers as compared to their other customers? What do you base your assessment on?

Appendix

Terminology

Bottleneck: Bottleneck is defined as the element (node or graph) that limits the system in attaining higher throughput beyond a certain threshold. This threshold is determined by the bottleneck's physical throughput capacity, organizational rules, or operational practices. In the context of this interview, a bottleneck is generally indicated by a supply shortage of material needed for production

Importance of product: Importance of a product refers to the significance a product has for the company's current or future bottom line.

Criticality of product: Criticality of a product refers to the product's propensity to be affected by supply shortages (i.e., bottlenecks).

Unplanned bottleneck: Unplanned bottleneck refers to a bottleneck that emerges in the system without being consciously designed into it.

Dynamic industry: Refers to the number of new product launches in the industry, the number of competitors offering similar products, number of companies entering and leaving the industry, and innovation being created in the industry.

Routinized industry: Refers to a mature, efficiency-focused industry, as opposed to dynamic industry (see above).

Bottleneck severity: Bottleneck severity refers to the combination of the number of bottlenecks occurring in a supply network (frequency) and the impact they have on the business of the focal firm.

Tier-n management: Refers to a company managing its suppliers not only on tier-1 stage but also on tier-2, tier-3, etc. stage. Tier-n management may include supplier selection, training, quality assurance, audits, and intervention in case of conflicts between suppliers.

Product complexity: Refers to the number of different parts a product consists of.

Process complexity: Refers to the number of process steps involved to produce a particular product as well as to difficulties (technical, operational, or organizational) to execute them.

Power (over suppliers): Refers to the focal company's ability to influence individual suppliers. Power may be determined by a combination of the market positions of both the supplier and the focal firm, the ease of switching, the significance for each other's business activities in terms of volume or competencies, and other stakes each company may possibly have.

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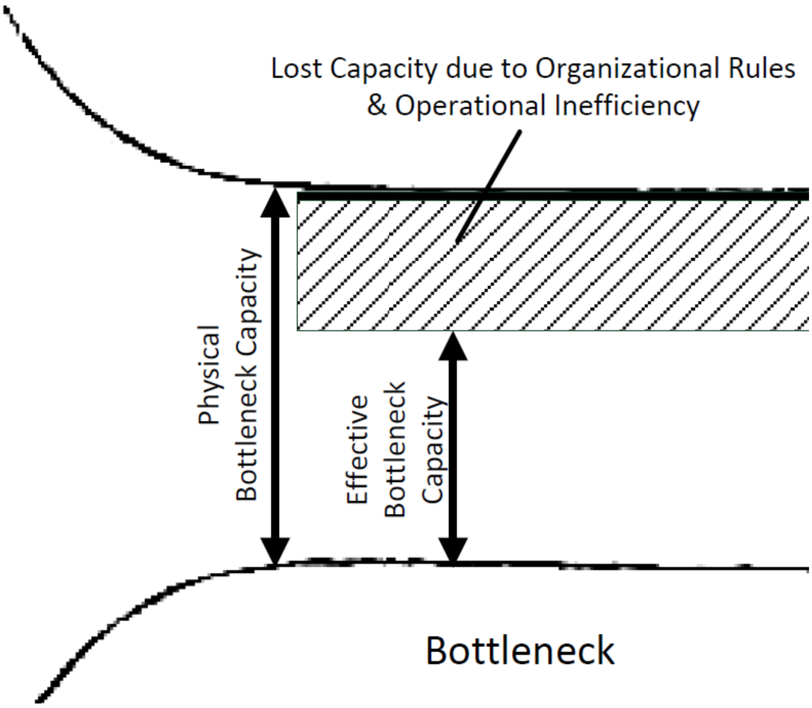
Bottleneck



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Bottleneck Classification

Parameters	Characteristics		
Location	Internal	External	
Origin	Organizational	Physical	Operational
Locus of Control	Internal	External	
Intention	Planned	Unplanned	
Duration	Short-term	Medium-term	Long-term
Appearance	Short-cycled	Midcycled	Long-cycled
Steadiness	Static	Dynamic („wandering“)	
Exploitation Options	Only through capacity increase	Through various options	