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Lean and TPM Practices in an Industrial Context

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Abstract

Today´s globalized market place, and rapid changes in businesses environment, brings forth a need for continuous improvement. Businesses all over the world compete against each other, therefore it is essential for manufacturing business to never "stand still". In a high cost country as Norway, it is always a risk for outsourcing. To prevent this from happening, manufacturing companies need to continuously increase their performance, deliver on quality expectations, and remain competitive on cost. To meet these needs, Lean and TPM are vital concepts for success in this industry.

Lean and TPM are two closely linked terms that together can create world class results through learning and empowerment of employees. In this thesis, key practices from both the concepts was used for analyzing the current situation at the Cast House at Alcoa Lista, an organization that was one of the earlier adopters of the Lean concepts. By analyzing the current situation through key practices of Lean and TPM, possible improvement suggestions were identified.

The analysis showed at the Cast House has come a long way seen in a Lean and TPM perspective. However, the results uncovered some improvement possibilities. Based on these, several improvement suggestions were presented and discussed.

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Table 1 Abbreviations

Abbreviations	
ABS	Alcoa Business System
KPI	Key Performance Indicator
FIFO	First-In-First-Out inventory
SMED	Single Minute Exchange of Die
JIT	Just-In-Time
TPM	Total Productive Maintenance
KPI	Key Performance Indicator
OEE	Overall Equipment Efficiency
TPS	Toyota Production System
PDSA	Plan-do-study-act
CONWIP	Continuous work in progress (a type of pull system)
WIP	Work in Progress
US	Ultra-sonic
OEE	Overall Equipment Efficiency
Conti	Continuous homogenizing furnace
RPA	Rapid Plant Assessment

1. Introduction

1.2 Background

Running a production facility in a high cost country as Norway has its challenges, as Norway has some of the highest hourly compensation costs in the world (Bureau of Labor Statistics, 2013). In today's globalized market place and rapid changing environments, where manufacturing businesses compete against business all over the globe, it has become vital for manufacturing businesses to not "stand still". If a business fails to improve itself, it is just a matter of time before it is completely outcompeted by its competitors. Norwegian manufacturing companies need to continuously increase their efficiency, deliver on quality expectations, and remain competitive on cost. If a manufacturing company fails to deliver on the above, there is always a risk for outsourcing. In this work the concepts of Lean and TPM is vital for success in the manufacturing industry.

A common misconception about Lean and TPM, is that they are a set of tools, that if implemented, will guarantee excellent results. This is the downfall for many companies. The tools that are used in Lean and TPM are often useful for the continuously improvement process, however, they are not the most important part of Lean and TPM. To achieve World Class Results, companies need to see the bigger picture. Through total involvement of the whole organization, from top to bottom, and creating a culture for continuous improvement, an organization can through relentless waste reduction, achieve a leaner production. By building a culture for continuous improvement, a lean organization can, through many small improvements, achieve major performance improvement.

Alcoa Lista has long traditions in Lean, and is conceived as successful in the area. They were an early adopter of the concept of Lean, and have long traditions within this subject. This makes Alcoa Lista an interesting case of study, to truly understand these subjects.

As will be discussed later in this thesis, the concept of continuous improvement is one, if not, the most important concept within Lean and TPM. Continuous improvement is self-explanatory, a Lean and TPM-organization must improve continuously. This means that the Lean and TPM journey is never-ending. Improvements can always be done. Based on this, Alcoa Lista as an experienced organization within in the subjects, was chosen as the primary case study for the research in this master thesis. By reviewing and trying to decode the practices and culture in a mature Lean and TPM organization as Alcoa Lista, it is possible to get at deeper understanding of the concept and challenges of Lean and TPM.

1.2 Scope

The scope of the research is to review the Cast House at Alcoa Lista in a Lean and TPM perspective. As Alcoa is a worldwide organization, there are many principles that are common for the whole corporation. Therefore, in some cases, the research will include Alcoa as an organization, and Alcoa Lista at a plant level. To review the Cast House in a Lean and TPM perspective it is necessary to have a basis for comparison. For this reason, a case study of Fibo, a company that the latest years has excelled within the subject of Lean, was chosen. Also, a comprehensive literature study will be conducted. A comprehensive literature study is necessary in order to find possible improvements at the Cast House, that has actively worked with Lean and waste reduction for a long time.

A close dialog with both management and employees was continuously maintained during the writing of this thesis. Because of the size (in both area and complexity) of the Alcoa Lista Plant, the Cast House was selected for more hands-on and detailed part of the case study.

1.3 Objective

The objective of this thesis is to review the current Lean and TPM status at the Cast House at Alcoa Lista. By doing so it is possible to identify the degree of leanness at the plant, and further use the concepts of Lean and TPM to highlight possible improvement opportunities. An implementation of the suggested recommendations can be hopefully being used to improve the current situation at the Cast House at Alcoa Lista. the Cast House as part of a competitive market needs to continuously improve themselves. Therefore, the thesis may contribute with ideas and initiatives to their never ending Lean journey.

1.4 Limitations

The thesis is conducted within a limited time. Therefore, implementation of the suggested improvements will not be included in this thesis.

The fact that Alcoa Lista has long traditions within the concepts of Lean, the culture, practices, and methods are embedded into the core of the organization. Because of this it was challenging for an outsider to decode. It is therefore possible that I have overlooked some aspects. The fact that Alcoa Lista is a cornerstone company in the county, and the fact that the author comes from this area, may have an impact on the research. Based on this, sensitive areas as Lean and TPM concepts, that are often perceived as tools in reducing staff size, may affect the result of this thesis. The amount of process-critical information, that could be used in this thesis, was also limited.

1.5 Methodology

The thesis combines several research methods. First a comprehensive literature study is done, where the underlying principles of the concepts of Lean and TPM are discussed and identified. The second method in this thesis, is the use of the case study method. The closeness of to the case(s) aims to produce an in-depth and invaluable understanding, that will hopefully result in new learning about real-world behavior and its meaning(Yin, 2012). The case study method embraces several procedures, and includes the design of a case study, collecting data, analyzing the data, and presenting and reporting the results.

There are four basics types of designs for case studies. That is, (1) *holistic single-case design,* (2) *holistic multiple-case design,* (3) *embedded single-case design,* and (4) *embedded multiple-case design.* This thesis will use the third type of design. The chosen cases are Fibo and the Cast House at Alcoa Lista.

The collection of data in the case study method is not limited to a single source, in fact good case-studies benefit from multiple sources of data (Yin, 2012). Common sources of evidence in doing case studies are:

1. Direct observations

Direct observations are made in a field setting. This is one of the most distinctive features of case studies. Data is collected by using your own five senses and taking field notes. This was the most important data source in the writing of this thesis. Observations was made through "Gemba" walks at the Cast House. To further understand the complexity and culture embedded in the organization, I also followed several shifts on two different processes (Casting and Sawing), observing and talking to the operators and managers.

This was valuable because the operators experience the challenges and the system every day at work. In addition to the observations made on the shop-floor, I was assigned an office in the process department at the Cast House at Alcoa Lista. By being "where it happens" and having an office in the office landscape, it was possible to make observations and experience the culture first hand.

2. Interviews

The interviews in case studies are open-ended, also called "non-structured interview". Many interviews were conducted with relevant managers and operators. This was believed to be the best way of conducting the interviews, since the interview object are more relaxed and it is then easier to extract information from the person.

3. Archival records

Archival records refer to information stored in existing channels (e.g. electronic records). Archival records were used to gather data to the agent based modelling analysis, calculate the Overall Equipment Efficiency, and get a general idea about the production at the Cast House.

In addition to these case study data collection methods, a questionnaire concerning the learning environment on different levels at the Cast House was conducted. This was, together with the case study method, used to assess the current environment and identify possible future improvements. The data collection methods are depicted in Figure 1.

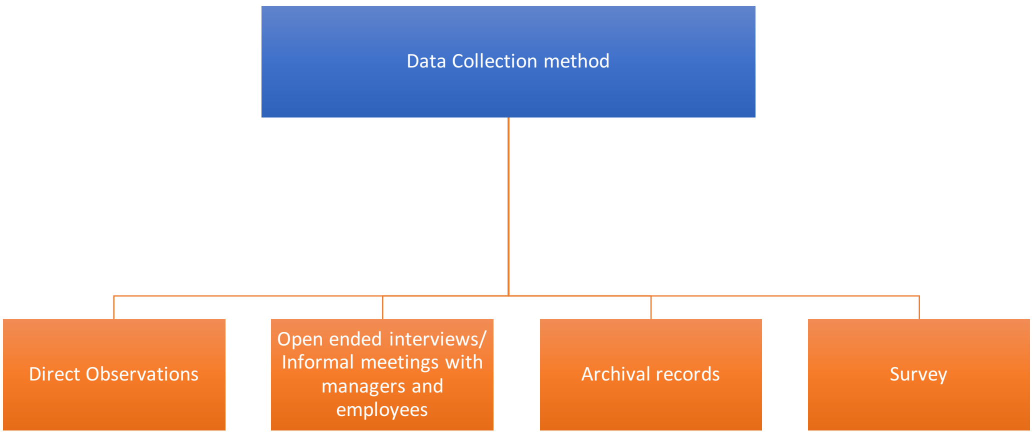


Figure 1 Data collection methods

1.6 Structure of the thesis

The thesis will follow the structure presented in Figure 2. That is, first the introduction about the thesis will be given. Then a literature study about the concepts of Lean and TPM will be conducted. For reviewing the current Lean and TPM situation at the Cast House at Alcoa Lista, some tools are needed. These tools are presented in “Basis for analytical framework”. In this chapter a combination of the losses and wastes from Lean and TPM are constructed. This chapter will also include the development of a questionnaire, presentation of a leanness rating tool, and an analytical simulation software. Then a brief introduction to Alcoa Lista and their business system will be presented.

In the next section, a Case study of Fibo will be presented. Then the analysis of the current Lean and TPM status at the Cast House will be conducted. The analysis is split up into the following subchapters: *Projects, Lean tools, Eight Pillars, The Learning Environment, The production processes at the Cast House, Rules in use,* and *Rapid Plant Assessment.* These chapters are based on identifications from the literature study, and the basis that was presented in “Basis for analytical framework”. Based on this analysis possible improvement suggestions for the Cast House will be presented. Finally, a discussion and conclusion of the thesis will be given.

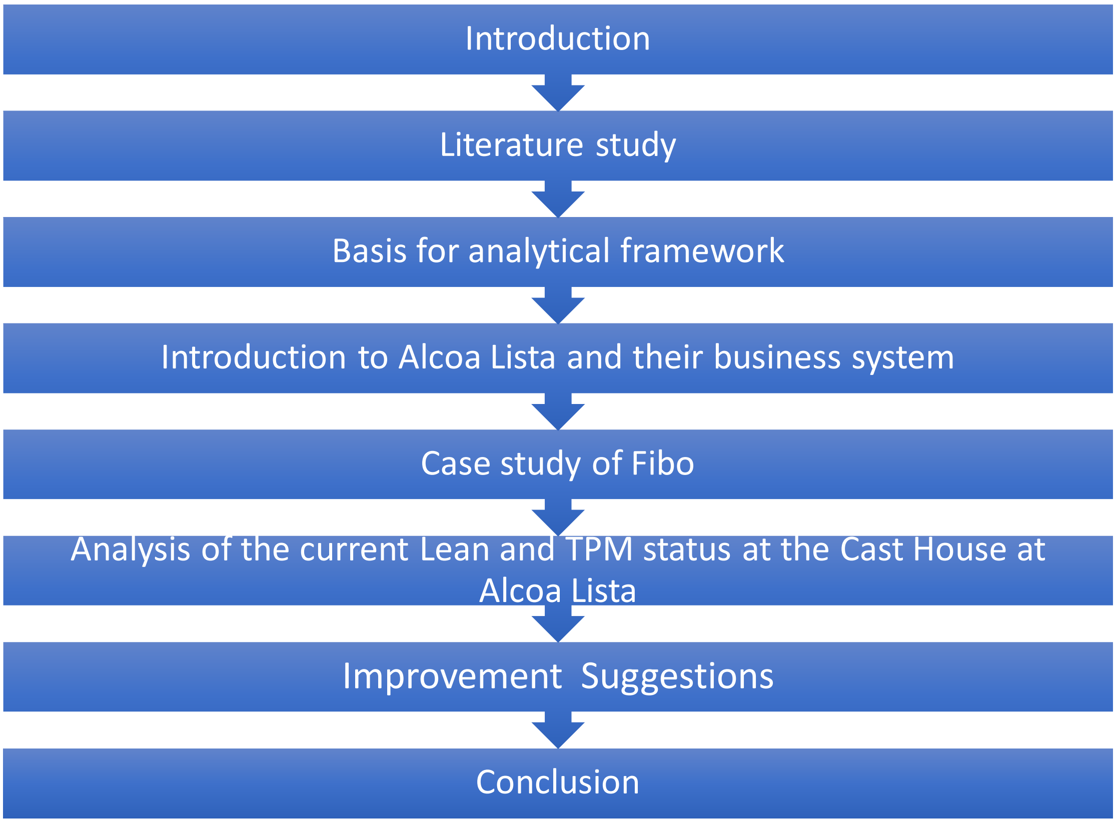


Figure 2 The structure of the thesis

2. LITERATURE STUDY

2.1 Introduction

Lean and TPM are two closely linked terms, content and definition often overlap. Which words that the acronym TPM represent varies, however the most common are: *Total Productive Maintenance, Total Productive Management,* and *Total Productive Manufacturing.* The planned approach to maintenance was first introduced to Japan by Seiichi Nakajima, referred to as the "father of TPM", in 1951. As a part of the rebuilding of Japan after World War 2 Nakajima studied the American preventive maintenance. Based on this research, he introduced Productive Maintenance (the predecessor to TPM). TPM was later (1969) developed at Nippon Denso Co., a part of Toyota Motors, under the leadership of Nakajima. Nippon Denso Co. became the first company to win the recognized TPM-award, that was awarded to them by the JIPM (then Japan Institute of Plan Engineers) (Williamson, 2015)

Taiichi Ohno and Shigeo Shingo, both key persons in the development of the Toyota Production System (TPS), have cited Nakajima on his foundational work in the areas of eliminating equipment breakdowns. TPM can, according to Williamson (2015), be referred to as the equipment side of TPS.

The term Lean was coined by John Krafcik in 1988 in his master´s thesis at MIT Sloan School of Management. It was first presented to the broad audience by James Womack, Daniel Jones, and Daniel Roos in the book *The Machine that changed the World (1990),* and further popularized by Womack and Jones (2003) in their book *Lean thinking* . The Machine that changed the World is in literature often referred to as the "first book" to reveal Toyota Motor company's superb lean productions system, TPS. The production system was spearheaded by the *Taiichi Ohno,* codified by Shigeo Shingo, and strongly influenced by the work of W. Edwards Demming (PDSA-cycle) and Joseph Juran (TQM), Henry Ford, and Nakajima (Martin and Osterling, 2014).

Womack, Jones, and Riggs based their research on TPS, therefore TPS is often translated to Lean, and vice versa. However, if one ask professionals what Lean means to them, one would get a variety of answers. One might argue that this ambiguity is the reason that organizations experience such a varying benefit from their work with Lean.

Lean is based on the principles from *continuous improvement*, which also is reflected in the concept itself. However, as time has passed, Lean has evolved. Current important topics in Lean work today, as leadership practices and culture, was not addressed in the early Lean literature. As more and more organizations and people adopt and studies Toyotas methods, new discoveries continuously improve the knowledge and performance of Lean. It is no doubt a dynamic and complex subject.

Another millstone in Lean history was when Jeffrey Liker (2004) published *The Toyota Way*. This was the first book that researched how Toyota operates in terms of philosophy, culture, processes, and problem solving.

2.2 LEAN

2.2.1 Introduction

The concept of Lean has undergone a significant evolution and expansion since it originated from the auto-industry (Hines et al., 2004). The dynamic nature of Lean makes it difficult to agree upon a definition. Pettersen (2009) argues that a definition of Lean will only be a “still image” of a moving target, and will thereby only be valid in a limited period. This rather extreme statement might be true, however, in describing a concept definitions are useful. A good and simple definition is: “Lean is the permanent struggle to flow value to one customer”(Rother and Liker, 2014, p.6). This is described as a “First Definition”, which is a definition that describes what “we are trying to do”, rather than how to approach it. The use of definitiobs that is based on the approaches in Lean, like “*developing people”, “continuously improving”, “problem solving, “efficiency”,* often leads to uninspiring add-on programs (Rother and Liker, 2014).

According to Womack and Jones (2003, p.15), Lean provides “.. a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone request them, and perform them more and more effectively”. They also state that Lean facilitates a way to accomplish more with less, that is, less human effort, less equipment, less time, and less space. By becoming leaner, an organization will come closer and closer to provide the customer with exactly what they want.

2.2.2 Lean literature

There are a variety of principles that are necessary to understand, if one truly want to grasp the idea behind Lean. In this section, four different interpretation of Lean are presented, and discussed. The publications that will be presented are the following: *Lean Thinking* by Womack and Jones (2003), *The Toyota way* by Liker (2004), *Toyota Kata* by Rother (2010), and *Decoding the DNA of the Toyota Production System* by Spear and Bowen (1999).

Publication number 1: Principles of Lean Thinking by Womack and Jones:

The first publication that will be presented, is Womack and Jones´s (2003) *Lean Thinking*. They divide Lean into five principles: *Value, The Value Stream, Flow, Pull,* and *Perfection.* The meaning of these five principles will now follow.

Value: According to Womack and Jones (2003), Value is the starting point of Lean. They define *Value* as “A capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer” (Womack and Jones, 2003, p.353). Value is what the customer wants, and only that. All activities that do not add value for the customer, are considered a waste of resources.

The Value Stream: The second principle, *The Value Stream,* are the activities that are needed to design, order and provide a specific product from concept to launch, order to delivery, and raw material to when the customer have the product (Womack and Jones, 2003). All activities in *The Value Stream* that do not add *Value,* should be eliminated or reduced to a minimum.

Flow: The *Flow* along the Value Stream should be continuous, and not batched. That is, the Value-creating steps occur in a tight sequence, so the product will flow smoothly to the customer. Waste like waiting time can be eliminated, and problem will be exposed. A common way of illustrating this concept are through the following analogy: A boat moves down a river where the water levels are high, making rocks and obstacles are hidden by the water and are therefore not discovered. The obstacles at the bottom are problems in the production line, and the water is the inventory in-between the adjoining processes. Inventory causes the problems in the production line to be hidden, due to the flexibility it facilitates. However, if the inventory is removed (the water level is lowered), the problems surfaces and problems are solved permanently. (Womack and Jones, 2003)

Pull: A *pull-system* is according to Womack and Jones (2003) a system where nothing is produced by the upstream activity (the supplier) before the downstream activity (the customer) signals a need. The product will in this way be pulled through the value stream, rather than pushed.

Perfection: The fifth and last principle is *perfection*, which means that an organization always should work and improve towards perfection. If one look at these five principles as steps in a Lean process, the step after perfection will be to start with defining the *customer value.* This improvement process is depicted in Figure 3.

Figure 3 Seeking perfection (Lean Enterprise Institute, 2016)

Publication number 2: The Toyota Way – 14 management principles

In the book "The Toyota Way", Jeffery K. Liker presented his findings from his research of the Toyota Production System (TPS), based on his 20 years of observations and research of Toyota and companies learning from Toyota. Liker (2004) identified an approach to Lean that consists of 14 management principles. These management principles are divided into four categories.

The first category is *Philosophy.* By having a long-term philosophy, Toyota can build a learning organization that can adopt to the changes in their environment and survive as a productive organization. According to Liker (2004), Toyota´s investments in continuous improvement and learning would not gain benefits without this long-term foundation.

The second category is process-centered. That is, the right *process* will produce the right results. Toyota has learned that the ideal process begins with one-piece flow. One piece flow is when one piece is moved at a time between the operations in a work cell. According to Liker (2004), flow is the key to achieving best quality at the lowest cost with high safety and morale.

The third category is concerned with the development of the organization´s *People and Partners.* By developing the organization´s people and partners, value will be added to the organization.

The last category is based on Toyota´s *problem-solving.* That is, continuously solving problems leads organizational learning. This is according to Liker (2004), the highest and most important level of TPS. Through continuous problem solving, problems can be identified and be removed permanently. Also, the problem-solving process itself is also important. The analysis and communication of lessons learned are important for improvement.

Together problem solving, people and partners, process, and philosophy are referred to as the "4P" model. According to Liker (2004), most organizations today are in the "process" part of the pyramid in Figure 4. They also state that if businesses do not adopt the other 3Ps, the work they do in the process level will lead to nothing more than dabble. Since the improvements that are made do not have the commitment and intelligence behind them to make them sustainable.

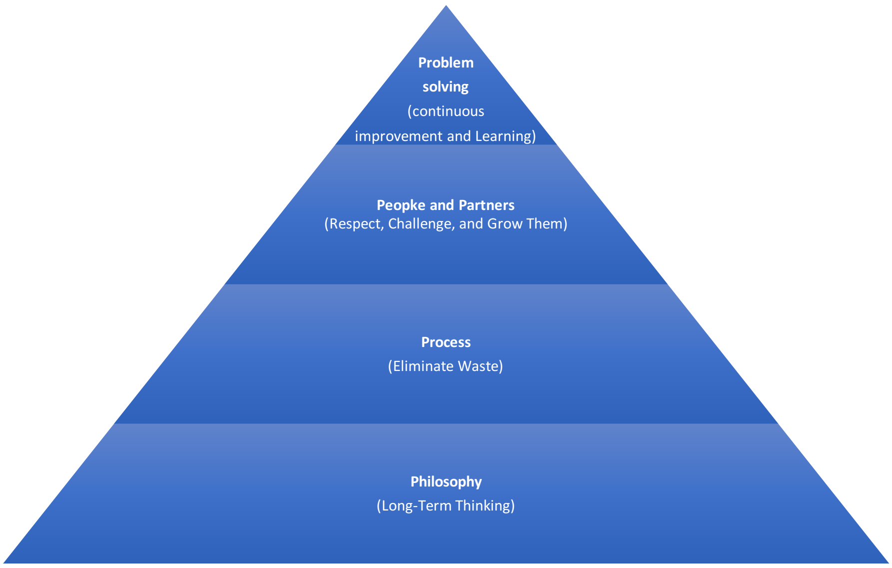


Figure 4 4-P model (Liker, 2004)

Publication number 3: Toyota Kata

Articles about TPS started to appear in the mid 1980s, and by copying Toyota many companies have improved significantly. However, Rother (2010) argues that no other company has manage to adapt and improve its quality and competitiveness as systematically and effectively as Toyota. The reason that companies have failed to do so, is how they learn from Toyota. What companies are doing is observing the current visible practices, elements, and techniques at Toyota, then classifying them into principles. Then they are try to adopt these principles. In other words, companies are trying to *reverse engineer* TPS. This is according to Rother (2010) the wrong approach, since critical aspects of Toyota are not visible. Instead of focusing on the solutions that Toyota has developed, companies should investigate how Toyota develop their solutions. By doing so, the company can be adaptive and continuously improve, by understanding the conditions and create their own smart solutions.

In Toyota Kata, Rother (2010) focuses on the scientific problem solving nature of TPS. Kata is split into two linked behaviors: *improvement kata* and *coaching kata*. The concept of kata builds on the principle of continuous improvement and scientific problem solving through repeating the PDSA-cycle. The Japanese word, kata, itself can according to Mike Rother be defined and translated as “A way of doing something; a method or routine” (Rother, 2010, p.15). A more specific and deeper definition of Kata is “A way of keeping two things in alignment or synchronization with one another” (Rother, 2010, p.16). The link between coaching kata and improvement kata is presented in Figure 5.

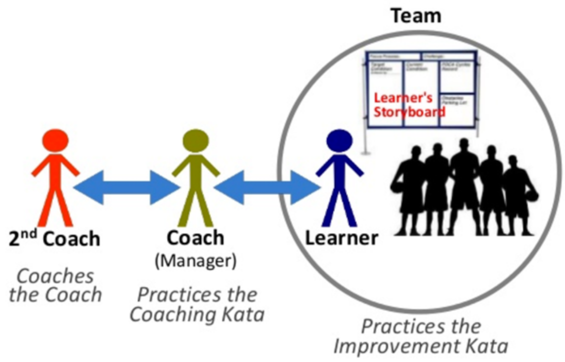


Figure 5 Improvement and Coaching Kata (Rother, 2014b)

The coaching kata is according to Rother (2014b) a pattern for teaching the *improvement kata* pattern. Whereas the improvement kata is “a practical four-step model of scientific thinking and acting, for achieving challenging goals” (Rother, 2014b, p. 30). This four-step model is depicted in Figure 6, this shows how a challenge is identified (1), then then current situation is understood (2), for example by mapping the values stream. Then the next target condition (3) is identified, for example by mapping the desired future state of the value stream. This target condition is then tried to be reached, through doing scientific problem solving, by removing the obstacles (4). (Rother, 2014b)

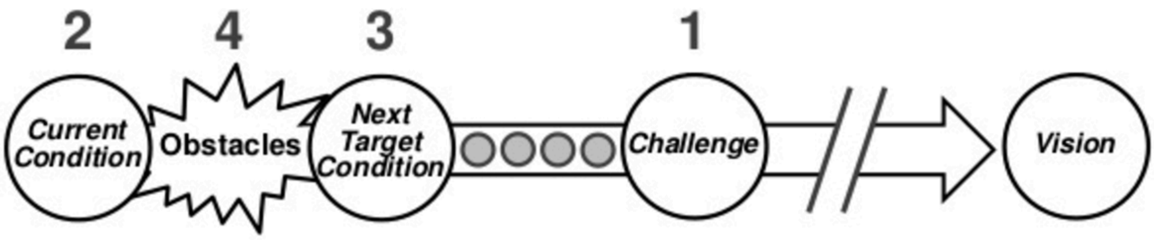


Figure 6 The Four-step Model (Rother, 2014b)

Publication number 4: Steven Spear and Bowen´s- Decoding the DNA of the Toyota Production system.

In the article “Decoding the DNA of The Toyota Production System”, Steven Spear and H. Kent Bowen present their interpretation and idea of TPS. Spear and Bowen (1999) question how businesses decode TPS, and argue that a common misconception is that TPS is a set of tools and practices, instead of a complete business system and philosophy

According to Spear and Bowen (1999), the key for understanding TPS for outsiders is that they need to understand that TPS creates a community of scientists. That is, Toyota utilize the scientific method in their daily work. So, when Toyota identifies a problem that needs to be solved, sets of hypotheses are established and then tested. By doing so, Toyota can do systematic problem solving, instead of random trial and error, which Spear and Bowen (1999) describes as “a blindfolded walk through life” (Spear and Bowen, 1999, p.98)

Spear and Bowen (1999) describes TPS through four principles, that they refer to as the “Rules in use”. These rules consist of three *rules of design,* which show how Toyota set up all their operations as experiments, and one *rule of improvement,* which describes how the scientific method is used by workers at every level of the organizations. The rules are:

- *Rule 1. How People Work: Activity*

All work should be highly specified according to content, sequence, timing, location, and outcome.

- *Rule 2. How People Connect. Connections*

Every customer/supplier connection must be direct. This connection can be between humans, or the machine that supplies a good, service or information.

- *Rule 3. How the Production Line is Constructed. Pathways*

Every pathway of products and services must be specified direct and simple.

- *Rule 4. How to Improve: Improvements*

All improvements have to be done in accordance with the scientific method, under the guidance of a teacher at the lowest possible level of the organization. Spear and Bowen (1999) describe how employees at Toyota are assigned a leader that are responsible to coach them in problem solving. This is what Rother (2010) described as *Coaching Kata.* The workers are thought to formulate and test hypothesis, in other words, they are trained in the scientific method.

These *rules in use* should be managed by *built in tests*, these tests should relate to the hypotheses presented in Figure 7. In Figure 7, the signs of the specific hypotheses and corresponding responses are presented. When there is a sign of a problem this problem should be solved at the lowest possible level, using the scientific method.

Rule	Hypotheses	Signs of a problem	Responses
1	The person or machine can do the activity as specified. If the activity is done as specified, the good or service will be defect free.	The activity is not done as specified. The outcome is defective.	Determine the true skill level of the person or the true capability of the machine and train or modify as appropriate. Modify the design activity.
2	Customers' requests will be for goods and services in a specific mix and volume. The supplier can respond to customers' requests.	Responses don't keep pace with requests. The supplier is idle, waiting for requests.	Determine the true mix and volume of demand and the true capability of the supplier; retrain, modify activities, or reassign customer-supplier pairs as appropriate.
3	Every supplier that is connected to the flow path is required. Any supplier not connected to the flow path is not needed.	A person or machine is not actually needed. A nonspecified supplier provides an intermediate good or service.	Determine why the supplier was unnecessary, and redesign the flow path. Learn why the nonspecified supplier was actually required, and redesign the flow path.
4	A specific change in an activity, connection, or flow path will improve cost, quality, lead time, batch size, or safety by a specific amount.	The actual result is different from the expected result.	Learn how the activity was actually performed or the connection or flow path was actually operated. Determine the true effects of the change. Redesign the change.

Figure 7 The Hypotheses of the Rules-in-use (Spear and Bowen, 1999)

Comparison of the different publication

The publications that was presented, all describe Lean somewhat different, however the essence of them are for the most the same. The authors of the publications emphasize that the essence of TPS is the learning aspect and the continuous strive against a desired future state. This happens through scientific problem solving. The problem solving should happen at the lowest possible level. A misconception, described by both Spear and Bowen (1999) and Rother (2010), is that Lean (TPS) is a set of tools and practices instead of a complete business system. By following this type of mindset, many organizations start their journey by copying the tools and practices from Lean. Whereas they rather should focus their energy on creating an organization of scientist, that solve their problems according to the scientific method.

The way the different authors has described what goes beyond the concept of learning/scientific problem solving, varies to some degree. The essence of the four interpretation's is presented in Table 2. Most of these principles can be attributed to at least one of the other interpretations. The table also shows how the different authors highlight different aspects of TPS. For example, Womack and Jones (2003) highlights the importance of the never ending continuous improvement process, through *seeking perfection.*

Table 2 Main ideas of the different publications

Lean Thinking	The Toyota Way	Toyota Kata	Decoding the DNA of The Toyota Production System
Perfection; Value: The Value Stream; Pull; Flow;	Philosophy; Process; People and Partners; Problem-solving.	Daily Kata; Maintenance Kata	Improvements; Pathways; Connections; Activity;

2.2.3 Important Concepts in Lean

In this section, important concepts in Lean will be presented.

Continuous Improvement/ Kaizen

As discussed, the most important part of Lean is scientific problem solving/learning. The idea behind these concepts are that organizations and individuals can through scientific problem solving and learning continuously improve themselves, and therefore ensure development. In Japanese, *continuous improvement,* is translated to *kaizen.* Kaizen is also recognized as an English word, and is according to Oxford Learner´s Dictonaries (2016) "the practice of continuously improving the way in which a company operates". Opposite to the traditional western way of managing, which worships major changes, improvements under kaizen are small and incremental. These will over time result in dramatic results. The concept of kaizen also differs from traditional western management practices in the way that kaizen is process- and human-oriented, rather than result driven (Imai, 1997). The idea of continuous improvement is that it is easier to make many small improvements, than few large.

It is possible to separate between two types of kaizen, *maintenance* and *improvement kaizen*. Maintenance kaizen refers to the daily work of reacting to an unpredictable world in order to meet the standard (e.g. in terms of productivity, quality, safety) that is expected (Liker and Convis, 2012). The other type of kaizen, *improvement kaizen*, is most often only referred to as *kaizen* since this is the real goal. This is the work of continuously raising the bar.

According Liker and Convis (2012), who both has researched Toyota extensively, a common misconception about Toyota is that they have perfect processes. This contradicts the whole idea of kaizen, which states that all processes can be improved.

PDSA-cycle

The PDSA-cycle (Plan-Do-Study-Act), popularized by W. Edwards Deming, is a systematic series of steps for gaining learning and knowledge for continual improvement (The W. Edwards Deming Institute, 2017). This is a proven scientific method for problem-solving. In the first step, an opportunity for improvement is recognized, and a *plan* for change is made. In the second step, *do*, the plan is executed. The next step is *study*, where the outcome of the plan is monitored and analyzed, and the learnings from the previous step are identified. This is based on what have been learned in the *study* and *act* steps. If the change did not work, start the cycle again with a new plan. If the plan were successful, use what is learned and improve the current plan and start the cycle again. The process of the PDSA cycle is presented in Figure 8.

Figure 8 The PDSA-cycle

Learning organization

As identified, the fundamental process underlying the concept of Lean is *learning*. Learning is in a Lean perspective organizational learning. In fact, the last of Liker´s (2004) 14 management principle is to become a learning organization. According to Hess (2014), what is needed for building a successful learning organizations, what he calls a "High Performance Learning Organization (HPLO)", is the *right people*, in the *right learning environment*, that use the *right learning processes*. A high-performance learning organization must employee people that have the right learning mindset. Successful learning organizations hire and develop people who like and wishes to learn. They also hire leaders that are not only good learners, but also good teachers and role models.

These people need to be in an environment that promotes learning. According to Hess (2014), a good learning environment is one that fosters intrinsic motivation and give the students some control over their learning. The learning environment needs good role models (teachers). He also states that the learning processes in good educational environments, resembles a journey of discovery, and in this journey the learner play the main character. Having the right learning processes include having learning conversations and using critical thinking processes. In a Lean perspective, examples of such thinking processes is Rother´s (2010) *Kata* and the *PDSA-cycle*. In Kata, the coach plays a passive role, and the learner actively solves the problem.

Hess (2014) makes the connection between the learning environment of an HPLO with the questions that is used in the highly regarded and research based "Gallup Q12" survey, which measures employee engagement. The test consists of 12 questions and out of these 12, 10 of them can be matched with the learning environment of a HPLO. These are as follow:
"

1. *I have the opportunity to do what I do best*
2. *In the last seven days I received recognition or praise for doing good work*
3. *My supervisor, or someone at work, cares about me as a person*
4. *Someone at work encourages my development*
5. *At work my opinions seem to count*
6. *The mission/purpose of my company makes me feel like my work is important*
7. *My associates are committed to doing quality work*
8. *I have a best friend at work*
9. *In the last six months, someone gave me feedback*
10. *In the last year, I have had opportunities to grow and develop*

" (Hess, 2014, p.49)

From what Hess (2014) has described, it is clear that a learning organization needs to engage its employees. Creating an organization that engages all employees, and that participates in the problem solving, is as earlier identified as the essence of Lean.

Muda (waste)

Cutting waste is maybe the most "famous" Lean concept, because this adds Value for the customer. The Japanese word for waste is *Muda*. However, *Muda* have a deeper meaning than only translating the English word "waste". That is, work is a series of processes that starts with various inputs and raw material and ends with a final product. The resources (labor , machines, material) either adds or do not add value. In this sense, *Muda* refers to all non-value adding activities in the work that is done. According to Imai (1997), the first person to recognize the enormous amounts of waste that existed at the shop floor was the Toyota executive Taiichi Ohno. He classified Muda in the following seven categories:

1. *Muda* of overproduction
2. *Muda* of inventory
3. *Muda* of defects
4. *Muda* of motion
5. *Muda* of processing
6. *Muda* of waiting
7. *Muda* of transport

Just-in-time

Toyota (2017) defines *Just-in-time* (JIT) as making only what is needed, when it is needed, and the amount that is needed by the customer. JIT is a system that are designed to achieve the best possible quality, cost, and delivery of products and services by eliminating wastes in a company´s processes. This way the company can deliver the product just in time to meet the customers ‘requirements. Original the concept was developed by the Toyota Motor Company. (Imai, 1997)

Jidoka

Jidoka highlights problems by stopping work immediately when a problem first occur. This leads to improvements that builds quality into the system, by eliminating the root causes of the problems. Jidoka is also referred to as autonomation, this is automation with human intelligence. This means that if a defect or another problem is discovered, the affected machine shuts down, and humans solves the problem.

Pull system (Kanban system)

The traditional approach for regulating production is to schedule each process in the value stream, this is what is called a “push system”. The schedules are based on predictions of what the downstream processes will need in the future. In this way, each process will produce what is believed to be the need of the next process. By doing so, the material will be pushed on the next process, whether it is needed or not.

The alternative approach is the *pull system,* or “kanban”. *Kanban* is in Japanese a signal of some kind. In a pull system the production is regulated by the customer process´s withdrawal from the supplying process´s store, rather than schedule (Rother, 2010). Illustrated in Figure 9 (Toyota, 2017), a customer gets a production instruction and needs to use material. A Kanban card is then used to withdraw material from the supplying process´s store. The supplying process then produces to replenish the withdrawn item, just as a supermarket would have ordered a new product if a place was empty. In this way overproduction can be eliminated.

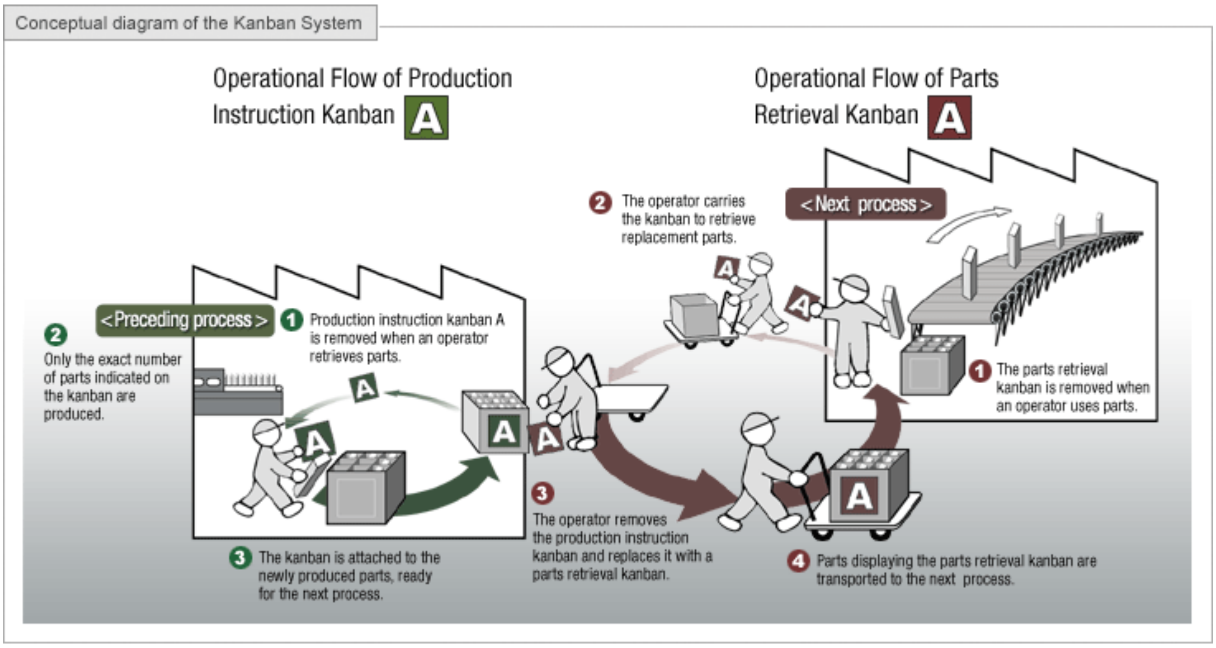


Figure 9 Pull system (Toyota, 2017)

2.2.4 Lean tools

As presented earlier, the lean tools are the visual part of Lean. These should not be mistaken to be the essence of Lean, however, they are helpful tools achieving leanness. In this section a selection of Lean tools will be presented.

Kata- the four-step model

Rother has developed some tools that can be used for executing Toyota Kata in practice. These tools are primarily a storyboard and a set of five standardized questions. The coach asks the learner the five standardized questions, and he/she has a passive role in the Kata process. Meaning, it is important that the coach do not help answering the questions. The results of the five standardized questions are recorded on something called the learners story board. This storyboard is also standardized. Both the tools include all the four steps of the Toyota Kata model: Challenge, Current Condition, Next Target condition, and solving Obstacles. By using this technique, scientific problem solving can be executed on all levels of the organization. The Learner´s Storyboard and the questions that are to be asked by the coach, are depicted in Figure 10 and Figure 11. (Rother, 2014b)

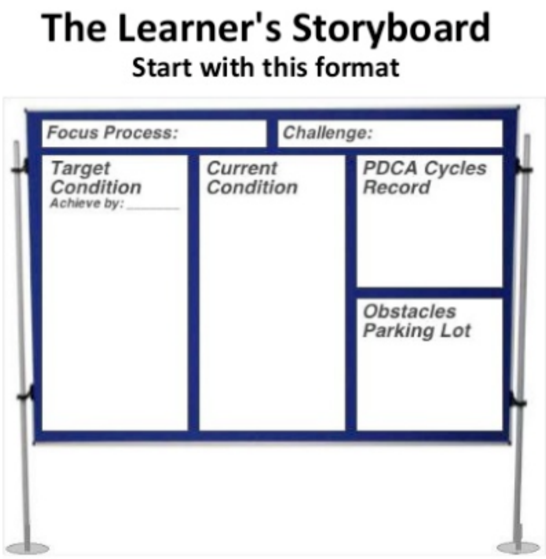


Figure 10 The Learners Storyboard(Rother, 2014b)

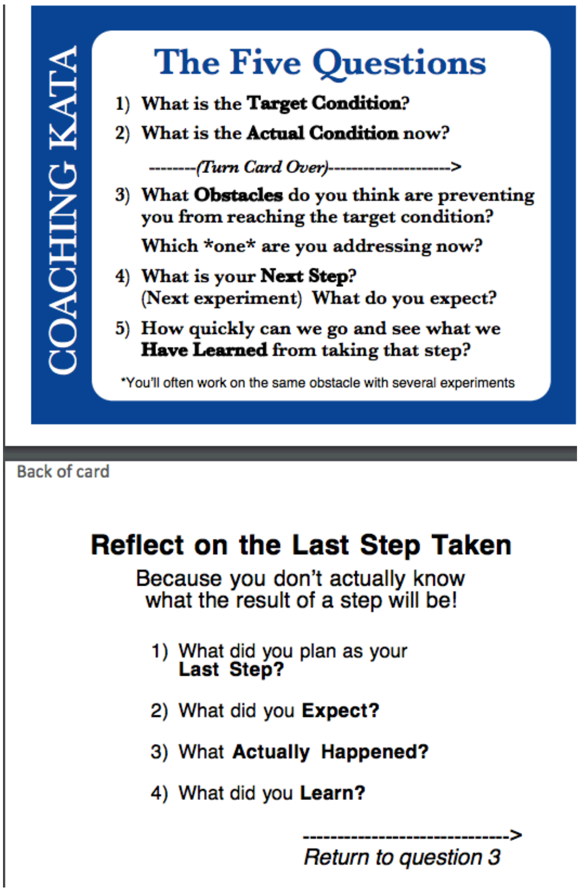


Figure 11 Five Coaching Kata Questions (Rother, ND)

Visual control

According to Liker (2004), *visual control* is any type of visual communication screens that are used to tell workers at a glance how work should be done and whether it is deviating from the standard. By using simple visual indicators, (e.g. traffic lights) organizations can assure that no problems are hidden. Examples of visual control is showing where something belong

(5s), what the standard procedure is for doing something, the status of the work in process, and other important indicators of performance.

5S

5s is one of the most widespread visual control tools. This contains five steps that all begins with a S, that describes a work practice that leads visual control. In mass-production where the five S´s are not used, wastes pile up and become an accepted dysfunctional way of doing business.

The five steps are the following:

1. *Sort*: sort out what is necessary, and what is not. Throw what is not needed away.
2. *Straighten*: arrange the items that are left systematically. Everything should have its own place.
3. *Shine*: clean and maintain the equipment and workplace on a regular basis.
4. *Standardize*: regular revisit the first three steps, and confirm the condition through standards and identify defects.
5. *Sustain*: This is a continuous process. The standards must be maintained and improvements must be made every day. This is done by using regular management audits to stay disciplined.

(Liker, 2004)

A3

A3 is a method for communicating, learning, and sharing of information. The name is based on the paper size that is used. The purpose of the report is to produce a "problem-solving story", that includes the problem, its root cause, and the countermeasure taken to solve the problem (Liker and Convis, 2012). The last part of the A3 report follows the principle of PDSA-cycle. The countermeasures are identified (plan), tried(do), and monitor(study), until after further adjustments (act).

According to Wig (2014), the A3 can be used to close the gap between the strategical (hoshin), and the operational part (kanri). On the macro-level, hoshin-kanri adapts organizational goals to the practical execution. On the micro-level the structured problem solving increases the ability to learn and develop people and knowledge.

Value stream mapping

Value stream mapping is tool to learn to see and solve disconnects, redundancies and gaps in how work is done (Martin and Osterling, 2014). This is done by mapping the flow of the processes, and identifying the activities that exist along the value stream. Value stream mapping is also used to map the desired future state of the value stream.

This offers a holistic view over the work flow through entire systems, and is therefore an effective tool to identify possible improvements in systems. One of the key contributors to sub-optimization (neglecting to take the effects of the improvements of other parts of the system in to consideration, and thereby get a lower performance level) is to start making micro-level improvements. The macro-perspective defines the strategic direction ("what") through *value stream mapping* and the micro-perspective identifies the tactical "how" through process-maps. It is therefore important to use value stream mapping first to identify the most important improvements. In Figure 12 you can see how the value stream are built up of processes that consist of several steps.

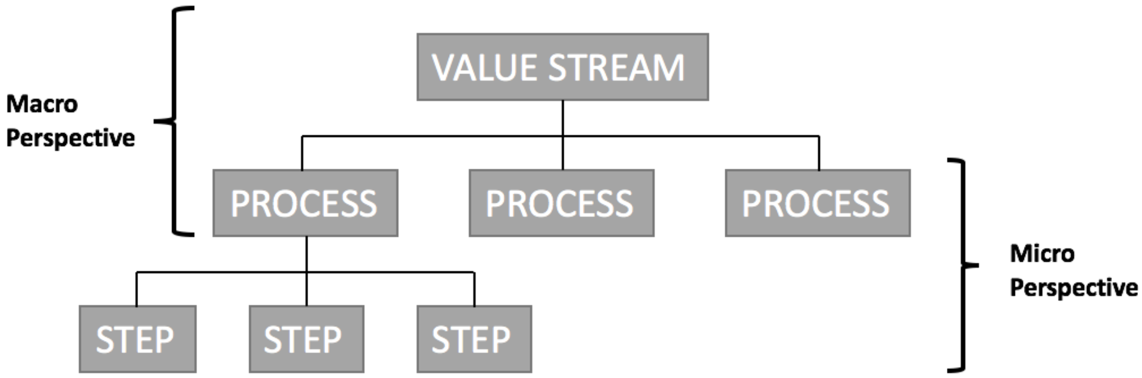


Figure 12 The Value Stream (Martin and Osterling, 2014)

Gemba walk

Gemba is a Japanese word for the "real place", and is used to describe where the action occurs. It is at the Gemba that the *value* is added to the product or service, that makes it possible for the organization to survive and exceed. It is therefore important that managers go to the value creating place to identify possible improvements.

SMED

Single-minute-exchange-of-die is a system for reducing the time it takes for changing the equipment for producing a product. The name represents the goal of reducing the change over time to single digits (10 minutes). The tool´s target is to make as many of the steps that are needed in the changeover external (executed while production is running), and streamlining the remaining steps. (Vorne, 2017b)

2.3 TPM

2.3.1 Definition and losses

According to Venkatesh (2015), *Total Productive Maintenance (TPM*) can be considered as the medical science of machines. TPM brings maintenance into focus, instead of considering it a non-profit activity it is considered a value adding activity. TPM brings down unscheduled maintenance (breakdown maintenance) to a minimum, the type of maintenance that is considered the most expensive. The goal of TPM is, according to Venkatesh (2015), to increase production while at the same time increasing morale and job satisfaction.

As mentioned in the introduction to this chapter, TPM originally started as a preventive maintenance program in Nippon Denso Co. (a Toyota company) in 1951, and over the years it developed into productive maintenance, and ultimately Total Productive Maintenance. TPM can be considered as a combination of the following concepts: *Preventive Maintenance*, *Total Quality Control* and *Total Employee Involvement*. Total Quality Control and Total Employee

Involvement are Japanese concepts. Preventive Maintenance was a practice that originated in the US, and is a strategy that results in optimized equipment effectiveness, and fewer breakdowns. According to McCarthy and Rich (2004), if equipment fails to deliver on its 100 percent potential, it is due to some physical phenomena that can be identified, brought under control, reduced and even be eliminated. This is what is referred to as the losses of TPM.

Nakajima (1988), that is considered as the father of TPM, state that a simple definition of TPM is that it is productive maintenance that involve total participation. A more comprehensive definition that Nakajima (1988) present in his book, was defined through the following five principles:

1. Maximize the overall equipment effectiveness (OEE).
2. Establish a comprehensive Productive Maintenance (PM) system for the life of the equipment.
3. Involve that plan, use and maintain equipment.
4. Involve all employees from top management to shop floor works.
5. Promote PM through motivation management, for example through autonomous small-group activities.

Based on the former definition, Nakajima (1988) identified the following *six categories of equipment losses:*

1. Break downs due to equipment failures.
2. Set up and unnecessary adjustments.
3. Idling and minor stops.
4. Running at reduced speed.
5. Start-up losses.
6. Rework and scrap.

The concept of TPM has evolved from the former definition into a companywide concept. Therefore, the definition was redefined by JIPM in 1989. The new definition involves all departments from top to bottom. It also contains the bold goal of *zero accidents, zero defects,* and *zero failures.* This definition of TPM is based on the following strategic principles:
"

1. Build a corporate constitution that will maximize the effectiveness of production systems.
2. By using a shop-floor approach the organization should be built in a way that prevents every type of loss (by ensuring zero accidents, zero defects, and zero failures) for the life of the production system
3. Involve all departments in implementing TPM, including development, sales, and administration.
4. Involve everyone- from top management to shop floor workers
5. Conduct zero loss activity through overlapping small-group activities

"
(Suzuki, 1994, p.6-7)

The overall object of TPM is to maximize productivity. Nakajima (1988) defines productivity as output/input. This means that the goal of TPM is to achieve the highest possible production output, by using as little inputs as possible. The inputs in production consists of *labor, machine* and *materials,* and the output comprises of *Production (P), Quality (Q), Cost (C), Delivery (D), Safety (S),* and *Morale (M)* (Nakajima, 1988). As more and more processes are automated, the machine part of the production plays an increasingly important role in today's production environment.

The number of losses has continued to evolve, and in Table 3 you can see the 16 major losses identified by Venkatesh (2015), which TPM aims to eliminate. These losses are split into three categories, losses that involve equipment efficiency, losses effecting human work efficiency, and effective use of production resources. By utilizing a more specific set of losses, it makes it easier and possible to identify losses at the shop-floor with a higher accuracy.

Table 3 16 losses of TPM (Venkatesh, 2015)

Loss	**Category**
1. Breakdown loss 2. Setup and adjustment loss 3. Cutting blade loss 4. Start-up loss 5. Minor stoppage/ Idling loss 6. Speed loss 7. Defect/ rework loss 8. Scheduled downtime loss	Losses that impede equipment efficiency
9. Management loss 10. Operating loss 11. Line organization loss 12. Logistic loss 13. Measurement and adjustment loss	Human work efficiency
14. Energy loss 15. Die, jig and tool breakage loss 16. Yield loss	Effective use of production resources

2.3.2 The Eight Pillars of TPM

What areas that companies choose to focus on in the execution of their TPM efforts, may vary slightly, however, the most common areas are identified and referred to as the *Eight Pillars of TPM.* The pillars are the following: *Focused Improvement, Quality Integration, Planned Maintenance, Autonomous Maintenance, Early Equipment Management, Training and Education, Safety, Health, and Environment,* and *TPM in administration*. These "pillars" need to be built on a foundation, this foundation is 5s. Therefore, before any of the eight pillars can be successful, 5s needs to be present. These eight pillars have proven to produce World Class Results and ultimately reach zero accidents, zero defects, and zero failures. The house of TPM is illustrated in Figure 13.

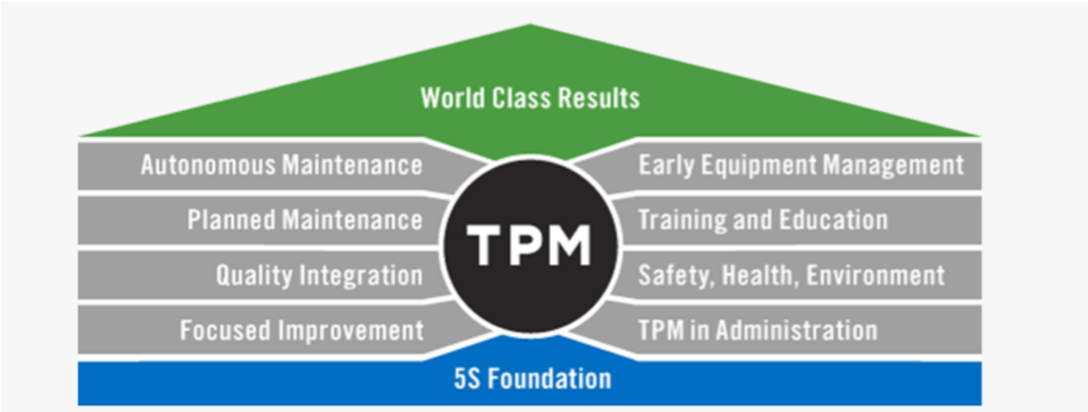


Figure 13 The House of TPM (Vorne, 2017c)

Pillar 1: Focused improvement

Focused improvement is activities that maximize the Overall Equipment Effectiveness (OEE) of processes and plants through the elimination of losses(Nakazato, 1994b). The difference between *continuous improvement* and *focused improvement* is that focused improvement is a method to achieve continuous improvement in environments where people complain that they are too busy, improvements are too difficult to make, or there is not enough money. These factors make the most challenging problems remain unresolved, and causes loss and waste to continue to build up, and making the possible improvements to seem even more unachievable. (Nakazato, 1994b)

According to Nakazato (1994b), focused improvements are implemented systematically and is characterized by project teams that include engineering, maintenance, production, and other specialized staff, and use a carefully planned and monitored approach. Nakazato (1994b) state that the following procedure is extremely effective for breaking out of the vicious cycle, that prevents improvements and locking them firmly into place:

1. Select a topic
2. Form a project team
3. Register the topic
4. Implement the improvement
5. Evaluate the results

Assessing the result of focused improvement should be done by evaluating the results through the Six Major Results (PQCDSM): Production, Cost, Safety, Quality, Delivery, and Morale (Nakazato, 1994b).

Pillar 2: Autonomous maintenance

Autonomous maintenance is maintenance performed by the production department. Autonomous maintenance make operators responsible for preventing that their equipment deteriorate, through correct operation and daily checks. The key idea of autonomous maintenance is, that the production department has to abandon the "I make-you fix" mindset, and assume ownership of its equipment, and take responsibility for preventing detereation.(Nakazato, 1994a)

Pillar 3: Planned maintenance

Planned maintenance aims to produce defect free products with trouble free equipment, to increase the customer satisfaction. By using a planned maintenance approach, rather than a breakdown approach, companies move from having a reactive approach to a proactive approach to maintenance. Qualified maintenance personnel train the operators to have a better understanding of the equipment (Venkatesh, 2015). Planned maintenance can be seen as a combination of *autonomous maintenance* and *specialized maintenance* (maintenance performed by the maintenance department). (Saitoh and Mizugaki, 1994)

Pillar 4: Early management

The pace of product-development is continuously increasing, therefore this pillar are becoming more and more important. The goal is to reduce the time from initial development of a product to full scale production, and to achieve a start-up that is fast, free of bugs and right the first time. (Ishii, 1994)

Pillar 5: Quality maintenance

To cope with the current fast changing environment, companies must review their quality assurance system with goal of handling quality issues through equipment management (Setoyama, 1994b). Especially in process industries, quality needs to be built into the processes, meaning that to produce perfect quality products it is necessary to set the correct and ideal process conditions (e.g. flow rate and temperature). For this to happen, equipment must be installed and maintained so they function as optimal and produce no defects. Instead of inspecting the finished product (being reactive), and reduce quality problems based on what has already occurred, quality maintenance aims to prevent that quality defects occur all together (being proactive). This is done by identifying check points (e.g. visual defect control) for the processes and equipment conditions, and checking these conditions periodical and, act accordingly (Setoyama, 1994b).

Pillar 6: Training and education

In TPM it is aimed to have multi-skilled employees with high morale and that are eager to come to work, and perform all required work tasks effectively and independent. According to Venkatesh (2015), it is not sufficient that employees only "know-how", they also need to "know-why". "Know-how"-knowledge is gained by experience. But for employees to "know-why", it is necessary to train and educate them. The goal is to create a company full of experts.

Pillar 7: Administrative and support department activities

In the administrative and support department, TPM activities does not involve production equipment. These departments, on the other hand, increase their productivity by documenting administrative systems and reducing wastes and loss, and by improving every type of organized acidity that supports the production. (Harada, 1994)

Pillar 8: Safety and environmental management

A successful TPM organization has a strong safety- and environmental focus, in fact the goal must be zero accidents and pollution. According to Setoyama (1994a), implementing TPM leads to improved safety. For example, there are no faulty equipment that can harm humans, so a zero-defect and zero-failure focus also improve safety. Another example, is how *autonomous maintenance* and *focused improvement* eliminate unsafe factors in the work place.

2.3.3 OEE

According to Willmott (1994), organizations need to establish the *Overall Equipment Efficiency* as the measure of improvement for TPM improvement activities. The formula for OEE is simple, but also very effective to use:

Equation 1 Overall Equipment Efficiency

$$OEE = Availability \times Performance \times Quality$$

These three inputs can directly be connected to the *six equipment losses* presented by Nakajima (1988). The availability is dependent on *breakdown losses, setup and adjustment,* and *changing cutting tool.* The performance rate is dependent on *idling and minor stoppage losses* and *reduced speed losses.* The quality rate is controlled by *start-up losses* (running in equipment and warm up) and *rework and scrap.* The OEE measure only consider the actual production time, meaning scheduled downtime-losses are not taken into the calculation.

Figure 14, shows how Nakajima (1988) connect the 6 equipment losses. *Loading time* represent the planned production time, for example if a production facility has production 20 hours a day, the loading time is 20 hours. *Downtime* is the time when the equipment is not operating for a longer timer-period, typical longer than 15 minutes. Subtracting downtime from loading time is useful when the *operating time* is not logged automatically.

The performance aspect of OEE contains two new inputs, the *theoretical cycle time* and the *processed amount*. The *theoretical cycle time* is the time it takes for the equipment, theoretical, to execute an entire cycle. This means, form a product is done to the next product is starts being worked on. *Processed amount* is the number of products that has been worked on during the operation time of the OEE-calculation. In the last of the three factors that make up OEE, *quality,* the number of defects (*defect amount*) represent the number of the processed amount that are not up to the specifications that are set.

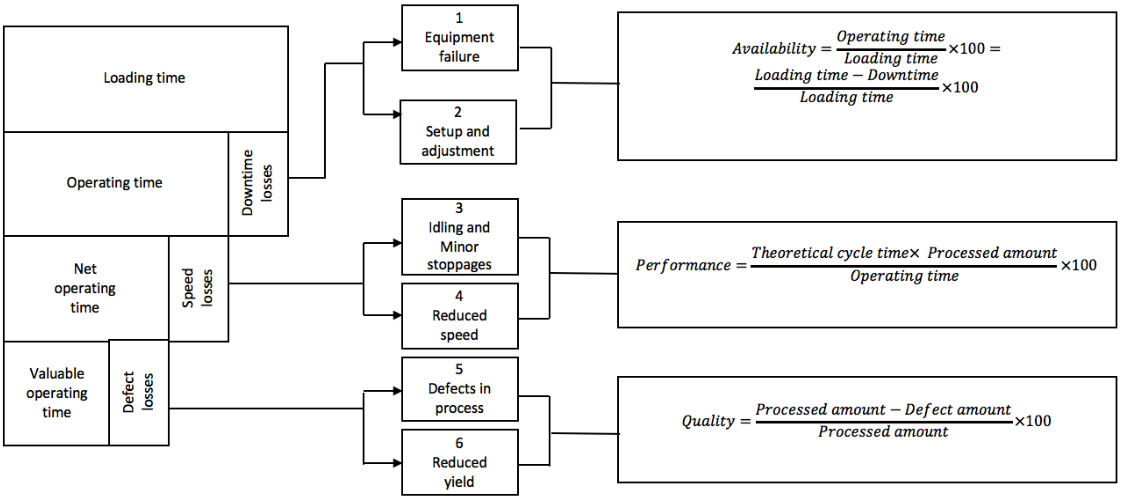


Figure 14 Connection between equipment losses and OEE calculation (Nakajima, 1988)

Nakajima (1988) also introduces world class conditions for all four measures (Availability, Performance, Quality, and OEE) based on his experiences. These are as follows:

- Availability greater than 90 %
- Performance efficiency greater than 95 %
- Rate of Quality products 99 %
- OEE greater than 85 %

3. Basis for analytical framework

3.1 Introduction

In this chapter, a framework for the review of the Cast House at Alcoa Lista will be presented. The analysis will apply a questionnaire, a leanness assessment method, and identification of important principles and tools in the two areas of Lean and TPM. Also, the current production processes at the Cast House will be analyzed through the use of Value Stream Mapping, agent based modelling, OEE analysis, and identification of losses. This chapter will talk through the aspects that not already threated under the literature study.

3.2 Combining Lean and TPM

By combining Lean and TPM in the research in this thesis, it is possible to get a more nuanced picture of the current situation at the Cast House at Alcoa Lista. The two concepts have much in common, however, there are some aspects in each of these methods that are stated more explicit, for example the Value in Lean and OEE in TPM. How TPM and Lean are connected in literature varies, some describes it as a tool in Lean (Wig, 2014), others describes them as two different methods. TPM is also, as mentioned, described as the equipment side of TPS. The definition of Lean and TPM are no doubt a highly subjective area of discussion. In this thesis, the link between Lean and TPM is depicted in Figure 15.

Figure 15 shows how the two methods overlap, and how some aspects are distinct for each of the methods. It also shows how Lean offers a customer focus, while TPM is more focused on the equipment side of production. Together, these concepts converge and create a learning organization and empowerment, and can together produce World Class Results.

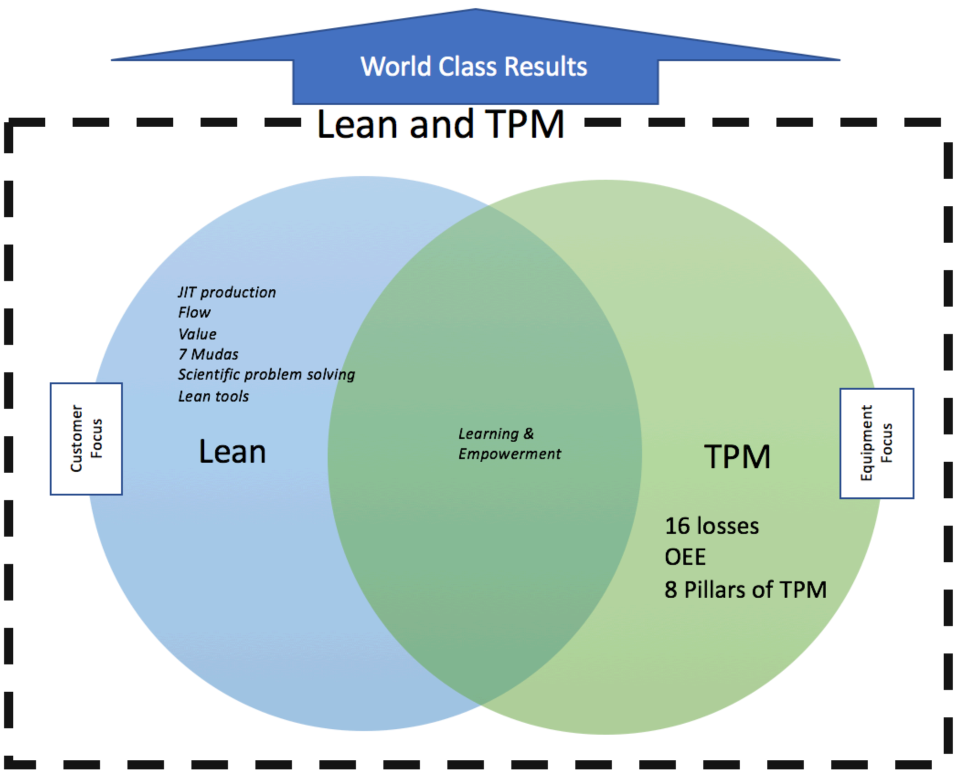


Figure 15 Lean and TPM combined

In Table 4, McCarthy and Rich (2004) presents how the two different concepts attribute different benefits to the six major results (PQCDSM), and also the environment. In other words, by combining Lean and TPM, an organization can improve more in these results, than only by adopting one of the methodologies.

Table 4 benefits of combining Lean and TPM (McCarthy and Rich, 2004)

Six major results + Environment	Lean	TPM
1. Productivity	Reduce non-value adding activities, increase added value per labor hour.	- Reduce the need for intervention. - Reduce breakdowns.
2. Quality	- Highlight quality defects early	- Potential to reduce tolerance. - Control of technology. - Reduce start-up loss.
3. Cost	- Lower inventory	- Reduce material and spear.
4. Delivery	- Lower lead times, faster changeover	- zero breakdowns predictability.
5. Safety	- Less movement, less clutter - Abnormal events become visible easily	- Less unplanned events. - Less intervention. - Controlled wear.
6. Morale	- Less clutter - Closer to the customer - Higher appreciation of what constitute customer value	- Better understanding of technology. - More time to manage
7. Environment	- No over- production - Systems geared to needs, not theoretical batching rules	- Closer control of equipment - Less unplanned events/Human error

3.3 Combining the TPM losses and wastes from Lean

As discussed earlier, Lean and TPM has different ways of defining waste (Lean) and losses (TPM). In Table 5, I have combined the 16 losses presented by Venkatesh (2015) and the seven wastes (Mudas) from Lean. If the box in the table is red, this indicates that the loss or waste is not directly or sufficiently included in the methods. For example, loss number two: set up and adjustment losses, is not a type of waste in Lean therefore it is marked with red. In this way, I bridge the terms together, and thus combining the equipment focus of TPM and the customer focus of Lean.

Table 5 18 losses, a combination of Lean wastes and TPM losses

	Loss	Description	TPM	Lean
Equipment Efficiency	1. Breakdown losses	Includes sporadic breakdowns resulting in in the process or production line to stop		
	2. Setup and adjustment losses	Stoppages losses due to setup changeovers between products. This category also include material shortage that leads to short stops		
	3. Cutting Tool Replacement losses	Changing the cutting blade, that results in speed loss.		
	4. Start-up losses	The losses that arise from starting up production until equipment start-up, running in, and production processing stabilization.		
	5. Minor stops and idling	When equipment temporarily stops or idles. Normal operating conditions are restored due to simple measures.		
	6. Speed losses	Speed of the process falling below the designed speed of the equipment.		
	7. Quality defects Rework losses	Losses due to defects and rework.		
	8. Scheduled down time losses	Scheduled maintenance or other scheduled downtimes.		
Human efficiency	9. Management losses	Waiting for instructions, materials, tools, etc.		
	10. Motion losses	Motions that do not add value/ unproductive motions.		
	11. Line organization losses	Waiting time losses due to poor line balancing. E.g. 60% manpower utilization.		
	12. Logistics losses	Distribution man-hour losses, due to *transportation of materials/products*, and *non-replacement with automated systems* (when automation is possible) E.g. Loading/unloading that could be automated, but is not automated.		
	13. Measurement and adjustment losses	Frequent measurements and adjustment to prevent the occurrence of poor quality defects. E.g. Frequent tool adjustment.		
Resource Consumption Efficiency	14. Yield losses	Loss of yield. e.g. Excess material stock/weight. Material losses due to difference between input and output.		
	15. Energy losses	Ineffective use of input energy.		
	16. Consumable losses	Loss due to manufacturing and repair of dies, jigs, and tools necessary for the production.		
Lean wastes (Muda)	17. Overproduction	Cause the production to be ahead of the production schedule. This is not a good thing in a JIT system. Examples of wastes are the need for additional space to store excess inventory, added transportation and administrative costs, an increase in interest burdens, and wasteful input personnel and utilities.		
	18. Inventory	Losses associated with inventory (relates to the water level analogy).		

(Venkatesh, 2015) (Industry Forum, 2015)

In the long run, these losses can be removed through creating an environment of scientific thinkers and empowering employees on every level of the organization. Also, by combining Lean and TPM, an important KPI in manufacturing can be adopted, and that is the use of OEE. As discussed, OEE measures the first seven losses, which is the unplanned losses of equipment down time.

3.4 OEE for the seven major equipment losses in this thesis

In the literature study the OEE-calculation method, and the connection with the various equipment losses, of Nakajima (1988) was presented. However, as this thesis will be based on the losses presented by Venkatesh´s (2015) losses, the connection will be somewhat different. The concetion in this thesis is presented in Figure 16. The figure show how the seven equipment losses that Venkatesh presented is connected with the different factors of the OEE (Availability, Performance, and Quality).

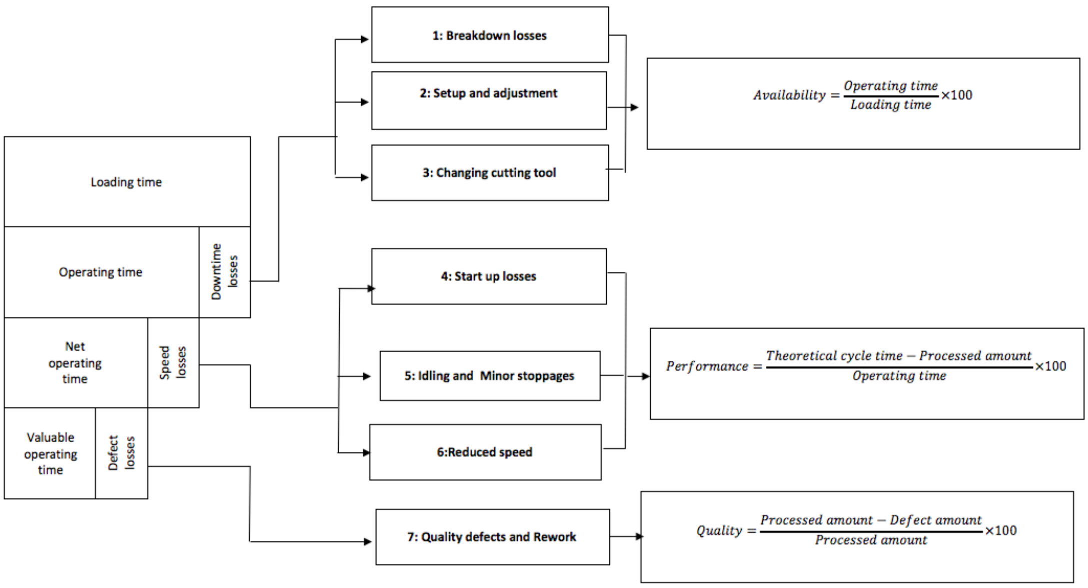


Figure 16 Connection between the losses of Venkatesh´s and the calculation of OEE

3.5 Questionnaire on Learning environment

The questionnaire was based on the ten connections Hess (2014) made between the environment of a High Performance Learning Organization, and employee engagement. Five of these ten connections are most relevant statements for this thesis. These five questions were therefore chosen to be included in the questionnaire. This was conducted at all organizational levels at the Cast House. By using fewer questions, it was believed that more personnel would find the time to answer. The five questions that were selected to be included in the questionnaire were the following:

1. *I have the opportunity to do what I do best.*
2. *At work my opinions seem to count.*
3. *In the last year, I have had opportunities to grow and develop.*
4. *Someone at work encourages my development.*
5. *In the last six months, someone gave me feedback.*

By using these questions in the questionnaire, it is possible to get an indication of how the learning environment at the Cast House is, and also the degree of employee engagement. The benefits of increased employee engagement are well known, and correlates directly with the performance of an organization (MacLeod and Clarke, 2009).

In the questionnaire, the following question was also included to map the current situation at the cast house:

1. *Have you participated in problem-solving with A3? (yes or no)*

All the statements, excluding the A3 question, were answered by using the *Likert scale*. The results were calculated in the following way: Strongly disagree (0 %), disagree (25 %), neutral (50 %), agree (75%), and strongly agree (100 %). Based on this, a weighted score was calculated, to assess the learning environment.

3.6 RPA- assessment

The Rapid Plant Assessment (RPA) process is a tool that was developed by R. Eugene Goodson to find a plant´s *leanness* in a fast and efficient way. According to Goodson (2002), the *RPA* can be applied for a various purposes, for example in the assessment of a possible supplier or a new acquisition. He also states that the tool can be used for assessing own operations, to learn what the plants are telling visitors, and where there might exist opportunities for improvement.

The *RPA* process are an assessment tool to use in plant tours. *The RPA rating sheet* assess the leanness of a plant through 11 categories. *The RPA rating sheet* is used based on observations of all aspects of a plant´s environment, talking with the work-force and mangers, and looking for evidence that shows if the plant follows the best practices.

The eleven categories will be rated on a scale from "poor" (1), to "excellent" (9), to "best in class" (11). According to Goodson (2002), "best in class" is only used when the plant is the best in its industry, worldwide. The total ratings of all the categories will get a sum between 11 and 121.

According to Goodson (2002), the assessment on the *RPA rating sheet* is useful because the eleven categories underlines broad areas of strength and weaknesses. Low score on a category will instantly show opportunities for improvement.

The *RPA rating sheet* will in this thesis be used to get a broad view of the current leanness state of the Cast House at Alcoa Lista. This tool will be presented and the results will be analyzed and discussed in chapter 6.8 (*Rapid plant Assessment*).

3.7 Agent based modelling

Anylogic is an agent based modelling simulation software. Agent-based modeling is a style of modelling, in that models agents (e.g. animals, groups, or cells) and how they interact with each other and the environment. In this thesis, the software will be used to visualize the line organization losses in a production line.

4. Alcoa Lista and their business system

4.1 Introduction

Alcoa Lista is located in Farsund County, at the southern tip of Norway. Alcoa Lista started their production in 1971, under the name *Elkem Lista.* The plant was then a joint venture between Elkem and Alcoa, but later it became fully owned by Alcoa, and thereby renamed to Alcoa Lista.

Due to productivity improvements, the number of employees the last 20 years has decreased significantly. Today Alcoa Lista employ 265 people, whereas 20 years ago this number was more than 300 employees higher. At the Cast House, there are currently 50 employees.

Alcoa Lista produces two types of products: aluminum billets for extrusion purposes, and liquid aluminum alloys to their neighbor, Benteler Automotive Farsund. Alcoa produces approximately 120 000 tons of billets and 15 000 tons of liquid alloys a year. Out of this, Alcoa produces approximately 95 000 tons of electrolysis metal themselves, and the rest is purchased from other suppliers.

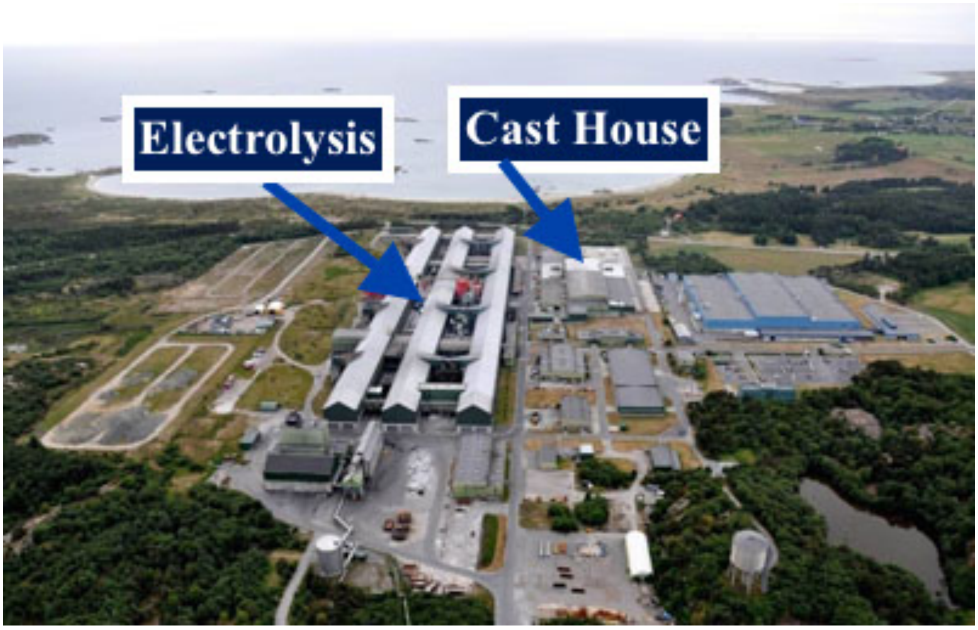


Figure 17 Alcoa Lista (Alcoa, ND)

The billets are custom-made for the customers. That is, there are no stock-products, every product is produced to a customer. Alcoa Lista consists of two main departments (Figure 17): Electrolysis (smelting) department that manufactures the aluminum, and the Cast House department that manufacture the aluminum alloys that is sold to the customers. The electrolysis department is the Cast House´s main supplier. The Electrolysis purpose is to produce electrolysis metal to the Cast House, where the aluminum alloys are produced. This metal is transported to the customers as billets by ship, trucks, and directly to their neighbor plant as liquid metal. Figure 18 shows the inside of the Cast House, where one can see two conveyors that are used to transport billets between processes.

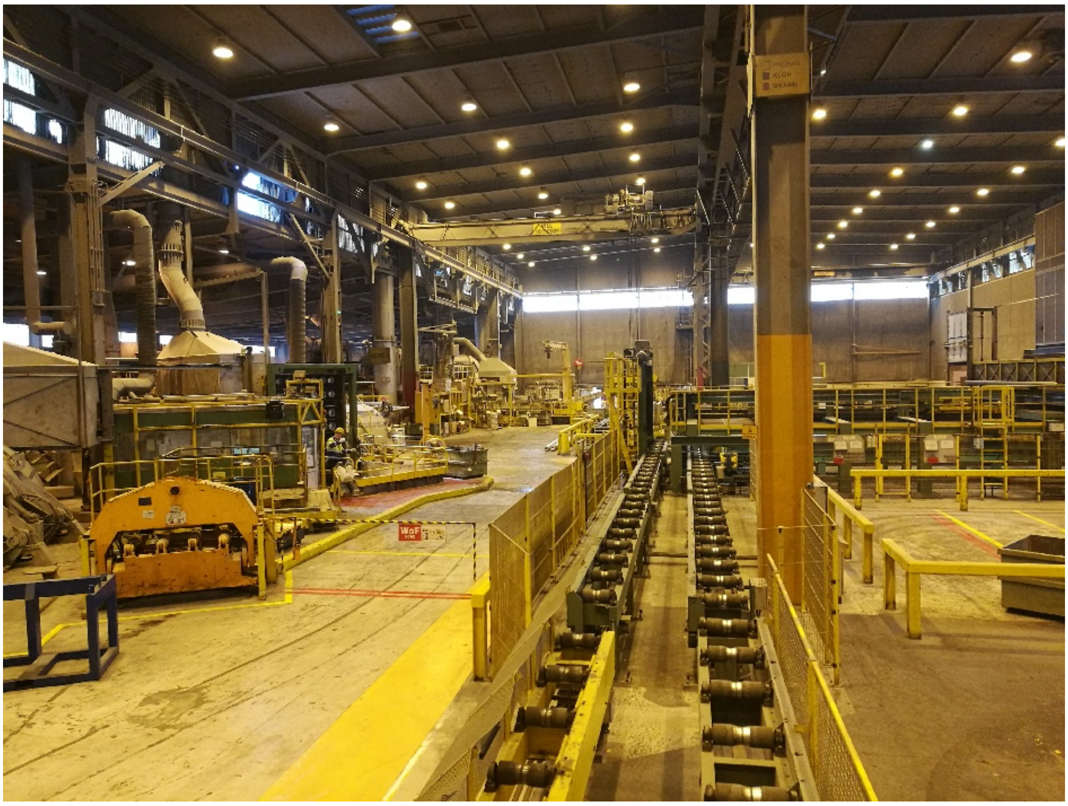


Figure 18 Inside the Cast House (Unpublished)

Alcoa is a worldwide company that is one of the leading and largest companies within production of Bauxite, Alumina, and Aluminum. In Figure 19, a description of all the locations of Alcoa´s plants around the world are given.

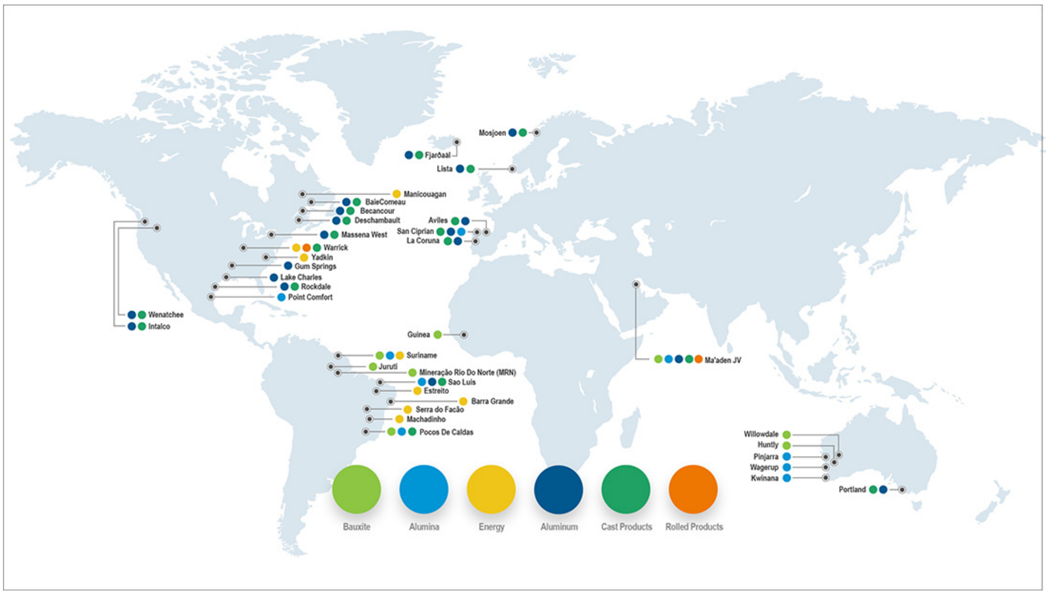


Figure 19 Alcoa, a worldwide company(Alcoa Inc, ND)

Alcoa Lista is a process industry plant, and with that, several challenges and unique features follow. These features and challenges does not exist in the assembly fabrication industry, where Lean and TPM originated from. The term "process industry" is an umbrella term for a wide range of industries including refining, general chemicals, iron and steel, power generation, gas, petrochemicals, papermaking, cement, food, pharmaceuticals, and textiles (Suzuki, 1994). The process plants in these industries range from completely continuous production to pure batch production. In the Cast House the production of billets are a pure batching processes, while the processes at the Electrolysis department has a continuous production of electrolysis metal.

The electrolysis process, casting process, and other processes at Alcoa Lista, are energy intensive activities. These processes consume large amount of electrical power, water, and fuel. Processes may handle various types of dangerous substances, and often demand high pressure and temperature. This results in the possibilities if explosion and pollution of the plant and its surroundings.

4.2 Company Specific Production System - ABS

Alcoa, as a company, was one of the earliest adaptors of the Lean philosophy outside of Toyota in the last part of the 1990s. Through research of the Toyota Production System, Alcoa together with the Steven J. Spear author of "Decoding the DNA of the Toyota Production System" (Spear and Bowen, 1999) developed their own interpretation of Lean. The product of this work became the company specific production system, *Alcoa Business System (ABS)*. ABS is in practice TPS tailored to Alcoa´s needs. When ABS was first introduced, the aluminum manufacturing plant at Lista was, as mentioned, a joint venture between Alcoa and Elkem, therefore the first years ABS was named *Elkem Business System* at the plant. However, the principles were, and still are, mostly the same.

Spear (2009) states that the results of implementing ABS in Alcoa (worldwide) was fantastic. For example, in Alcoa´s 2002 *Sustainability Report,* Alcoa estimated cost savings of USS$1 billion that could be contributed to ABS (Alcoa, 2003). Spear (2009) also states that another improvement was the decreased odds of getting hurt seriously enough to miss work in Alcoa. In 1987 the odds of this to happen were 2 percent per year. In practice this meant that the odds of getting seriously hurt at Alcoa over a decade were 20 %. The idea that the processes the workers found themselves in were safe, but the that workers was deliberately making errors, was rejected together with the idea that the workers was not smart enough to work safely. This mind-shift in Alcoa lead to a decrease in risks of getting seriously hurt at the work-place to decrease from 2 % to 0.1 % over the following 15 years (Spear, 2009). This is close to one of the most important target conditions in Lean and TPM, *zero accidents.*

The Value Proposition: the core of ABS

Another key person in the development was Keith Turnbull. In the 90´s he was sent to Toyota to observe TPS in practice, and interpret the system to Alcoa´s use. According to Turnbull (2003), Alcoa uses ABS to harvest unrealized wealth by:

a) Precisely understanding the customer need.
b) Pre-specifying *the activities*, *the pathways,* and *the connections* that is necessary to meet the customer need and commit to them.
c) Ensure that what is pre-specified are controlled through *built in tests.* This is used to control, identify, and prevent problems which may threaten predetermined outcomes.
d) Enabling every employee to recognize and trace problems back to their root- causes and eliminate them. Not only through specialized teams of problem solvers, but throughout the organization by participation of the people occupying the affected *pathway.*

Turnbull´s way of harvesting the unrealized wealth is consistent with the Lean literature presented earlier. To know what creates value for the customer, it is necessary to understand the customer needs, and deliver on these requirements. These needs can be met by *build quality in*. This is done by pre-specifying the activities, the pathways, and having direct connections. *Built in tests* are then used to ensure that the quality is acceptable to the standards that are pre-specified. By using this feedback, the quality is measured based on the inputs, rather than the output, to meet the customer needs.

The last point is the most important one, and is what I identified as the essence of Lean in the literature study, and a distinct feature of TPM. That is total involvement of every single employee, from top management to workers at the shop floor. The improvements do not only concern specialized teams of problem solvers, but all the people in the organization are scientific problem solvers.

In ABS, the customers and suppliers are not only external, there is also an internal version of this relationship. This is every transaction along Alcoa´s value stream. Such relationship occurs on all levels in Alcoa´s organization. For example, at the high level a customer buys from ingot, ingot from smelting, smelting from refining, and refining from melting. Every supplier within ABS should ideally supply its customer:

- on demand;
- defect free;
- in batches of one;
- immediately;
- safely;
- with no waste.

The Rules-in-use

As mentioned, ABS is based on the work done by Spear and Bowen (1999), therefore ABS is built on the *Rules in use.* The ABS- design insist on simplicity and clarity in *customer/ supplier connections*, *pathways*, *activities*, and *improvements to the system.* This means to know the customers need, and meet it, pre-specify the customer supplier pairs, and connect them into a simple pathway. Work and the desired outcome of this work should be pre-specified. Improvements in ABS should be made as close in *time, location,* and to *the person* where the problem happens.

ABS utilizes *built in tests.* This enables feedback that evaluate if the work is done right, and if the outcome is right. By using the concept of *build quality in,* instead of *inspect defects out,* Alcoa can avoid firefighting and rework, and rather solve problem to root cause and improve the system. Also, ABS does not allow dividing assets (e.g production centers), as was common before. For example, in refineries the flowing liquid aluminum have deliberately been stored in containers so that there exists a separation between adjoining processes. (Turnbull, 2003)

The prior way that Alcoa organized their assets, was that assets were separated by queues (Turnbull, 2003). Queues provided a buffer so that assets did not shut each other down when one of them encountered a problem. Due to the “high water level”, the problems in these assets remained unresolved. By contrast, ABS brings the customer request along a pre-specified *pathway.* This pathway is made up of customer/supplier pairs, which each is doing work as *pre-specified,* each meeting customer needs, each knowing through *built in tests* that the way and outcome is right, and each solving problems as they are uncovered. Usually each supplier in this pathway is a person with one or more machines and processes. The pathway´s description is depicted in Figure 20. Along this *pathway* humans preform pre-specified *activities* with clear costumer/supplier connections.

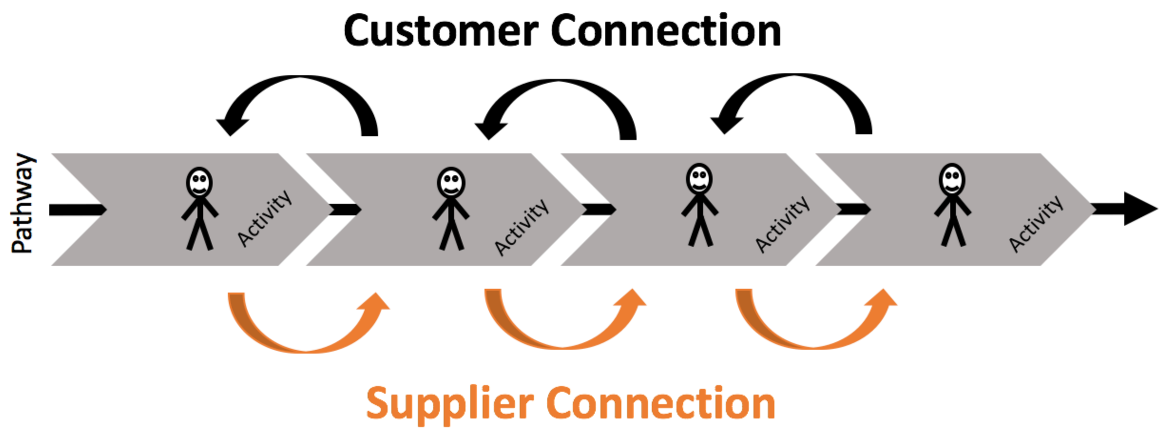


Figure 20 The strategic Rule- in-use: Pathway, Activity, and Connection

Some assets in ABS are not yet directly connected to the adjoining assets. A reason for this may be that technology is not reliable enough, or are so difficult to change over, so they are connected through a que. However, ABS does not allow permanent countermeasure, and ABS demands that countermeasures are eliminated. The countermeasures must be clearly associated with the root causes within the assets that requires them, and work must be focused every day to find solutions to the problems. Over time, the intent must be to eliminate the whole countermeasure. In the prior system, Alcoa kept their options open changing the work they did. *Activities, connections, pathways,* and *improvements* where in the prior system ad hoc, and root cause solving was postponed until later (most likely forever).

In ABS, pathways are pre specified as shown in Figure 21. Each person in the different pathways knows who their suppliers and customers are. In this way, the work they do is important to meet customer´s needs, and they get ownership and pride to their work. The problems with process B will be temporary taken care of by countermeasure to handle such inconvenience. Then it is up to the persons which operate process B to think up, and implement improvements, to meet the customer´s need.

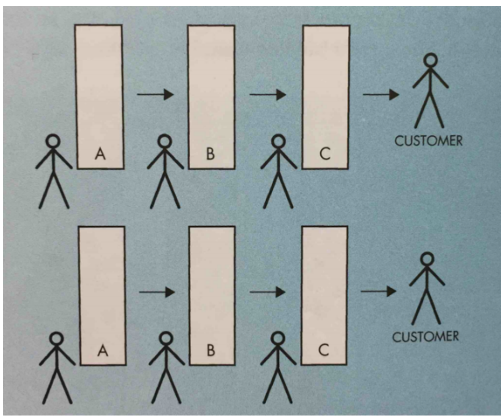


Figure 21 ABS way of organizing people (Turnbull, 2003)

There are some challenges that are important to acknowledge: (1) *Customers come unevenly;* (2) *the customer´s needs don´t match the supplier´s processes;* and (3) *the supplier has problems with processes* (Turnbull 2003). The prior way to manage these problems was to respectively, make the customers use queues, sell a near match from stock/ have the customer wait until they could match their processes, and deliver late/deliver partial order/deliver a compromise. ABS on the other hand, with its values acknowledges these realities and provides a different and better design.

In Table 6 you can see how Alcoa further breaks down Spear and Bowen´s Rules to another level. The *rules in use* utilizes as mentioned earlier *built in tests*. This is based on the simple idea of that people work best if they can see what they are doing.

Table 6 Rules-in-use (Turnbull, 2003)

Rule	Level 1	Level 2
1	Activity	1. Content 2. Sequence 3. Timing 4. Location 5. Outcome
2	Connection	6. Request is binary 7. Request is direct 8. Response is binary 9. Response is direct
3	Pathway	10. Pre-specified 11. Simple 12. No loops 13. No intertwined branches
4	Improvement	14. Everyone solves problems 15. Capable teachers help 16. Problems are solved when and where they occur 17. Problems are solved via testable hypotheses,

5. Case study of Fibo

5.1 Introduction

Fibo is a Norwegian technical enterprise that produces waterproof wall panels. Their main-office and manufacturing plant (Figure 22) is located in Lyngdal. Fibo is widely known as one of the leading Lean businesses in the country. In 2012 they were one of three companies to be nominated to the yearly award "The best Lean company in Norway" (Lean Forum Norge, 2012). Since then, they have continued to develop their Lean business system (FiboLean) in a positive direction.

Figure 22 The Fibo Factory in Lyngdal (VAF, 2013)

The information about Fibo´s Lean work was obtained through visiting their plant in Lyngdal, and through a non-structured interview with Fibo´s lean coach, Monica Briseid.

Fibo started their Lean journey in 2009. At that time they had a large amount of inventory and lack of control of this. They had unstable production, low uptime of equipment, low quality of the output, and lack of control from management. However, through the Lean method, Fibo has managed to overcome these challenges. Fibo refer to their work in Lean as *FiboLean*. However, they have aspects of their Lean work that traditionally has belonged to TPM. For example, as will be discussed later, they have incorporated an Autonomous Maintenance system and has a strong focus on OEE.

5.2 Fibo´s Lean journey

Fibo moved into their new factory in 2007. After 2 years (2009) in the new factory the overall plant utilizations was approximately 45 %, and some products had up to 50 % defects. The saying was that Fibo had a nice facade, but not as nice on the inside. Figure 23 shows examples of how it was inside the brand-new factory, the inside did definitively not match the facade of the factory. Fibo realized that sustainable changes had to happen, and with commitment from the senior managers, they embarked on their extremely successful Lean journey.

Figure 23 Before Lean at Fibo (Briseid, 2017)

Over the last years, the customers have started to demand a greater variety of products to choose from. Therefore, Fibo has increased the number of different products they produce from 54 to 740. This increasingly number of products demands more changeover, and a higher degree of order controlled production. This is because it is impossible to have all the different products on stock. At the same time as the variety of products has increased, the volume of Fibo´s production have increased 2,5 times. To be able to do this, Fibo has utilized the tools SMED and standardized work, and A3 has been used in the improvement work.

Lean at Fibo can be described as: *a management philosophy; respect for the humans; focus on elimination of waste through practical and simple methods; focus om continuous improvement; and Work against 1x1 flow (Briseid, 2017)*. Lean at Fibo is a culture that involves the whole organization. This is a culture with continuous improvement, where the humans in the organization are their greatest resource. Every employee at Fibo should always have focus on the customer´s need, both internal and external. Team-work is important in Lean at Fibo, the goal is to achieve the feeling of "one team Fibo" for all employees. Fibo is continuously working on improving the timeline from an order is placed to it is delivered to the customer, by removing unnecessary waste.

5.3 Master Plan

Fibo´s vision is updated each year, and how this vision will be reached is visualized through broken down work tasks for the different teams. This is visualized clearly on a wall in the production facility, as shown in Figure 24.

Figure 24 The Master Plan

The picture on top in Figure 24 illustrates Fibo´s vision. It includes their mission statement, KPI goals, their operative vision, and values. The pictures underneath include tables that describes "why something needs to be done", and "how this should be achieved", across the different departments and levels in the organization. These tables are developed by the different teams themselves, and are visible at the work stations they concern. This clearly shows how the teams and people in Fibo can contribute to the overall goal, and ensure that all the teams are pulling in the same direction. One of the "placks" are illustrated in Figure 25.

	Energi Hvorfor skal vi gjøre noe?	**Retning** Hva skal oppnås?
1	**Vi skal ha høyt HMS fokus slik at våre ansatte kontraktører og kunder kan føle seg trygge. Byggefasen er krevende og vi skal ikke gamble med sikkerheten**	**Vi skal ikke ha noen skader eller farlige hendelser** **Vi skal ha en god visualisering av HMS status** **Avvik skal håndteres direkte**
2	Vi trenger å ha fokus på prosessen både på gammelt og nytt utstyr. Innkjøringsfasen gjøres kortere dersom vi har fokus på at riktig prosess gir riktig resultat	Nivåene vi har på de aktuelle metodene (5S, OPVDL osv.) skal være i verdensklasse også i ombyggingsfasen. Oppstart av nytt utstyr skal gå så smertefritt som mulig
3	Vi trenger å ha fokus på utvikling av den enkelte medarbeider, utfordringer skal være gøy. Metodene vi har lært skal tas i bruk der det er nødvendig	Vi skal bruke alt vi har lært slik at vi sammen kan gjøre overgang fra gammelt til nytt utstyr sømløs
4	Vi trenger å bli en lærende og selvgående organisasjon slik at vi kan føre bedriften gjennom utfordringene på en god og bærekraftig måte	Alle ledere drar i samme retning og har en coachende tilnærming. Kata skal være en naturlig del av dette
5	Vi trenger å bli fleksible i alle ledd slik at vi kan takle morgendagens utfordringer	Vi ønsker å oppnå en stor fleksibilitet. Alle operatører skal kunne jobbe på alle maskiner
6	Kundene våre forventer mer og vi må yte god service ovenfor disse selv om vi bygger om	Vi skal oppnå pull i produksjonen- god flyt med minimale lager. 100% ordrestyrt produksjon er målet i fremtiden
7	Kundene ønsker at vi skal levere alt til enhver tid. At vi gjør om på hele fabrikken skal ikke gå ut over dem	Bransjens beste leveringspresisjon og servicegrad. Full fleksibilitet- alle dekorer- alle fresinger- kort leveringstid

Figure 25 Clear Team Goals (Briseid, 2017)

5.4 Education in Lean

Fibo invests in educating employees in Lean. All employees get a half day education in the concept of Lean. Leaders receive a minimum of 1,5 hours of education a week, and leaders and representatives conduct the "Lean leadership and improvement school" at Fibo. For all new leaders, reading circles in the "The Toyota Way" are organized. All employees receive basic training in Lean, and when a new method is introduced, employees receive training in this method.

Learning circles are organized cross functional, and include both employees and managers. Each learning circle lasts for 18 weeks a time. Also, reading circles for those employees that are interested are organized, where they review books like "Respect for People" by Robert Kusén and Arne Ljung.

5.5 24 hour meetings

In the 24 – hour meetings, representatives from the different departments discuss their performance through relevant KPIs. The KPI for all the process critical equipment is OEE. In addition to KPIs on process critical equipment, KPIs on sales, HSE, Customer support, and storage are used. All the KPIs are handwritten on a white board, by either red (bellow the standard) or green (above the standard). Also, the performance of the previous week is listed on the white board. The choice of using a white-board rather than computer screens are made deliberately. This is because they believe that the performance become more visible and create more awareness when the people have to write with the colored markers themselves. In Figure 26 you can see a how the 24- hour meetings are conducted by using three whiteboards. Usually these meetings are conducted at the "Gemba", but it was moved to the entrance hall during my visit due to ongoing construction work.

Figure 26 24-hour meeting at Fibo

5.6 Improvement culture

Every employee at Fibo are assigned to teams that range from 2 to 12 members. The teams decide on their own what problems that needs to be solved, they have their own improvement lists, and their own white-board meetings. The teams are rewarded monthly for good improvement work and when they have achieved exceptional improvement results. The teams receive monthly, quarterly, and yearly rewards, if the employees in the team do over 4 improvements per employee on average a month.

Fibo has their own internal database where improvement suggestions are logged, and they can in this way log the improvements structured and efficiently. This system is so effective that in 2016 the number of employee improvements at Fibo was impressively 2533 improvements. The number of employee improvements at Fibo is so important that it is included in their visual management system, and they visualize the number of improvements as depicted in Figure 27.

Figure 27 Visualization of improvement work (Briseid, 2017)

5.7 Total involvement

In FiboLean the goal is that "all employees should think on and execute improvements each work day as a part of their normal work tasks" (Briseid, 2017). This means that employees on the "bottom" also is included in the improvement work. As already mentioned, all employees get education and training in the concept of lean. Based on this education and empowerment, employees on all levels actively participate in the improvement work at Fibo. Examples of empowerment of operators are: team improvement suggestion do not need to be approved by managers, employees make their own standards, they get to solve problems scientifically using A3.

The concept of Autonomous Maintenance is also used at Fibo. Operators do many maintenance tasks themselves, for example lubrication and cleaning. There is a visual control system for the maintenance work tasks that the operators are responsible for doing. The maintenance work tasks are planned and organized according to intervals (weekly and monthly). The visual Autonomous Maintenance system can be seen in Figure 30. As the work tasks are done, the cards are flipped from red to green. The system is a part of a greater visual management system at the current, and other, work stations. This visual management system, consisting of several white boards, also includes A3´s that is currently beeing worked on by the operators.

Improvement suggestions, visualization with a smiley face for what months that the team has reached the goal of 4 improvements on average, KPIs, standardized work tasks, and a description of how the teams can contribute to reaching the vision, and other important topics for the current team are clearly visualized at the various work stations. In Figure 28 on-giong problem solving with A3 is shown and in Figure 29 you can see how the KPIs at the work-stations are visualized.

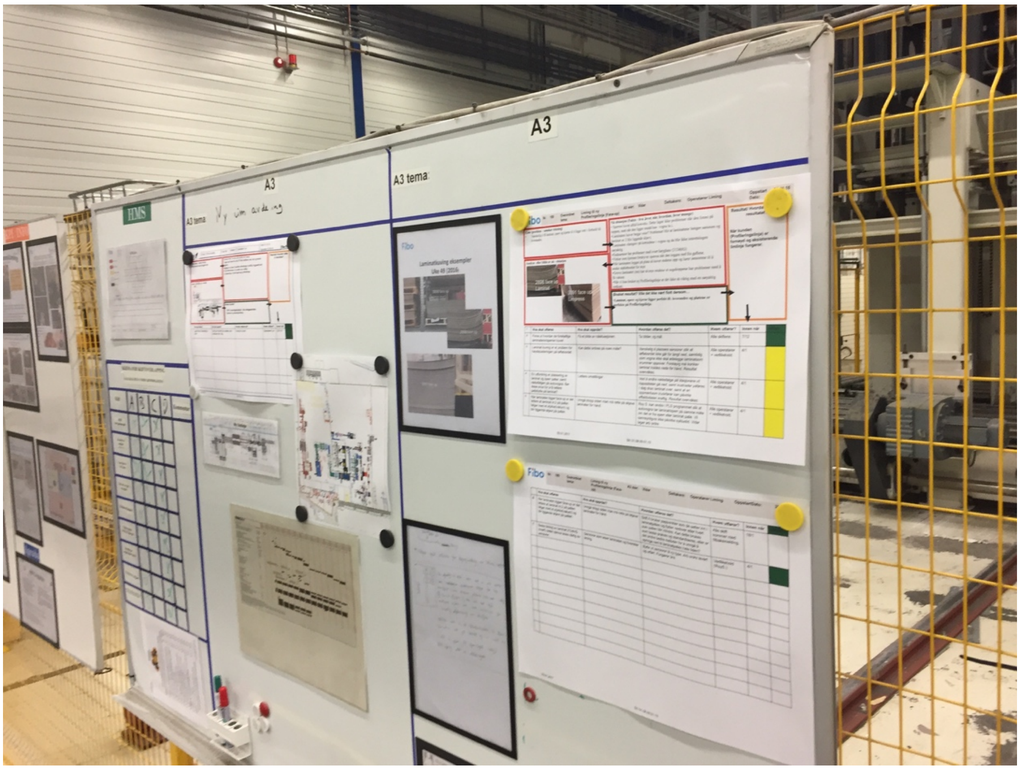


Figure 28 Visible A3 problem solving at the shop floor


Figure 29 KPIs at the workstations

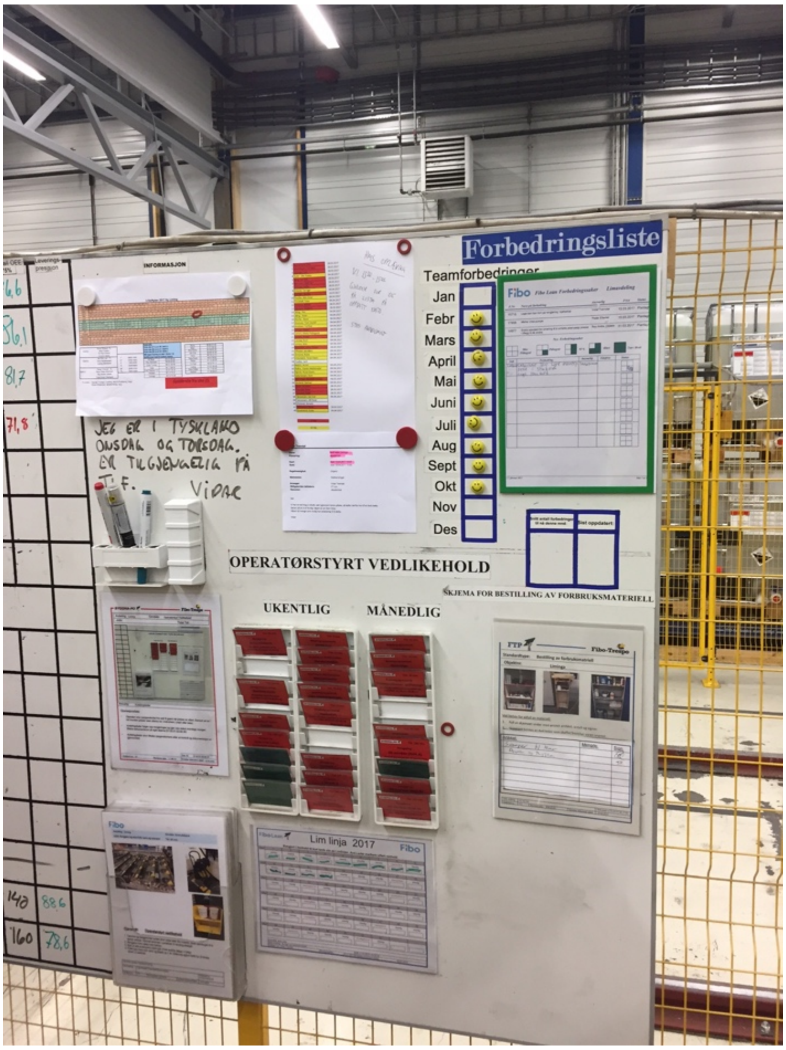


Figure 30 Improvement lists, autonomous maintenance tasks, and standards visible at the workstations

In addition to engage operators in problem solving through A3, Mike Rother´s Kata-method is used. In their Kata problem solving, Fibo choose a topic that needs improvement. The topics are chosen by the operators themselves. An example of a Kata topic that was solved, was that pallets got jammed in the production line. These topics are chosen for 5-6 weeks at a time. The process follows the same structure as described in the literature study, using the same questions (Rother, 2014b) and a passive coach that is not there to solve the problem, but coach the problem solver. *5s* is also used to engage employees at all levels, and 5s audits are performed by operators.

5.8 Summary

Fibo has managed to engage operators in scientific problem solving. They have also successfully empowered them through: education, autonomous maintenance, making their own standards, and 5s audits. They have clear and visible team goals, defined by the teams themselves, to ensure that everyone is pulling in the same direction and know what to improve.

They actively use OEE, both at the 24-hour meetings and the production meetings at the work stations. Important information about ongoing problem-solving, autonomous maintenance tasks, standardized work tasks and other important factors are visible.

A strong focus on employee engagement has made the problem solving a part of their daily work, not an ad-on activity. This is reflected in the number (2533) of registered improvements that is done at the plant. Fibo has come a long way in creating a culture of scientific problem solvers.

Throughout this thesis, there will be made connections, when suitable, between this chapter and the current state at the Cast House at Alcoa Lista.

6. Analysis of the current Lean and TPM practice at the Cast House at Alcoa Lista

6.1 Introduction

This analysis aims to review Lean and TPM practices in an industrial context. The unit of the analysis is the Cast House at Alcoa Lista. However, the Cast House is a part of a plant, that is a part of a worldwide organization (Alcoa). Therefore also aspects from Alcoa Lista as a plant level and Alcoa will to some extent be included. For example, the programs that are implemented are not unique for the Cast House, they are used all over the world by Alcoa. The following analysis are based on observations, conversations, open ended interviews and a survey. In Table 7 the points of interest (subchapters) of this analysis are presented, and the reason and purpose of the categories is presented under "objective" in the same table. The points marked with *italic text* in the left column, indicates what is used from the chapter *"basis for analytical framework"*.

Table 7 The structure of the analysis

Point of interest	Objective
6.2 Relevant projects	Identifying projects, and identifying possible positive and negative effects these projects may have on the current Lean and TPM status at the Cast House.
6.3 Lean tools	Identifying and discussing the use of the Lean tools that was presented in the literature study.
6.4 The Eight Pillars of TPM	Giving an overall impression of the current TPM status of the Cast House. There has not been an official TPM-program launch, therefore this is needed to identify the aspects of TPM that has the greatest improvement potential.
6.5 The learning environment *(Questionnaire on learning environment)*	The essence of Lean was in the literature study identified as scientific problem solving. The underlying idea behind this concept is learning. Therefore the current learning environment at the Cast House will be discussed, and possible problem areas will be highlighted.
6.6 The production processes at the Cast House *(18 losses, OEE-calculation, Anylogic)*	The Cast House has two production processes: the billet production and the production of liquid alloys to their neighbor plant. These production processes will be presented and discussed using value stream mapping. Examples of losses at the factory floor concerning the values streams, will be presented. Also, a simple agent based modeling simulation will be performed to identify possible improvement possibilities. An OEE analysis will be performed on a process critical equipment that is suspected to gain especially much in loss reduction.

6.7 Rules in use	In this chapter the *rules in use* of ABS will be discussed and analyzed in the light of the current situation at the Cast House. This to check if the theory is consistent with the real world.
6.8 RPA-analysis *(RPA-analysis)*	The RPA analysis will be performed to analyze the overall leanness of the plant. This tool will also be used to identify possible problems and improvement areas.

6.2 Relevant projects

As I already have described, Alcoa has their own business system (ABS). The business system is, as discussed, based on TPS. Therefore, ABS is synonymous with Lean at Alcoa Lista. There are however other projects at Alcoa Lista that can be attributed to the umbrella of Lean and TPM. Such projects are *Degrees of Implementation*, *the Internal Improvement Suggestion System, Human Performance*, and a *HSE-deviation system.*

6.2.1 Degrees of Implementation

Degrees of Implementation (DI) is a system for improvements in the Alcoa system. Where the improvements go through degrees of implementation. The key in this system is that the improvements that are made should be measurable. An improvement made in this system is therefore quite comprehensive. For an improvement to be included in this system someone from management must approve and lead the project.

6.2.2 The Internal Suggestion System

The Internal Improvement Suggestion system at Alcoa Lista is a system with a lower threshold than DI. All employees can make improvement suggestions. When there is a financial effect of the improvement, this is rewarded economically to the specific person that suggested the improvement and contributed in the implementation. This improvement system has a top-down approach, that is, the decision for implementing the change need to be approved by a committee. The leader of the area is assigned as leader of the improvements. This project was launched only months before this thesis was started. During the seven months it was operational 18 suggestions was registered.

6.2.3 Human Performance

Human Performance is a safety project in Alcoa. The primary tool in Human Performance is a standardized Human Performance white-board that is used to minimize the risk of injury. This is used at the start of each shift at the Cast House. In Figure 31 you can see the standardized white board that is used at the meetings, which includes aspects as “what can go wrong” and awareness of the nature of dangerous activities with Rasmussen´s Skill-Rule-Knowledge (SRK) framework.

Another tool is the use of a job safety analysis form, a pre-specified form for identifying possible hazards in the execution of work tasks that are rarely done. The purpose of Human Performance is that by thinking ahead and preparing for the work tasks that are high risk, the risk of an error can be lowered. Through Human Performance, Alcoa acknowledges that all humans make errors, rather than thinking the reason is unskilled workers. This system minimizes the risk for human errors to happen.

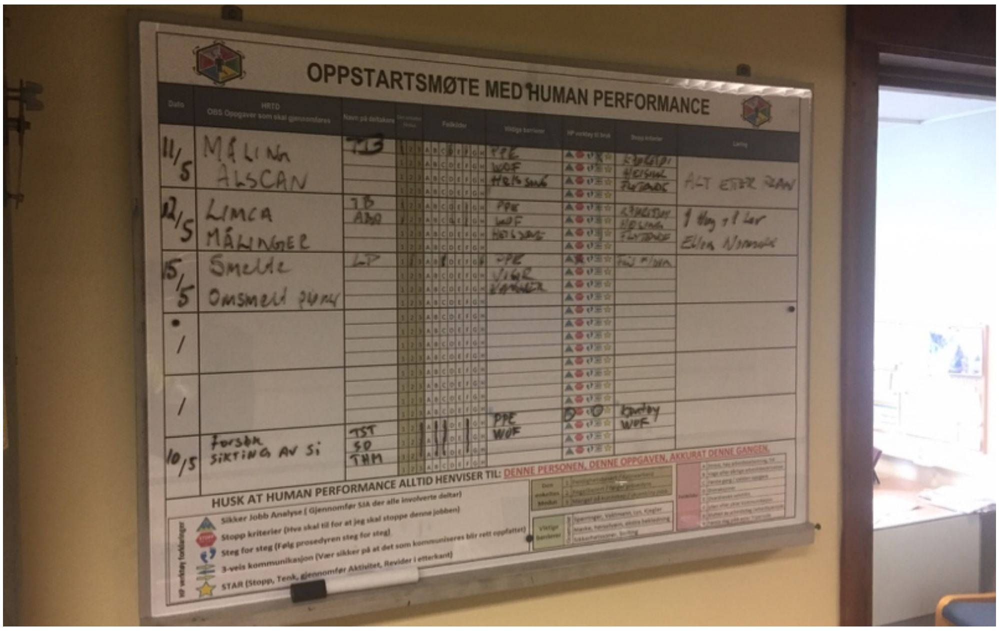


Figure 31 Human Performance Board

6.2.4 HSE -deviation system

The HSE-deviation system at Alcoa Lista is a system that registers deviations concerning safety. That is, dangerous conditions that can potentially cause harm for humans or equipment. In this system, a dangerous condition and possible improvements for removing this dangerous condition is registered. Then a person is assigned the responsibility of correcting the problem by the person that registers the dangerous condition. From this point, the person that is assigned the responsibility is the owner of the problem solving. This responsible person is typically a manger that is connected to the affected problem area. This can also be considered a type of an improvement suggestion system, that concerns safety.

6.2.5 Conclusion

The fact that the Internal Improvement Suggestion System only has 18 improvement suggestions in 7 months, indicates an improvement opportunity for Alcoa Lista. This can be seen as indicators to the following statements: (1) the suggestion system do not catch all improvements; (2) there are not a culture of continuous improvement at Alcoa Lista. For example, all the registered problems in the HSE-system is not taken into this calculation.

A better system for registering improvements should therefore be integrated. Both to make it easy for employees to communicate their improvement suggestions, and to get an accurate KPI on morale (one of the six major results in TPM).

6.3 Lean Tools

In this section I will identify and discuss the Lean tools that are used at the Cast House.

6.3.1 Visual Control

One of the first things you see when walking through the gate at Alcoa Lista is a screen that visualizes the performance of the different departments at Alcoa Lista. In Figure 32 you can see how the screen visualizes the key performance indicators by using red, yellow, and green (traffic lights). At the Cast House more specific KPI and information about their operations is visualized on screens strategical placed in the Cast House. In fact, the first thing you can see when entering the Cast House are such screens (Figure 33 show how the Cast House performance is).

Figure 32 Screens that visualize the performance of the different departments at Alcoa Lista (plant level)

At the Cast House the primary KPI is the number of casts that are made during the day. Another important KPI is the percentage of defects. If the number of defects in the casts made in a day drops below a certain percentage, the color changes to red or yellow. KPIs about safety and the current condition of equipment (maintenance) are also visualized on these screens.


Figure 33 Screen that visualize the performance of the Cast House

Another example of visual control system is the daily management board in the administration-office, depicted in Figure 34. On this board important work tasks are pre-specified and visualized by using red and green, dependent on the work task is finished or not. When the work tasks are done, the cards are flipped so the green side shows.

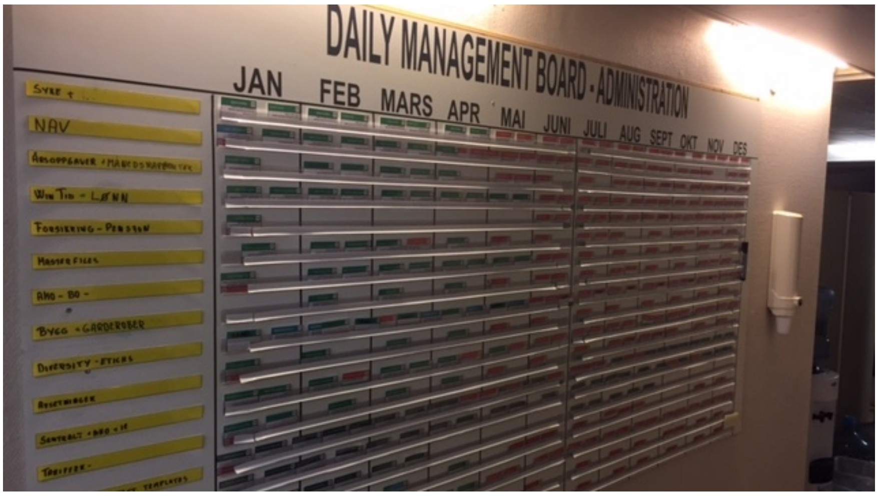


Figure 34 Daily Management Board in the administration

6.3.2 5s

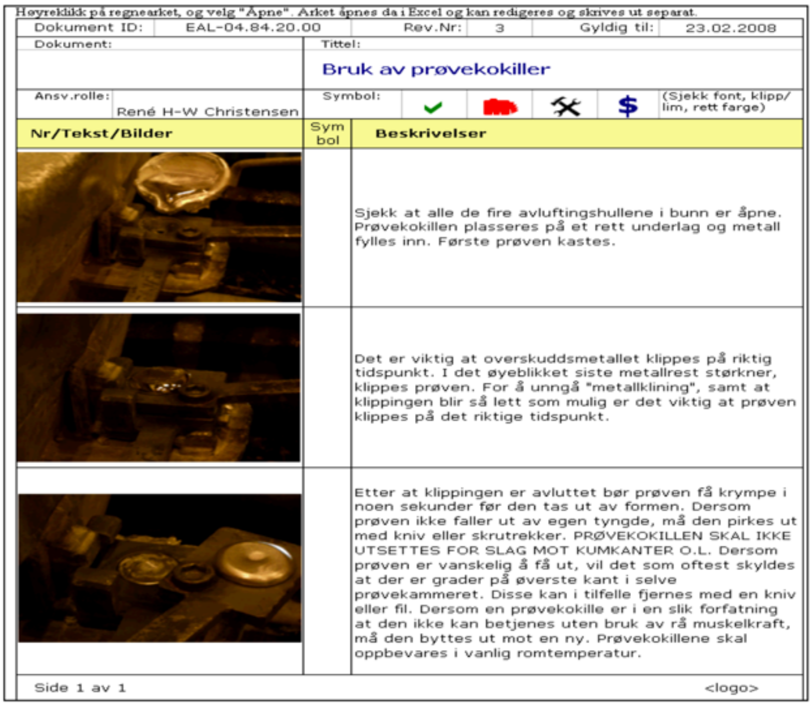
5s is a tool that is widespread at the Cast House. Throughout the entire plant there are visible 5s evaluation forms on the walls. Each form has a structure with a responsible person for evaluating the current area, picture of the standards, and a rating system that grades the performance in red, yellow, and green. Everything from tools to large equipment as trucks has their own designated (standard) place. In Figure 35 you can see how such standards are used, in this case the yellow lines and the letters “M” and “T” indicates the parking place for a truck and a “masi”. In Figure 36 an example of a 5s audit plaque is presented. As one can see a responsible person is assigned to the areas, and the standard is shown thorugh the use of pictures.


Figure 35 Standardization for parking of vehicles

Figure 36 Example of 5s audit plaque

6.3.3 Standardization

Close to all work-processes at the Cast House are standardized. Work is documented in different ways depending on what it concerns. There are Standard Practices (SPs) that specifies the procedures for the execution of work-tasks. There are also simpler works standards that are called "One Point Lessons" that are used to create awareness about important work tasks and are for example posted strategical and visual on walls. An example of a standardized work task document is presented in Figure 37. This show how workers can easily find out how the work tasks they do is done correct, and assure that everyone performs it the same way.



Høyreklikk på regnearket, og velg "Åpne". Arket åpnes da i Excel og kan redigeres og skrives ut separat.

Dokument ID: EAL-04.84.20.00 | Rev.Nr: 3 | Gyldig til: 23.02.2008

Dokument: | Tittel: Bruk av prøvekokiller

Ansv.rolle: René H-W Christensen | Symbol: (Sjekk font, klipp/lim, rett farge)

Nr/Tekst/Bilder	Symbol	Beskrivelser
		Sjekk at alle de fire avluftingshullene i bunn er åpne. Prøvekokillen plasseres på et rett underlag og metall fylles inn. Første prøven kastes.
		Det er viktig at overskuddsmetallet klippes på riktig tidspunkt. I det øyeblikket siste metallrest størkner, klippes prøven. For å unngå "metallklining", samt at klippingen blir så lett som mulig er det viktig at prøven klippes på det riktige tidspunkt.
		Etter at klippingen er avluttet bør prøven få krympe i noen sekunder før den tas ut av formen. Dersom prøven ikke faller ut av egen tyngde, må den pirkes ut med kniv eller skrutrekker. PRØVEKOKILLEN SKAL IKKE UTSETTES FOR SLAG MOT KUMKANTER O.L. Dersom prøven er vanskelig å få ut, vil det som oftest skyldes at der er grader på øverste kant i selve prøvekammeret. Disse kan i tilfelle fjernes med en kniv eller fil. Dersom en prøvekokille er i en slik forfatning at den ikke kan betjenes uten bruk av rå muskelkraft, må den byttes ut mot en ny. Prøvekokillene skal oppbevares i vanlig romtemperatur.

Side 1 av 1 <logo>

Figure 37 Standardized work (Carlsen, ND)

Another example of standardization is the use of processes parameters for each of the billet sizes that are produced at the Cast House. These parameters have proven to give good performance. For example, in the casting process of the billets the temperature, pressure, speed, etc. are standardized. There are however some aspects of the production that are not fully standardized, especially the work-processes downstream from the casting of the billets, this will be discussed further under chapter 6.7 (*Rules in use*).

6.3.4 A3

A3 is a tool that is frequently used in improvement projects at the Cast House, and is the primary tool for scientific problem solving at the Cast House. It is however not used by the workers at the lowest level of the organization. In comparison with this is different from what I experienced at *Fibo*, where workers on all levels can participate in problem solving with A3.

6.3.5 24-hour meetings

The 24-hour meetings at the Cast House is conducted each day (Monday- Sunday) and it is located at the "Gemba", in the middle of the Cast House factory floor. The agenda for these meetings are HSE (what have happened), Human Performance (how to prevent accidents), and the status of the production and maintenance. In the Human Performance part, the representatives from the different processes and departments brings the focus area that they identified on their "overlap meeting". Also, a "wish list" where workers can write what needs to be done (e.g. paint a room) are discussed.

Figure 38 24-hour meeting area

The status of the KPIs at the Cast House is delivered orally, no numbers are written down. The white boards that are presented in Figure 38 are for Human Performance and the "to do list". You can also see the screens that show information about the current situation at the Cast House. The lack of manual writing of KPIs on a white board is obvious compared to Fibo, this may cause information being hidden due to lack of visualization. Also, the fact that OEE is not used to measure the performance of critical equipment can be seen as questionable.

The overlap meetings in between shifts are conducted orally. In these meetings there are some defined points (HSE, Human Performance, production, problem/challenges) that should be discussed. The white-board in use in these meetings are the Human Performance board. No KPIs are visualized at the work-stations, unlike the use of white-boards at Fibo´s workstations.

6.3.6 Kanban

Some types of Kanban signals are used at the Cast House. When the Cast House needs electrolysis metal, a message is sent to "pull" material from the Electrolysis department. When one of the key customers, BAF, needs liquid alloy to their own casting production, a Kanban is sent to the Cast House. In this way "pull" is established both upstream and downstream of the Cast House. In the billet production line kanban is not used between processes. This topic will later be discussed in chapter 6.6 (*The production processes at the Cast House*).

The traditional way of pulling material from upstream processes, by using a physical card that indicates when there is a need for more input material, is also used. This is used to some extent in inventory control.

6.3.7 SMED

SMED has earlier been used to decrease the change-over time in the production of billets. This resulted in a world class performance change-over time. SMED can therefore be considered as a valuable tool for the Cast House. Because there are few production lines at the Cast House, it is not a tool that is necessary to use continuously.

6.3.8 Conclusion

In this section I have identified and discussed the various tools that are or have been in use at the Cast House. The use of Lean tools can be considered as high. Visual control, 5s, Standardization, A3, 24-hour meetings, Kanban, and SMED are all used and embedded into the organization. The Cast House has come a long way concerning the Lean tools that was discussed in this section. The following improvement potential was identified: the people on the lower level of the organization are not directly included in A3 problem solving, and the 24-hour meetings does not use a white-board to visualize and create awareness about KPI in the production.

In the literature study Kata-method and Value Stream Mapping was presented as two important tools in Lean. These tools are not currently used at the Cast House. The fact that the tools *Kata* and *Value Stream Mapping* is not used create an opportunity for improving their operations even more. However, it is important to remember that it not the tools that are used in Lean that is the important part, it is the results they yield. Further discussion and improvement suggestions of these tools will be presented in chapter 7 (*Improvement suggestions*).

6.4 The Eight Pillars of TPM

In this chapter I will map the degree of performance and use of *The Eight Pillars of TPM.* I have structured this section the way that each of the pillars are reviewed. However, *pillar number 5: early management* is not located at the Cast House, it is therefore not a part of this thesis.

6.4.1 Pillar 1: Focused Improvement

Focused Improvement is a pillar that is consequently used in the improvement work at the Cast House. The structure of Focused Improvement follows the structure that was presented based on Nakazato (1994b) in the literature study. Relevant personnel are included in teams, and in this way employees are engaged in improvement work. By using the method that Nakazato (1994b) present, improvement work at the Cast House are executed efficiently. The effects of improvements made in such groups are measured through the Degrees of Implementation-system that was presented under chapter 6.2 (*Relevant projects*).

6.4.2 Pillar 2 & 3: Autonomous Maintenance and Planned Maintenance

There were identified several maintenance tasks that are performed by operators. For example, cleaning of equipment in the casting process, cleaning of photocells on the saws, and changing some equipment when it is wearied out. However, an official implementation of a structured autonomous maintenance program has not found place. Most likely there exist more maintenance tasks that could be attributed to the operators, as structured inspection, cleaning, and lubrication of the equipment they operate on. A structured implementation process could expose such maintenance tasks. This could also lead to both better equipment performance and increased employee engagement due to empowerment of the operators.

Regarding planned maintenance, tasks at the Cast House are planned, unplanned, and condition based, dependent on the equipment. For example, the homogenizing furnace in the billet production machines has an overhaul at least once a year, but if it is indication based on condition monitoring (e.g. oil samples) maintenance is performed. As indicated above, it is possible to attribute more maintenance tasks to the operators, these maintenance tasks should be planned and performed at strategical times according to need.

6.4.3 Pillar 4: Quality maintenance /built-in quality

This is one of the most important principles of ABS that emphasizes the important of built-in tests. Throughout the value stream at the Cast House there are several optimal process conditions that are established. In the casting process an a4 sheet is made for each product, where flow rate, temperatures of the liquid alloy, pressure, velocity of casting process, etc. is specified. Optimal equipment conditions are often specified in "standard procedure", for example by using pictures. Another example of built-in quality is that when the homogenizing furnace heat threats the billets, it is a temperature sensor that ensures that the billets are heat threated for the correct time at the correct temperature.

6.4.4 Pillar 6: Training and education

Approximately 85% of the operators at Alcoa Lista are certified (educated operators in their field), so the level of education of the employees can be considered as high. There is an internal software system for educating employees in the work they perform. However, when it comes to education in Lean and TPM there is room for improvement. By educating the employees and giving them a greater understanding what the concepts represent, it is possible to engage more workers in the continuous improvement work at the Cast House. For example, at Fibo all employees get a half day of education in Lean.

6.4.5 Pillar 7: Administrative and Support Department Activities

The organizational structure at the Cast House is flat and without any shift leaders. In Figure 39 the old organizational structure at the Cast House are depicted. In this structure there were shift leaders on every shift. The shift leaders are today removed from the organizational structure, and all employees are organized into teams, as depicted in Figure 40. By doing this Alcoa managed to cut waste by removing unnecessary leaders and empowering their operators. Another important factor in this topic is the fact that there are only one "emergency mechanic" on job outside normal work hours for the maintenance personnel. Examples of more specific waste removal initiatives in administrative and support department activities are the "Daily Management Board" presented in Figure 34, and the use of 5s in the office landscape.

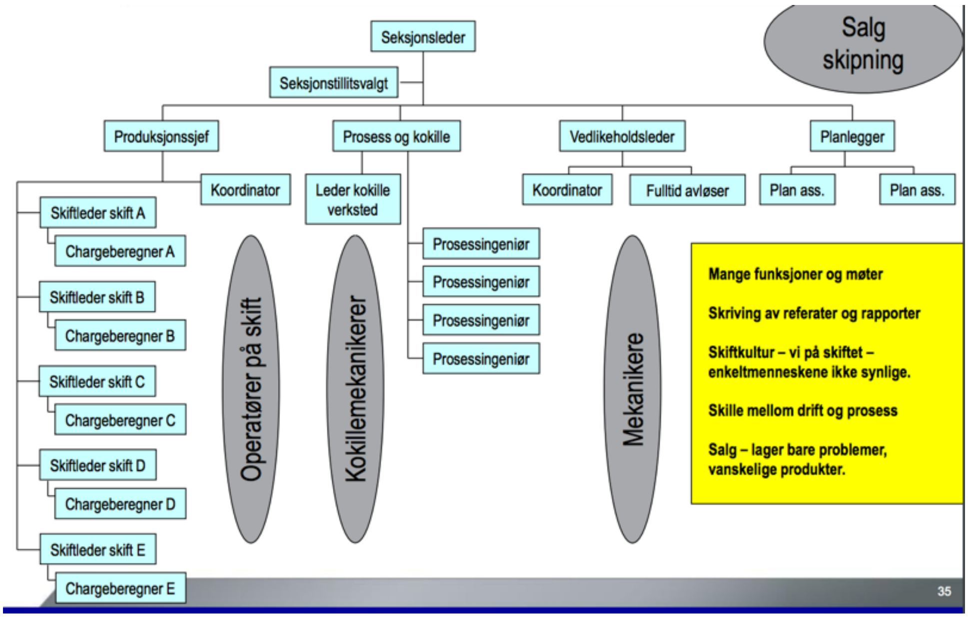


Figure 39 Old organizational structure Cast House (Carlsen, ND)

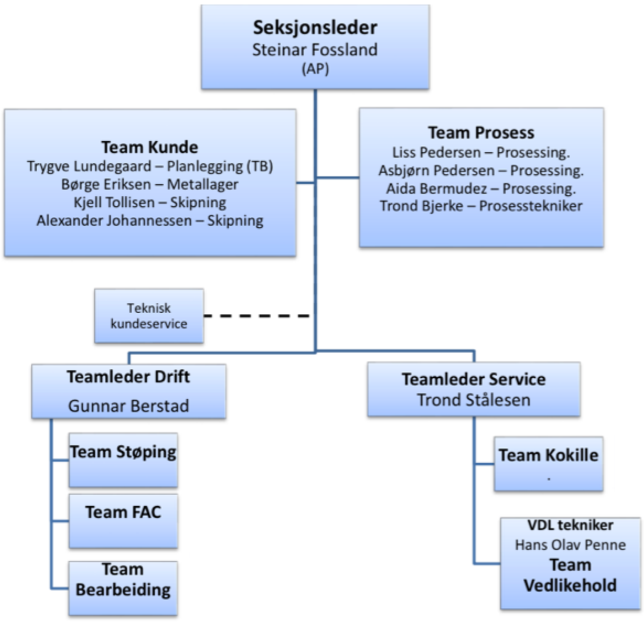


Figure 40 New organizational structure Cast House (Unpublished)

6.4.6 Pillar 8: Safety and environmental management

Safety and environmental management are two things that Alcoa Lista take serious. Alcoa Lista has developed their own *Human Performance* system. In the *2014-2015 sustainable report* Heggland (2016) (a senior leader in Alcoa) attributes the good safety results in Alcoa Norway 2014 to the work that has been done in *Human Performance*.

After spending a lot of time in the Cast House, it is obvious that safety is a subject that they take serious. There are good routines for training of new personnel and effective initiatives for preventing accidents. Worker-on-foot is an example of such an initiative, which is used to prevent collision between humans and vehicles. The fact that they have their own problem solving system for safety improvements (*HSE-deviation system*), can also be considered a positive feature of the status in this pillar.

The Cast House only had 1 registered accidents 2016. This is no doubt an impressive number considering the high energy intensive environment the employees work in. However, it is not good enough. In a Lean and TPM perspective, this number should ideally be 0 (*the zero-accident goal*).

Alcoa Lista is certified ISO 14001 (environmental standard) and the 50001 (Energy standard). They have action plans and KPIs for all the most important environmental challenges. The most important environmental challenges for Alcoa Lista are: energy consumption, handling of process material and emissions. The organization is well below the pollution limits set by the government (Alcoa, 2016).

6.4.7 Conclusion

The employees at the Cast House are empowered through a flat organizational structure and have good knowledge of their equipment. At the Cast House and the overall Plant, there are few defects produced, few breakdowns and few accidents. There is a strong focus on 5s which are the basis for all TPM work.

Improvement potential that was identified in the analysis of the Eight Pillars of TPM is that more maintenance tasks can be assigned to operators through planned maintenance tasks as inspection, lubrication, and cleaning. Also, I believe it would be beneficial to educate the employees in the concept of Lean and TPM, so they get to "know-why" the work in these areas could be beneficial.

6.5 The learning environment

As presented in the literature study, the essence of Lean is problem solving. This should happen on all levels of the organization, which means that the overall goal in a Lean organization is to become a learning organization.

In this section the result from the questionnaire that was presented in chapter 3.4 (*questionnaire on learning environment*) will be analyzed. The Cast House´s organizational learning will be analyzed through the following three categories: Leadership, people, and processes. These categories were chosen based on their ability to cover the entire aspects of learning in an organization. *Leadership* is connected to the ability to create a learning environment, people is a natural category because learning happens between people, and *processes* highlights the way learning happens.

6.5.1 Results of questionnaire on learning and engagement

In the questionnaire personnel were separated into two groups: *operators* and *non-operators*. A total of 14 operators and 6 non-operators participated in the survey. The group referred to as *non-operators*, included *team leaders, a senior manager, engineers,* and *other technical staff.* The reason for using such a broad group of personnel in the questionnaire, is due to the flat organizational structure at the Cast House. The purpose of this questionnaire was to uncover the different learning environment between the factory floor and the rest of personnel. In Figure 41 the result of the questionnaire is illustrated in a radar-chart. In the figure the orange line indicates the results from the *non-operators*, and the blue line corresponds to the results from the *operators.* The numbers in the radar-chart correspond to the following questions:

1. *I have the opportunity to do what I do best*
2. *At work my opinions seem to count*
3. *In the last year, I have had opportunities to grow and develop*
4. *Someone at work encourages my development*
5. *In the last six months, someone gave me feedback*

Figure 41 Results on the questionnaire on learning environment

As presented in chapter 3.4 (*questionnaire on learning environment*), the personnel got the opportunity to express their opinions from *completely disagree* and *completely agree* on every question. This answers gives an indication on the learning environment at the Cast House, through both the operators and non-operators eyes.

As the model illustrates, the group of *non-operators* rated the degree of learning as higher on every question. Based on this, it is possible to state that the non-operators experience a high degree of learning and engagement. On the other hand, the operators rate their learning environment and engagement as lower on all questions. The fact that the group of non-operators score higher on these questions is not a surprise. Most of this group´s daily work concentrates around problem solving, which means that learning also is a natural part of their work. The calculated results that is visualized in Figure 41 can be found in *Appendix C*. Further I will discuss the results of each of the question from the questionnaire.

In question 1, regarding whether the personnel have the opportunity to do what they do best, the results stand out from the rest by being the question which the opinion of the operators and non-operators deviated the least. This can be due the flat organizational structure that empowers the operators in their daily work. In the next question, the opinions of the groups are more consistent with the overall impression. The answers deviate, and the group of non-operators express that their opinions at work do matter. On the other hand, the operators experience that their opinions don't seem to matter.

Question number three, regarding whether the workers *have had opportunities to grow and develop,* is the result that separates the two groups the most. Again, the non-operators are more satisfied than the operators. Question number four and five gives the same impression, that the group of non-operators are more engaged due to learning.

As presented in the framework there was also asked a question concerning the work with A3. This showed that all the six non-operators had participated in problem solving with A3, while only two of the fourteen operators had done so.

6.5.2 Leadership

The lack of learning environment can be attributed to two factors: there is a need for better learning processes at the Cast House, and a master plan that describes the goals of the organization. These goals should be broken down to team and personal goals, to make it possible for all the employees at the Cast House to know how they can contribute to reach the organizations overall goal. This will also ensure that all the employees (operational), and middle management (strategical) are pulling in the same direction.

6.5.3 People

The humans at the Cast House show a strong ownership to their equipment and take pride in their work. I consider them as skilled personnel, that has a valuable control of their own tasks and areas. Also, every employee in the work force know who their customers and suppliers are (internal and external), and wishes to meet their needs.

The employees have a strong culture that is characterized by skepticism and resentment against changes in general. One reason for the strong culture may be the fact that most of the employees have long traditions in the organization (several have more than 40 years' experience). This strong culture seems to make the employees less committed to continuous improvement. There are indications that the younger employees are more open to change and continuous improvement.

Another common feature in the work force is their missing engagement in using the Internal Suggestion System. As mentioned in the literature study, one of the features for ensuring successful learning in organizations is the *right people*. The right people has a right learning mindset. They must have a need to learn new knowledge. In this case, it seems that part of the work force is not interested in learning new things. This can be considered a product of long experience and a strong culture. As highlighted several times in the thesis, problem solving should start at the lowest possible level in a Lean organization. Based on this, I question the staff's ability to ask critical questions and start problem solving. The employees at the Cast House seem to care little about the suggestion systems that is in place. Again, the strong culture and long experience of the employees, that seems happy with the current situation, can be seen as a reason to this learning challenge.

6.5.4 Processes

The result from the questionnaire highlights the need for more employee engagement at the operator level at the Cast House. All the questions show a need for including the operators in learning and development. As discussed in chapter 5 (*Case study of Fibo*), *Fibo* involves their operators actively in scientific problem-solving, and they educate all their employees in the concept of *Lean*. I believe that doing the same at the Cast House could result in higher employee engagement at the operator level. As I mentioned earlier this correlates with the performance of an organization. Involving operators can be done through methods as A3 and the Kata-method, and educating them in the concepts of Lean and TPM-

6.5.5 Conclusion

The questionnaire showed that the employees at the operator level experience a low degree of learning. The fact that both the concept of Lean and TPM are based on learning and empowerment of the employees in the organization, this can be seen as an improvement potential. By including the operators directly in scientific problem solving, which I stated was the essence of Lean in the literature study, higher employee engagement and performance can be achieved. The need for team and personal goals were also identified, this can make it possible for the employees to know how they can help the Cast House reaching their overall goal.

6.6 The production processes at the Cast House

In this section the current production of the two products (billets and liquid metal to BAF), that are produced at the Cast House, are analyzed using Value Stream Mapping. Also, examples of the 18 losses presented in the framework will be identified. A simple simulation of the billet production process, and an OEE analysis on an equipment will be performed to see if there are any improvement potentials.

6.6.1 Value Stream mapping of the Billet production

In Figure 42, the value stream of the billet production at Alcoa Lista is mapped. In this map, the Electrolysis department is described as a separate supplier. This is because the scope of research in this thesis is the Cast House. The transport of liquid "electrolysis metal" from the Electrolysis to the Cast House is done by specially designed vehicles. The operators of these vehicles are employed at the Electrolysis department, and is therefore marked as an external shipment. In Table 8, a description of the symbols that are used in the value stream maps is presented.

At the bottom of the value stream map in Figure 42, the different *average cycle times* of the processes and transportations has been marked, and results in a *lead time* (the time it takes from initiation to completion of a production process) of approximately 9 hours. As described earlier, the liquid electrolysis metal is a part of a *pull-system*, where the *charge-calculator* orders metal when needed. The pull process is illustrated in Figure 42 with an electronical information arrow and a kanban card. The main work task of the charge-calculator is to ensure that the mixing of the different alloys that are produced at the Cast House are according to specifications. The information from the charge-calculator*,* together with the information from the *production control,* is communicated electronical down-stream the value stream.

There are two *rigs* that both consist of two furnaces and a casting mold, these *rigs* are referred to as *rig 5* and *rig 4*. The furnaces are where the aluminum alloys are mixed. When the conditions inside the furnaces (temperature and quality) are correct, the casting process can begin and the liquid alloy is transferred from the furnaces to the casting area through a chute. The furnaces in both *rig 5* and *rig 4* are operated by the same person. The operator of the furnaces approximately use 85% of his time on *rig 5* and 15% on *rig 4.* The total time from the furnaces receives metal from the electrolysis to the casting is done, is approximately 3 hours, as indicated in the value stream map.

The *casting-process* at *rig 5* is operated by two operators, and *rig 4* by one operator. The production on both the *rigs* are batching processes producing approximately 70 billets in each cast, depending on the size. From *rig 4* and *rig 5* the approximately 7 meter long casted billets are lifted by crane (represented by a forklift) from the casting process to magazine A (triangle). This is done by one of the operators at the casting-process. During the transportation, the operator conducts a visual inspection (*glasses*) of the billets to check if there are any significant visible defects on the surface of the billets. If defects are present, the current billet are marked as scrap. This information is further communicated electronical to the operators at the *conti-processes*. It is not the downstream processes that pull the bolts from the casting-process, therefore the flow of the value stream is represented by thick black arrow with white lines inside. These arrows indicate a push relationship, that is, the supplier pushes the product on the customer.

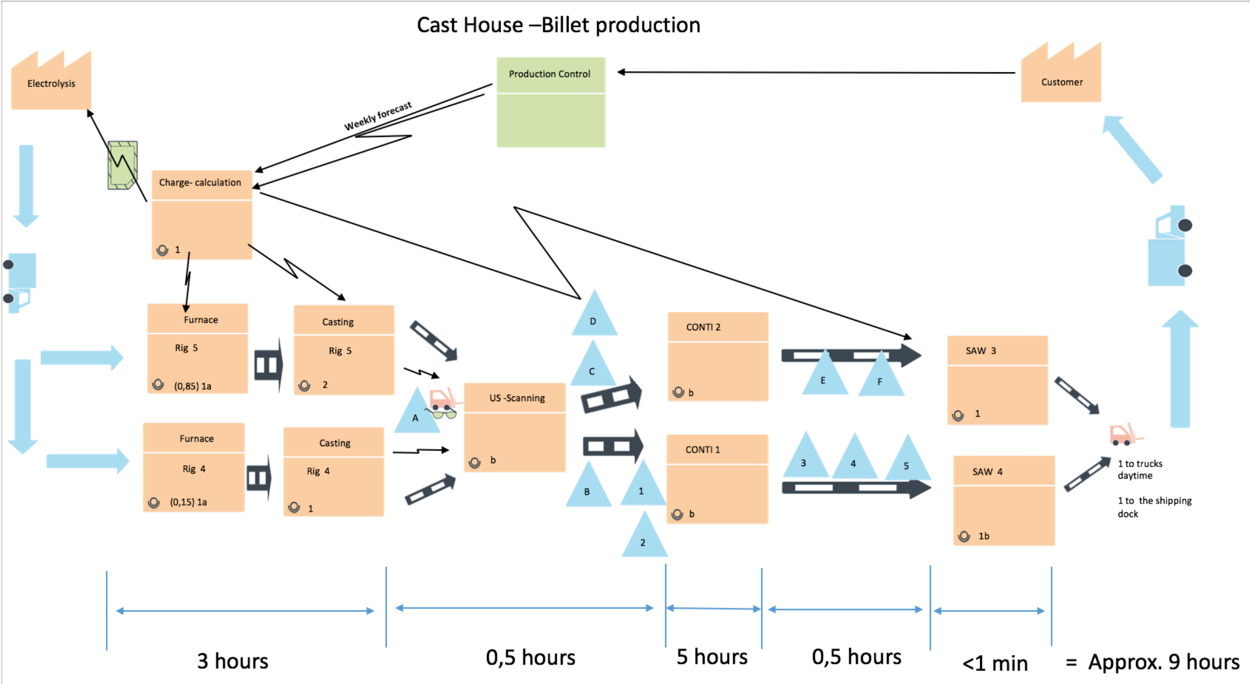
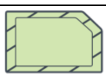
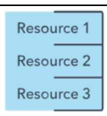


Figure 42 Value Stream Map of the billet production at the Cast House

Table 8 Symbols used in the Value Stream Maps in this thesis (Lucidchart, 2017)

Symbol	Meaning	Symbol	Meaning
	Customer /supplier		Dedicated Process Flow: Fixed Activity within a department (number in lower left corner indicates the number of operators performing this activity.
	Kanban card		
	Electronical communication		Visual inspection: Gather information by observing
	Production control		Internal transport
	Manual Communication		Material push arrow
	Supermarket: a tool used in Kanban, when a certain a amount of resources are removed this trigger the production of more of these resources by the upstream processes		Material pull arrow

In the next process, *Ultra-Sonic Scanning (US-Scanning)*, the billets are checked for internal defects. If the billets have defects these are also marked as "scrap" by one of the operators at the *saws*. These billets, together with the *scrap billets* from the visual inspection, are sent to magazine B. At the conveyers between magazine B and magazine 1 and 2, they are taken out of the value stream and stored until they are reworked. In this way, they are stopped from moving through the entire value stream. This is a good example of how built-in tests are used in the billet production value stream. When the "scrapped" billets are to be reworked, they are transported by forklift from the storage area to the oven.

The billets with no defects are either stored in magazines C and D or at magazines B, 1 and 2, dependent on which of the *conties* the billets should be homogenized in. *Conti* is short for *continuous homogenizing furnace*. This equipment is used to getting the product (billets) according to the customers' specifications through heat treatment. Such a homogenizing process can be considered positive in a Lean perspective, because of the one-piece flow through the furnace, rather than using a batching process in this work.

All the magazines in the horizontal direction are a part of the pathways of the bolts and must be passed, and can in this way be described as FIFO (First-in-First-out inventories). It is, however, possible for the operator (b) to choose from the magazines in the vertical direction, indicated by placing the inventory above each other in Figure 42. These magazines are also FIFO inventories. Which of the *conties* that is used are dependent on the diameter of the billets. It is one of the operators at the *saws* (b) that decides the pathways of the billets, either the upper line (*conti 2*) or the lower line (*conti 1*). The time it takes from a billet is craned on to magazine A until it enters one of the *conties,* is approximately 0,5 hours, due to transportation and performing the ultra-sonic inspection.

It takes approximately 5 hours for a billet to be homogenized and cooled down in the *conties*. After the billets have been homogenized and cooled, they are transported to the saws. As a default, the billets from *conti 1* goes to *saw 4,* and the billets from *conti 2* goes to *saw 3.*

As depicted in Figure 42, the billets from *conti 1* cannot be transferred to *saw 4*. It is, however, possible to transfer billets from magazine F (bolts from *conti 2*) to *saw 3.* After the billets are sawed (top and bottom), they are bundled together. Then these bundles are transported out of the factory by forklifts.

The billets are either placed on a trailer for transportation down to the docks (green line in Figure 45 and Figure 46) or loaded directly onto trucks for transportation by road (blue line). There is no inventory between the sawing process and the transportation of billets, this indicates that all billets are produced for a customer.

On average, there are one person that are responsible for loading trucks that transport billets by road, and one person that drive billets down to the docks for transportation by ship. The transportation of the billets is depicted in Figure 46, where the blue line indicates the loading of the trucks and the green line show the transpiration to the loading docks.

In Figure 43, it is possible to see how the flow is at the floor plant. The green lines from *rig 5* and *rig 4,* indicates where the billets are lifted from the area they were *casted,* to the first magazine (A). From this, the billets go through the *ultra-sonic scanner (US-scanning),* then the billets either goes to *magazine C and D* (blue arrow), or *B, 1, and 2* (red line). The billets are transported along a conveyor to *conti 2,* and then placed on the magazine 3, 4, 5 prior to *saw 4.* The billets from *conti 2* along a conveyor to *magazine E and F*. Then the billets are cut and bundled together by *saw 3* (blue line) and *saw 4* (red line).

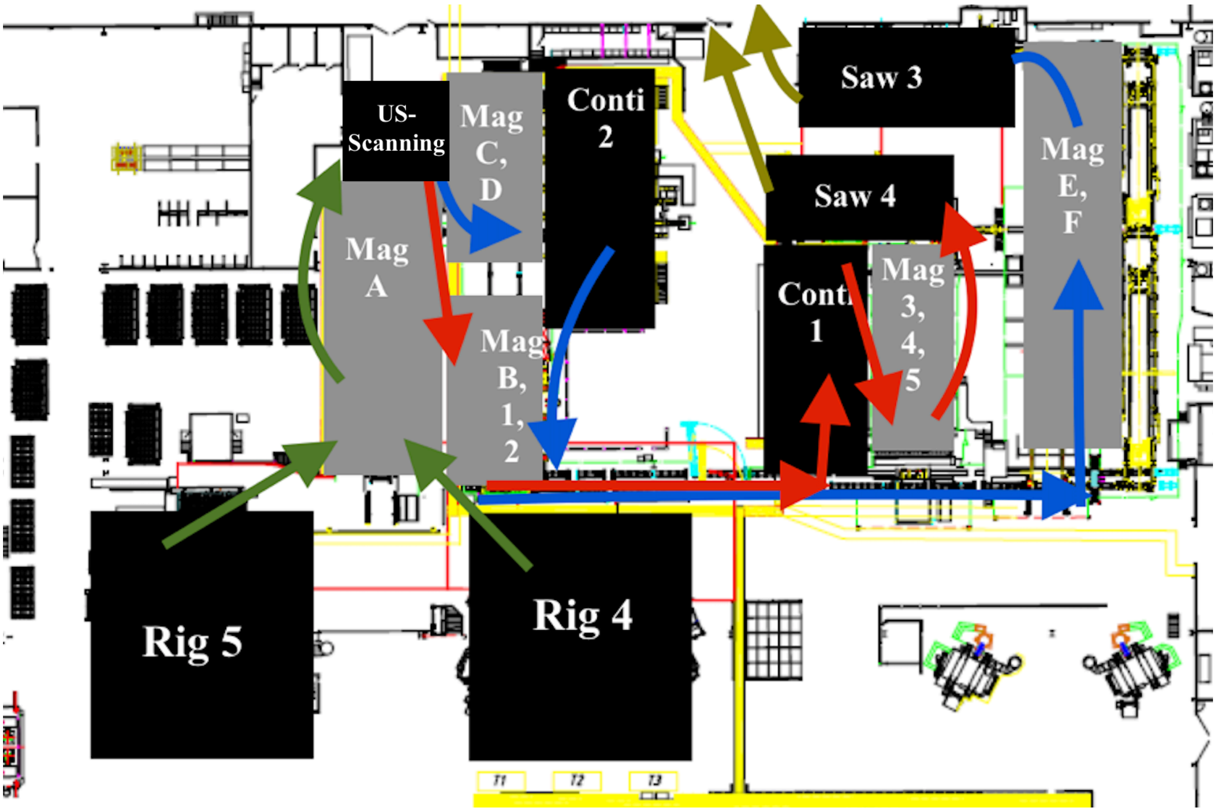


Figure 43 Flow of the billet production

6.6.2 Value stream mapping of the production of liquid alloy to Benteler Automotive Farsund

The second product that the Cast House at Alcoa Lista produces is liquid aluminum alloys to their neighbor plant, Benteler Automotive Farsund (BAF). The Value Stream for the liquid aluminum to BAF is depicted in Figure 44. The *charge-calculator*, *production control*, pull system from the electrolysis, and the transport of electrolysis are the same as in the billet production value stream. The difference is in the kanban-system that is between BAF and Alcoa. Here the operator at the furnace get electronical information about when the liquid metal is needed. The operator then transports the metal by forklift to BAF. As depicted in Figure 46(red line) the transportation distance between Alcoa Lista and BAF are minimal. This is in a Lean and TPM perspective a positive feature that affects the lead-time (the time it takes from when customer orders a product until it is delivered). In fact, there are no push arrows in this value stream map. This is a nearly perfect JIT production system. The system predicts the need of their customer, and in this way supply them with right amount of liquid alloy at the correct time, without even ordering it themselves.

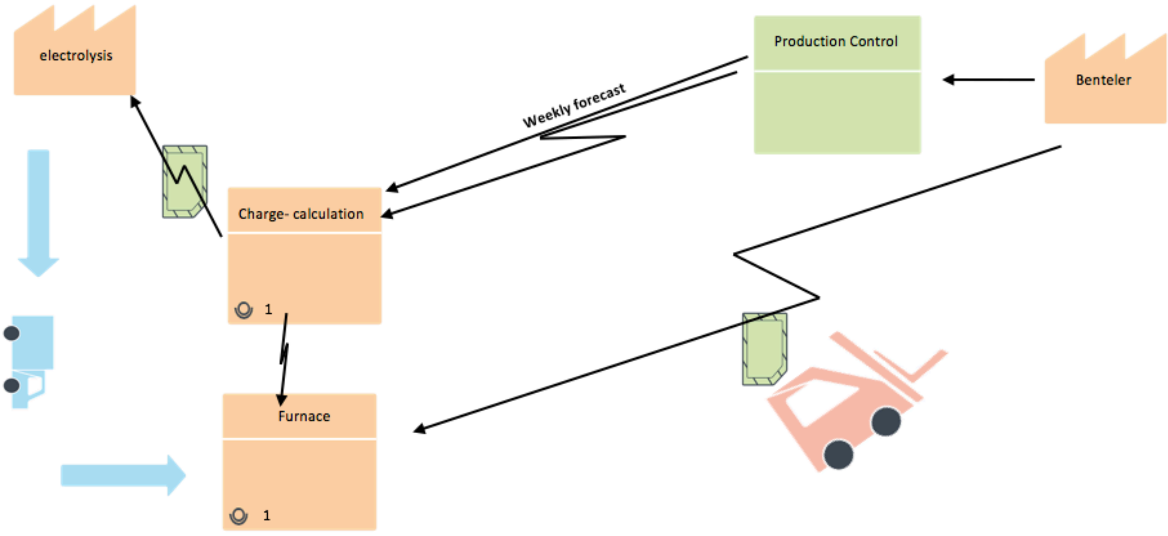


Figure 44 Liquid alloys to BAF

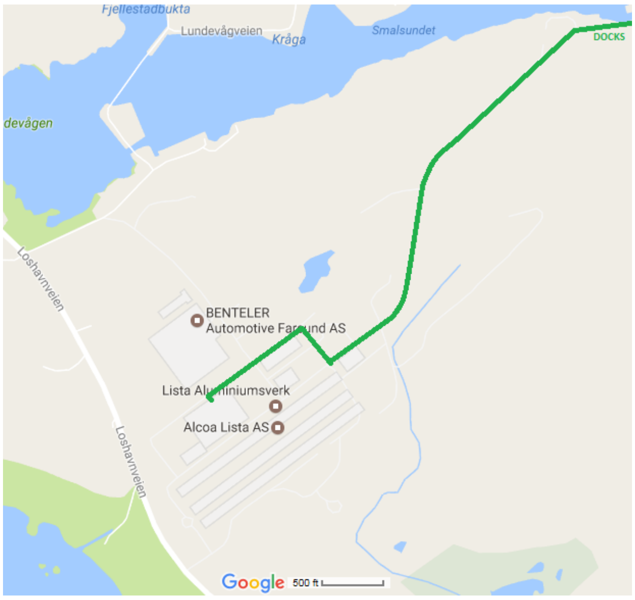


Figure 45 Transportation to docks (Google, 2017)

Figure 46 Transportation of products (Google, 2017)

6.6.3 Identification of losses along the Value Streams

In this section, the losses concerning *human efficiency, resources efficiency* and the *Lean wastes* from chapter 3 (*basis for analytical framework*), that combined the losses from TPM and Lean, are presented.

Through observations at the factory-floor, examples of losses at the Cast House were identified. The purpose of the loss identification is to give an illustration of how the concept of Lean and TPM can be combined to find possible improvements at the Cast House. The losses that are presented in the tables in this section does not include the seven major equipment losses that affect OEE. These eight equipment losses will be discussed in section 6.6.5.

Human losses

In Table 9, examples of identified losses that affect human efficiency is listed. The first of the losses in the table, *management losses (number 9),* can be said to be low. Because the Cast House has a flat organizational structure, most of the daily work at the shop floor is not dependent on managers. However, as I will discuss further later in the loss identification, there are a lot of waiting concerning materials at the sawing operations.

Under *motion losses (number 10),* several wasteful motions made by humans at the shop floor were identified. That is, only *saw 4* has an automatic bundling system, which causes the operator to have to put “runners” under the bundles manually on *saw 3*. When loading the bundles of billets, it is sometimes difficult to know where the middle is, causing wasteful motions to happen. This is because the driver of the forklift has to try several times to find the correct spot in the truck. The fact that there are a control rooms for each of the saws, causes the operators to perform wasteful motion in-between them.

Under *line organization (number 11)* there are listed two losses. The operators at the saws sometimes have to wait for the finished billets to be removed. Also, waiting on material from the upstream activities are common. This is attributed to *line organization,* because it comes from an uneven distribution of resources along the value stream. This loss is considered as one of the losses with greatest improvement potential.

Logistic losses (number 12) contains three identified losses. The first is, a part of the production line is not automated (pulling material from magazine B to 1 and 2). The second, is that the loading position of the trucks could be closer to the exit of the Cast House. This causes the billets to have to be transported a long distance that do not add value. The last identified logistic loss at the Cast House, is the fact that the mold maintenance shop is located at the opposite side of the Cast House. It is possible to move it closer to where the casting happens. Under *measurement and adjustment,* there is not listed any examples because this seems to be a category with little losses for the Cast House.

Table 9 Human efficiency losses

The Human Losses	
9. Management Losses	Waiting for instructions; materials; tools, etc.
10. Motion Losses	Only one of the saws has a fully automatic bundling system. This causes the operator to perform wasteful motions.
	Loading of billets onto trailers. It is sometimes difficult to know where the middle of the bundle of billets are. Therefore it may demand several tries before bundle of billets are positioned correctly.
	There are two control rooms for the two saws. A lot of motion could be avoided by controlling both of the saws from a single control room.
11. Line Organization Losses	When the billets are cut to specification, they are bundled together to the customer's specification. If these bundles aren't removed within a certain time, it causes the saw to have to stop its operation and wait until the bundle is unloaded.
	Wait for billets to saw (sawing operation).
12. Logistics Losses	No automatic feeding from magazine B to 1 and 2.
	Loading position for the trucks could be closer to the exit of the Cast House. (Figure 46)
	Suboptimal location of the workshop to the mold service, which leads to unnecessary *transport* of equipment across the Cast House.
13. Measurement and Adjustment	Little losses concerning measurement and adjustment.

Resource losses

There are three different types of resource losses: *yield, energy,* and *consumable losses.* Under *yield losses (number 14)* the following loss was identified: it was indicated by a manager that there exists a possibility of recycling waste material internally to a higher degree. Under *energy loss (number 15),* two different losses were identified: the delivery of liquid metal to BAF causes the Cast House to be "stand-by" to respond to requests. The other *energy loss* is the fact that the billets are homogenized before the top and bottom is cut off, causing these parts to be unnecessary homogenized. Under *consumable losses (number 16),* examples of consumables in the production processes are listed in Table 10.

Table 10 Resource efficiency consumption losses

The Resource Consumption Losses	
14. Yield Loss	Waste material could be recycled internally. Today most waste material is shipped away for recycling;
15. Energy Loss	The ordering process between BAF and the Cast House, leads to inefficient use of energy.
	The sawing of top and bottom of the billets happens after the billets are homogenized. This causes the top and bottom to be homogenized, leading to inefficient use of energy.
16. Consumable Loss	Expensive work cloths due to the high-risk nature of the Cast House´s operations (hot liquid metal)
	Repair and construction of molds for the casting process
	Oil for casting process

Other (customer) value losses

These losses represent two of the seven losses that was not sufficiently included in the 16 losses of Venkatesh (2015), as presented in chapter 3 (*basis for analytical framework*). *Muda of overproduction (number 17)* can be said to be close to optimum, because all products are produced to customers. That is, there are no stock products at the Cast House. The second loss in this category, is *muda of inventory (number 18).* In Figure 42, that shows the value stream of the billet production, one can see that there is a lot of inventory (indicated with triangles) in-between processes. *Muda of inventory* is considered, together with *line organization*, as the loss with greatest improvement potential in the production processes at the Cast House

Table 11 Lean wastes not included in the 16 TPM losses

Lean wastes not included in the 16 TPM losses	
17. "Muda of Overproduction"	Close to optimum, all products are produced to customers.
18. *"Muda of Inventory"*	High amount of inventory between the processes (magazines).

6.6.4 Agent based modeling of the billet production

To further test, visualize, and identify possible improvement suggestions concerning *line organization losses (number 11)* in the billet production, *Anylogic* was used. *Anylogic* is an agent based modelling simulation software. By using parameters from the production, as size of magazines, cycle times and production rates, it was possible to get an indication of the utilization of the equipment.

In the simulation of the production line a common product (billet size) was chosen to simulate the production of billets. Two experiments of the flow were conducted: (1) the flow of the current situation and (2) billet production by using only one of the saws (saw 3). Both the simulation experiments where performed over the same time spectrum. The result of this simulation is used to visualize the improvement potential.

A high production rate and the production of the most common product (billet size) was used in the simulation. The production rate (number of billets casted during a day) was added to the source (*sourcestøp*). Then the billets was batched *(KUM)* to simulate the batching nature of the production, and then they were unbatched so the "agents" (billets) could flow freely through the system, one by one.

The magazines (A, B, C, D, E, F, 3, 4, 5) was gathered as one FIFO-que where it was appropriate, and the corresponding capacity of these magazines was specified. In the following equipment: *conti 1(cycletimeConti1* and *conti1), conti (cycletimeConti2* and *conti2), saw 3 (s3),* and *saw 4 (s4),* average cycle times where specified. Also, the capacity of the *conties* where specified. This was done by using a FIFO- que as well, thereby replicating the continuous homogenizing process (which is a FIFO que that moves in a specified speed continuously through a heated container). The buttons that are depicted in Figure 47 was used to block the corresponding pathways for the billets

First, a simulation (Figure 48) was conducted of the current situation of the billet production. This showed how both *saw 3* and *saw 4* has a low utilization (the yellow bars in Figure 47). The throughput of billets was 2070 at *saw 3* and 840 at *saw 4*, a total of 2910 billets went through the system.

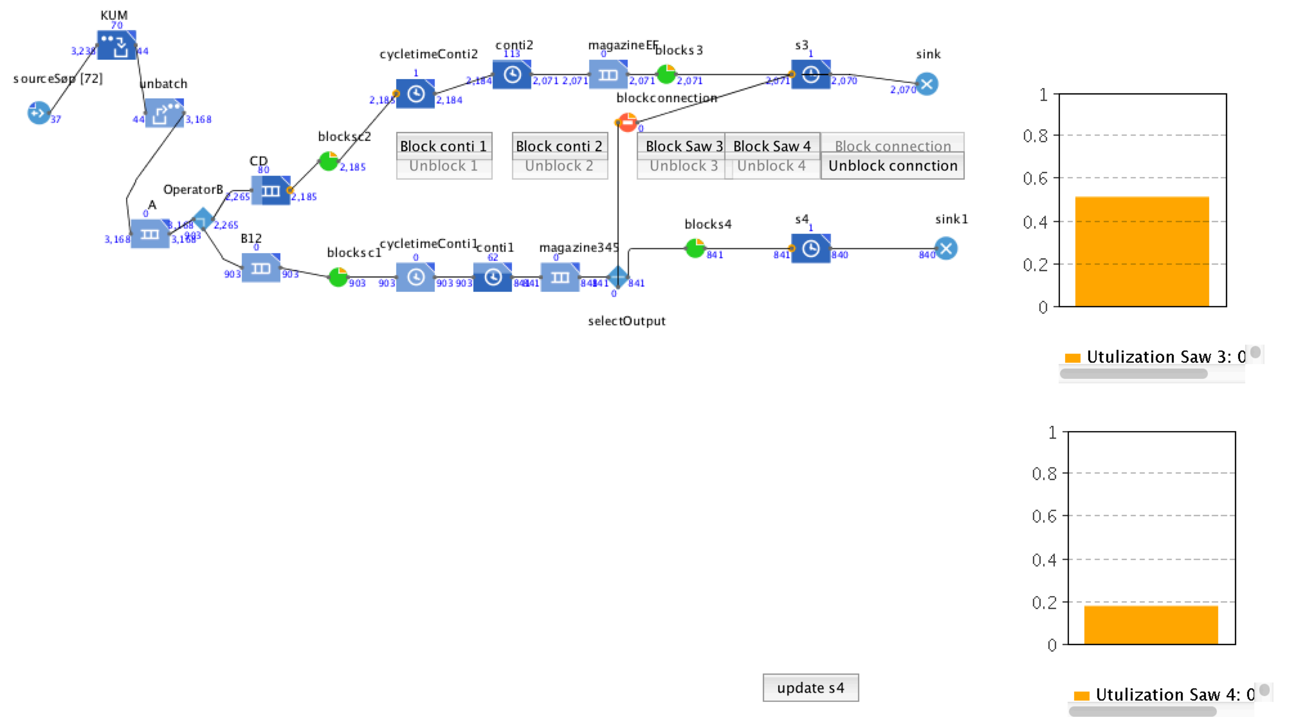


Figure 47 Current situation of the billet production

Then the connection between *magazine 345* and *saw 3* was opened, and *saw 4* was shut down by blocking the connection prior to it, making all the billets flow through *saw 3*. The simulation was performed over the same time spectrum as the simulation in Figure 47 (current sate). The result was an increased utilization of *saw 3*, while the total through put was close to the same (2844).

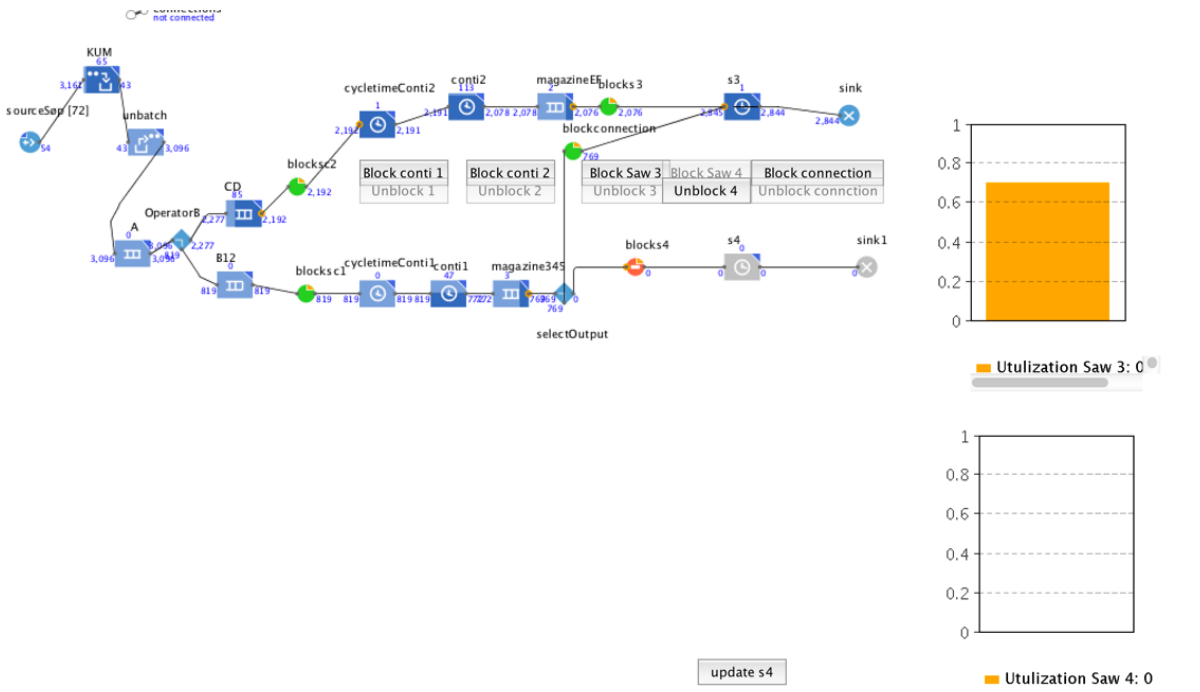


Figure 48 billet production with only one saw operating

These simulation experiments indicate an improvement potential in the *line organization (loss number 11)*. Through this analysis, the improvement potential seems to be connected to the sawing operations in the billet production line. This finding will be used next sections.

6.6.5 Identification of the equipment losses for important equipment in the billet production

The losses in this section concerns the equipment that is used at the Cast House. As was done in the last identification table of the analysis, there was identified possible losses. In the loss identification, it was separated between the following equipment: *casting* (*rig 4* and *5*), *conties* (*1* and *2*), and *saws* (*3* and *4*). This was deemed to be the most critical value adding equipment in the billet production.

Table 12 Equipment efficiency losses

Equipment Losses	Casting	Conti	Saw
1. Breakdown losses	Scrap cast (the cast flows out in the bottom of the "casting pit", causes large downtime losses). Other breakdowns.	Breakdowns.	Breakdowns.
2. Setup and Adjustment Losses	Change of molds for new billet size; Cleaning of equipment (e.g. remove metal for molds)	When a product (billet) needs to be homogenized at a specific temperature, the *conties* needs to be emptied; Shortage of materials: no billets to homogenizing.	Specify product specifications for stickers (computerized); Change stamp for product specifications (must be done manual); Shortage of material (no billets in the magazines prior to the saws, long stops typical more than 15 minutes).
3. Cutting Tool Replacement Losses	No cutting tool	No cutting tool	Change of cutting tool.
4. Startup Losses	Shift change.	Shift change; start after lunch.	Shift change; start after lunch.
5. Minor Stops and Idling Losses	Not starting the casting process at the earliest opportunity.	Not identified	Billets jammed in saw; The position of the stamp that marks the billets become uncalibrated, and needs to be placed in the correct position.
6. Speed Losses	NOT IDENTIFIED	Not identified (continuous speed)	Slow speed due to low work load.
7. Quality Defect and Rework Losses *"Muda of defects"*	Bad cast (the casting produces wreck).	NOT IDENTIFIED	Billets are sawed at wrong length.
8. Scheduled Downtime Losses	Lubrication; Other maintenance tasks.	Lubrication; Other maintenance tasks.	Lubrication; Other maintenance tasks.

As Table 12 indicates, there are several aspects that can be considered as improvement possibilities. However, based on observation at the factory-floor, communication with employees at the Cast House, and the agent based simulation, it was natural to assume that the equipment that could benefit the most of loss removal was the saws, more specific *saw 3*. Therefore this equipment was chosen as a case for developing an OEE measure and conducting an OEE analysis.

In Figure 49 the sawing process is presented through a flow-chart. The saw includes 3 different main work processes: (1) Set up, (2) Sawing, and (3) Bundling. The first process is only executed when there is a different product that enters *saw 3* (e.g new customer, size, alloy). The next work-process is the sawing operation. If there are billets in the magazine before *saw 3,* this billet is pulled from the magazine and the billet is cut at the top and bottom, according to the customer's specification. If there are a material shortage, the operator has to shut down the operation and wait for material. In this way, the availability decrease, due to *set-up and adjustment losses (loss number 2).*

When the appropriate number of billets are sawed, runners are placed manual in pre-specified locations, and the billets are bundled together. If the bundle isn't removed from the offloading area of the saw within a specific time, the sawing process has to stop and wait for the truck driver to unload them. This affect the loss category *minor stops and idling (loss number 5)*, as specified in Table 12.

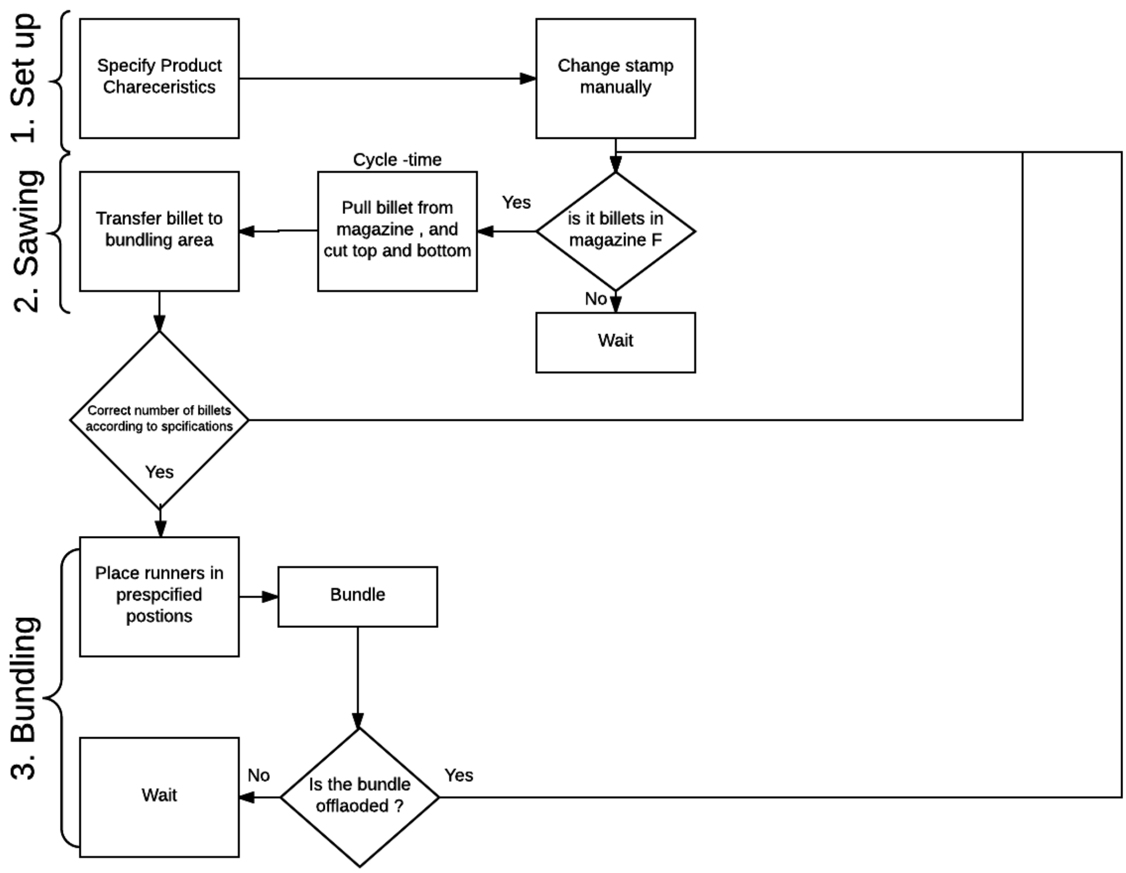


Figure 49 Saw 3 process map

6.6.6 Constructing and calculating OEE

In this section I will construct an OEE to measure the efficiency of *saw 3.* The biggest challenges with the construction of an OEE for *saw 3,* was to get accurate data for calculating the OEE. There are a lot of data from the PLCs stored in the PLC software that is used to handle such type of data at the Cast House. However, not all the data is structured in a way that it is possible to use (e.g. data is logged, but it is not known what kind of signal it shows).

A goal was set for the development of the OEE measure: it should be easy to use, and it should accurately show the Overall Equipment Efficiency. From the data that was structured, it was identified a way to present an OEE that was easy to use. As described in the literature study OEE is calculated by multiplying the following factors: *Availability*, *Performance*, and *Quality*. These factors were identified in the following way:

Availability

In the PLC-software, it was possible to identify the speed of the cutting blade. As long as the saw was turned on, the speed of the cutting blade is constant. Therefore the average cutting speed divided by the normal cutting speed of the saw, gives the same result as operating time divided by the loading time of the saw, as indicated in Equation 2. This data could be extracted from the PLC-software by reading a graph.

Equation 2 Availability

$$Availability = \frac{operating\ time}{laoding\ time} = \frac{average\ cutting\ speed}{constant\ cutting\ speed} = \%$$

Performance

The availability factor does not take into account the minor stops and idling where the operator does not turn of the sawing blade. However, this is measured in the performance factor. To calculate the performance efficiency three inputs are needed:

1. *Theoretical cycle time*
2. *Processed amount*
3. *Operating time*

The *theoretical cycle time* was identified for the most common billet sizes, by counting the number of cuts in a continuous cutting sequence. Then this number was divided by the time (in minutes) it took to perform these cuts. The average time between two cuts indicate the theoretical cycle time it takes from one billet enters the saw until the next enters the saw.

The bundling was not considered in this cycle time. The reason is that the bundling should ideally not affect the sawing operation, since it is possible to finish the bundling and offloading without stopping the continuous sawing operation (therefore the sawing operation is marked with cycle time in Figure 49).

The second input that was needed to calculate the performance efficiency, is the number of billets that is produced. Since there are continuously produced different sizes of billets, it is necessary to identify the number of each size that was cut. This was done by counting the number of cuts made on each billet sizes. The PLC software provides the total number of cuts performed by the saw in the time spectrum. Because the billet casting process is a batching process, it was easy to identify the number of cuts of the various billet sizes that entered the saw.

By subtracting the number and divide them by two (two cuts per billet) the number of billets in the specific billet size could be identified. This had to be done for each of the sizes (approximately 2- 4 different sizes a day). Then the number of billets of each size was multiplied with the corresponding ideal cycle time, and then added together. The sum of this number was then divided on the total number of billets that day. In this way, an average weighted cycle time for the day was established.

Equation 3 Weighted average cycle time

$$Weighted\ avearge\ cycle\ time = \frac{\sum_{i=billet\ size\ 1}^{n} (cycle\ time\ current\ billet) * (number\ of\ current\ billets)}{total\ number\ of\ billets} = minutes$$

Then the average weighted cycle time could be used to calculate the performance efficiency:

Equation 4 Performance

$$Performance\ efficiency = \frac{(Weighted\ average\ cycle\ time) * (total\ number\ of\ billets)}{Operating\ time} = \%$$

Quality
The loss that affect the quality (see Table 12) is *quality defects and rework (loss number7),* however the number of billets that are cut at the wrong length at the saw are currently not counted. This error almost never happens, therefore it was natural to assume that the number is 0 in my later calculations. An improvement suggestion is therefore to start counting number of billets cut at the wrong length in the sawing operation, to get an even more accurate OEE.

Equation 5 Quality

$$Quality = \frac{Number\ of\ billets\ cut\ at\ the\ wrong\ length}{Total\ number\ of\ billets} = \%$$

In Figure 50 shows what I have described. The yellow lines indicate when the saw is turned off, thereby affecting the *Availability* of the saws. The purple line show examples of losses that affect the performance. That is, the saw is still turned on, however no cuts are made. In this figure one can also see how the cuts made by the saw is counted (turquoise), when the saw makes a cut (green), and the size of the billets (black line).

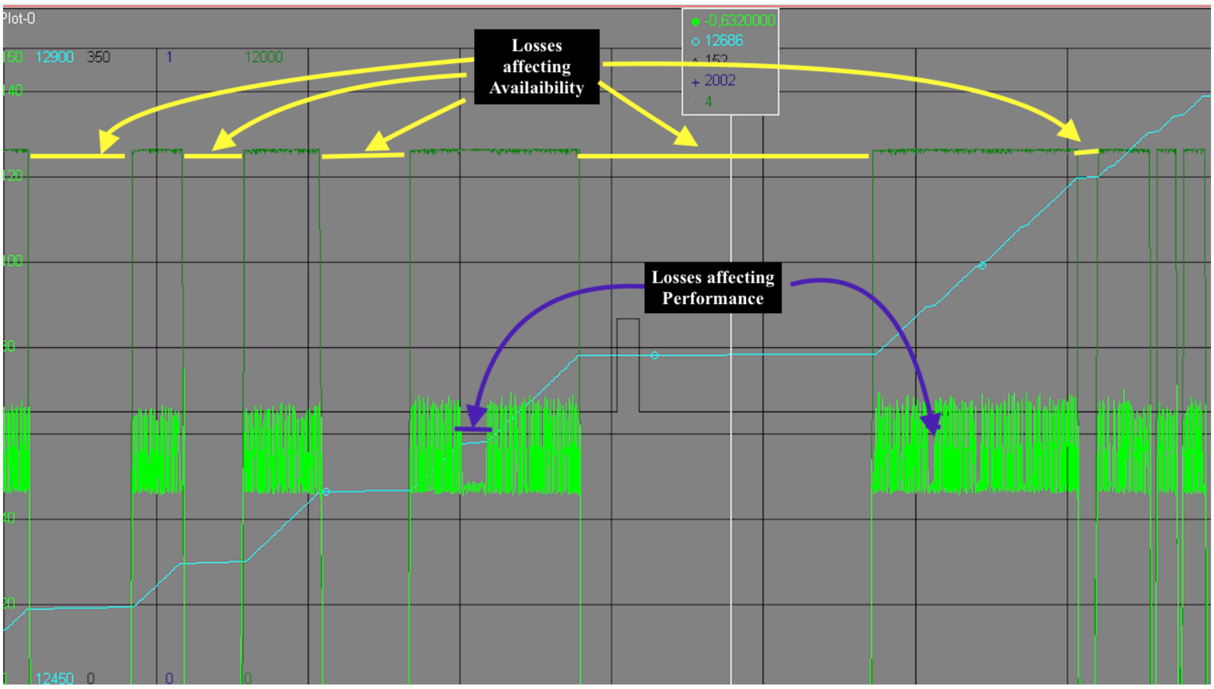


Figure 50 PLC software showing Availability and Performance

In Figure 51, the losses that was identified for the saws, are connected with the OEE factors it effects. Mark that *"material shortage"* is mentioned both in *set-up and adjustment (loss number 2)* and in *idling and minor stoppage (loss number 4).* This is because long material shortages will affect the availability (the saw is shut down) and under small material shortages the saw is not necessary turned off. This show how ingenious this performance indicator is, because it is not possible to "trick it" by letting the sawing blade run without cutting any billets.

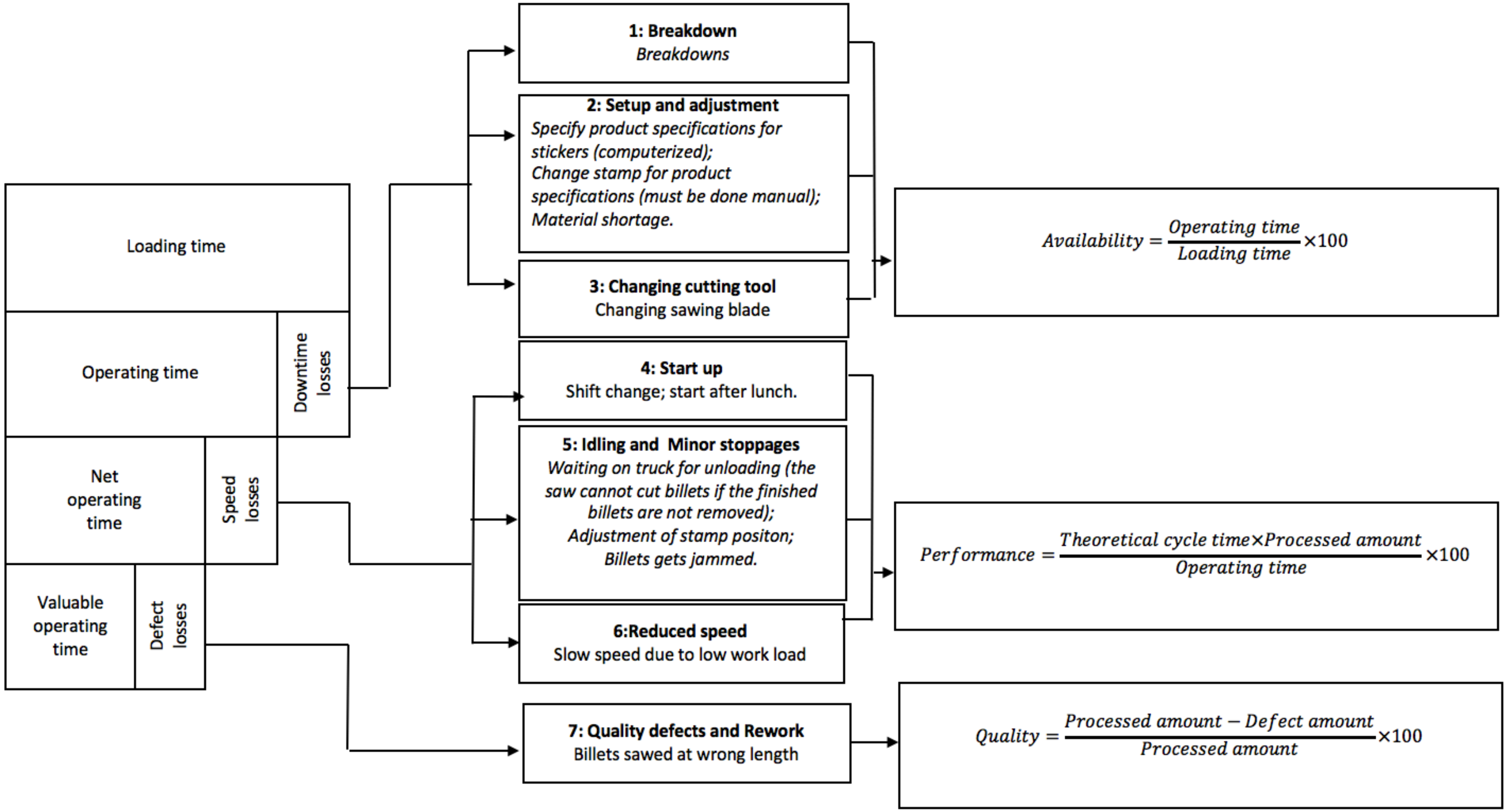


Figure 51 Connection between losses of the saws and OEE

In *Appendix B* an example of how the calculation of the OEE for one day was conducted. An OEE analysis was performed for 4 days of normal production on *saw 3*. This gave the result presented in Table 13:

Table 13 OEE calculation of saw 3

Day	Availability	Performance	Quality	OEE
1	0,76	0,46	1	0,35
2	0,65	0,48	1	0,31
3	0,69	0,44	1	0,30
4	0,66	0,56	1	0,37
Average	0,69	0,49	1	0,33

The results in Table 13 show that there is an under-utilization at *saw 3.* Considering that the production was under normal production conditions, the results of the availability, performance, and OEE are much lower compared to the world class results presented by Nakajima (1988): availability greater than 90 %, performance efficiency greater than 95 %, and OEE greater than 85 %.

6.6.7 Conclusion

In the billet production value stream, there are many positive features. The material is pulled from their upstream supplier (the electrolysis department) by using an electronical kanban card. The inventories between processes are FIFO based, and there exists built in tests that ensure that the defects do not need to go through the entire value stream. The fact that continuous homogenizing furnaces are used, is also a positive feature of this value stream, because this leads to one-piece flow, rather than a batching process. Also, the fact that all products are produced to customers, can be considered a positive feature, as there exist no stock products between the Cast House and their customers.

The liquid alloy production is closed to perfect in a Lean perspective. The system predicts the need of their customer and supply them Just-In-Time through a kanban-system. Also, the fact that there are no inventories, must be said to be a positive feature of this production process.

Along the value stream of the billet production, several losses were identified, however the two losses with the greatest improvement potential were deemed to be *line organization losses* and *muda of inventory.* Based on this, one of the saws was selected to develop an OEE-calculation method, and perform an OEE-analysis.

The result that is shown in Table 13, shows the same as the agent based modelling analysis. That is, there are improvement potential concerning the *line organization losses* concerning the *sawing operations*. The result from the OEE calculation also shows how the performance factor is the lowest. In Figure 51, the losses connected to the *performance factor* is *start up (number 4), idling and minor stoppages (number 5)*, and *reduced speed (number 6)*. This indicates what I have presented earlier, that there exist improvement possibilities in *line organization (number 11)* and *muda of inventory (number 18)*. This means there are an overcapacity at the saws that leads to material shortage. It is also room for improvement, because there is too much room for inventory. This makes it easy not to perform 100 %, because of the flexibility the inventory provides.

6.7 Rules-in-use

Until now, the theory behind ABS, identification of the projects, Lean tools, and the eight pillars of TPM has been presented. The learning environment has been discussed and the production processes at the Cast House has been presented and analyzed.

Now I will discuss if the *rules-in-use*, that optimal should be embedded in the core of the Cast House just as it is in Toyota, is in place. I will therefore in this section analyze and discuss the Cast House´s operations in the light of the four rules.

6.7.1 Rule 1: Activity

Activity is in ABS further broken down into: *content, sequence, timing, location,* and *outcome.* Using standardized work (as described under *Lean tools*), the employees at the Cast House have clear roles and work tasks.

An example of such standardized actives is the planned cleaning of an equipment in the Casting Process. The tasks are performed by two operators 3 times a week (*timing*). The *content* is clearly defined and responsibilities are pre-specified to each of the operators (operator 1 and operator 2). The *sequence* of the different work tasks is clearly defined, even the *location* of the operators during the execution is specified. The desired *outcome* of the work task is depicted in the standardized work procedure (in the document).

There are however some aspects of the billet production at the Cast House that is not specified according to the second level of activity. This is the downstream activities from the casting process. In this case the timing of when the billets are pulled from the magazines are decided by the operator marked with a "b" in the value stream map in Figure 42. Because the activity is not pre-specified sufficiently, this causes the different shifts to do this activity differently.

6.7.2 Rule 2: Connections

As shown in the value stream maps most of the connections (communication arrows) in the billet production are direct and simple. For example, the connections in the liquid alloy production (Figure 44) can in a Lean perspective not be much closer to the optimum. The request is binary and so direct that the drivers of the metal has direct contact with the measurement sensors that controls the levels of alloys in their customer´s system. For both production processes (billet production and liquid alloy production) at the Cast House, the request and response of electrolysis metal is direct and binary as Turnbull (2003) state it should be.

An example of direct connections between customers/suppliers in the billet production is the visual inspection of the billets when they are lifted on *magazine A*. The billets are then, if necessary, marked as defects by the crane operator. This information goes directly to the operator (b) of the *conties* that are responsible for controlling the pathways of the billets, and is then scrapped by this person.

There was also identified a connection that is not direct. This regards the response from the operator (b) that controls the *Ultra-sonic scanning (US-scanning) process* that follows directly after the casting process. Casting operators do not immediately get a response about how the quality of the billets they have produced. The casting operator cannot directly see the results of his work, and in this way he/she cannot know if he/she needs to improve or correct the work he/she is doing. This should be done direct and binary to the operators in the casting process. The information should size, shape and location of defect.

6.7.3 Rule 3: Pathways

As in the first two rules-in-use, the relationship between the Cast House and BAF must be highlighted as an exceptional example of a customer/supplier pair. There is no inventory at all in this process, and the pathways cannot be any simpler. When BAF needs liquid alloy, the driver takes the pre-specified driving-route and delivers the alloy Just-In-Time to the customer. Also in this rule, the liquid alloy production stands out as a true north for JIT production systems.

Another customer/supplier pathway that is direct, is the ordering of electrolysis metal, where there is no inventory in-between the customer (Cast House) and the supplier (Electrolysis). The pathway that the metal take from the electrolysis to the furnaces at the Cast House follows a pre-specified driving route.

The pathways in the billet production are also simple. There are only two possible pathways to choose from. Either through *conti 1* or though *conti 2*. As I stated in the *Lean tools* section under standardization, the pathways downstream from the casting process are not sufficiently pre-specified. The pathway is to some degree pre-specified, that is, as large diameter billets take one pathway and billets of smaller diameter takes the other pathway. However, if several casting batches of the same billet size arrives, it is necessary to also use the other pathway. This causes the performance of the equipment in the pathway to decline. The reason for this is the lack of predefined pathways that ensure a best practice. The result of this is that the billets will not take to optimal pathway every time. Every operator does what he/she think is the best. This may affect the saws´ OEE, because of shortage of material in the magazines before the saws.

As stated several times there are a lot of inventory between the processes in the billet production. However, the inventory between processes are luckily FIFO-ques. This is the preferred countermeasure for adjoining processes that has not achieved one piece flow.

6.7.4 Rule 4: Improvements

So, finally to the most important rule of them all, *Improvements.* In Table 6 Turnbull (2003) states that improvements are based on the four following principles: *Everyone solves problems, capable teachers help, problems are solved where and when they occur,* and *problems are solved by testable hypotheses.*

Under chapter 6.5 (*The learning environment*), some challenges concerning this Rule was identified. Operators are not sufficiently included in the daily continuous improvement work. As I presented in the case study about Fibo, they engage their employees on all levels and include them in problem solving. In this way everyone solves problems, problem are solved where and when they occur, and problems are solved through testable hypotheses (A3, Kata and Improvement sheets). Considering the findings from the literature study, where the true essence of Lean is to create an organization of scientist, this can be considered a major shortcoming. As Spear and Bowen (1999, p.98), who laid the ground work for Alcoa Business System, state: " Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization".

The nearest I came to identifying scientific problem solving on the lowest possible level at the Cast House was the improvement work done by the maintenance personnel, which seems to have embedded a sort of scientific problem solving method. At the beginning of each work-day (they work Monday to Friday, normal hours) they check if the *emergency mechanic* has worked on the equipment that they are responsible for. If the emergency mechanic has worked on their equipment, they ask themselves: how can we prevent this from never happening again (plan), fix the problem (do), let the equipment run (study), and if it happens again they do it again (act). This can be considered as problem as described by both Turnbull (2003) and Spear and Bowen (1999).

6.7.5 Conclusion

In the top three rules (activity, pathways, and connections), the Cast House can be said to perform well and follow the philosophy of Alcoa Business system. *Activities* at the Cast House are for the most pre-specified. The *pathways* of the billet production are simple, but has a need for a higher degree of pre-specification. There is also a need for reducing the amount of inventory in-between adjoining processes in the long run. FIFO ques are suitable, and preferred countermeasures. However, it is not a permanent solution and should in the long run be removed.

There was also identified a *connection* that is not direct. This regards the response of operator "b" that controls the *ultra-sonic scanning process* in the value stream map in Figure 42. The response of operator "b" does not immediately communicate the quality of the billets that the operators in the upstream process "casting" has produced. In this way the operators at the "casting process" cannot directly see the result of the work that he/she have done. In this way, the casting operators do not know when and how to improve.

In both the rules *pathway* and *activity,* the need for higher degree of pre-speciation of the work of operator "b" (the person who controls the pathways in the billet production in Figure 42) was identified. Also, the fact that most problem-solving at the Cast House is not done as ideally described by Turnbull (2003), shows a possible improvement opportunity.

6.8 Rapid Plant Assessment

In this chapter I will use the *RPA rating sheet*, and the description of the different topics that Goodson (2002) described in his article *How to Read a Plant Fast*. By using this tool it is possible to get an indication of the degree of leanness at the plant. Based on the result of this work, it is possible to benchmark the Cast House by comparing the result to the data collected by Goodson (2002) and his students.

The Rapid Plant Assessment method cannot be used alone to rate the degree of leanness of a plant. The tool is too simple – it assesses the leanness based on the surface of a plant. Nevertheless, it indicates possible improvements at the Cast House. By analyzing the results from the *RPA rating sheet,* together with the rest of the analysis in this thesis, I will be able to rate the degree of leaness of the Cast House.

I will now present and discuss the eleven categories for rating *leanness* at the Cast House.

6.8.1 *Category 1:* Customer satisfaction

Goodson (2002) describes how the workers in the best plants know who their customers are, both internal and external. He also highlights that the best plants primarily goal should be to meet customers need. Therefore the best plants should clearly visualize the customer satisfaction. Goodson (2002) further presents the value of welcoming visitors when arriving, with relevant information about the plant

All visitors at Alcoa Lista are welcomed with a video that gives information about plant layout, workforce, customers, and products. Ratings on quality is displayed on screens around the Cast House, however, there are no ratings for customer satisfaction displayed. This can be considered as an improvement potential for the Cast House.

In ABS, there is a strong focus on direct *connections* and *pathways* between the customers and suppliers. This has led to as strong customer focus at the Cast House, where all employees know where their products go. During a breakdown at the plant, an operator expressed his frustration concerning that the customer would not get his product in time. This shows that the employees clearly know their customer and care about them. Based on this I rate the customer satisfaction as *excellent* (9).

6.8.2 *Category 2:* Safety, environment, cleanliness and order

In Category 2, Goodson (2002) marks how important it is that the plant is well organized and clean. The best plants use a visual labeling system the mark tools, inventory, process and flow. Further, the plant should have a good working environment concerning air quality, noise level and lighting. He also highlights the importance of moving product safely and efficiently (Goodson, 2002)

As I have highlighted earlier in this thesis, there is a strong focus on safety at the Cast House. This is reflected when walking around the Cast House. There are several fail safe initiatives that ensure if an error happens, this will not lead to any injuries. For example, in some areas with limited space, it is not allowed for workers to stay when there are moving vehicles inside. Also, other areas where there are high risks (e.g. craning of the billets) are restricted. As I mentioned in chapter 6.4 (*Eight Pillars of TPM*) and in chapter 6.2 (*Relevant projects*), the use of Human Performance and the HSE-deviation system contributes to a sustainable safe environment.

5s is, as discussed, wide-spread at the Cast House. Everything has its own place and are up to the standards that are set, making the cleanliness and order close to perfect. Every equipment has its own place, and are marked with labels. Both expensive and inexpensive parts are treated with respect, because the employees know that they are as necessary to the products as the expensive equipment. This shows several examples where the Cast House fulfills Goodson´s criteria for category 2. Based on this reasoning I rate this category as *best in class (11 points).*

6.8.3 *Category 3:* Visual Management System

Category 3 concentrates on visual control. Goodson (2002) describes clues of good visualization. Such examples are: *use of kanban scheduling, color coded production lines,* and *visual work instructions, quality,* and *productivity charts.* He also states that the current state of the overall operation should be possible to see from a control room or a status board.

Goodson (2002) state that process-industry traditional has strong visual management practices, and the Cast House is no exception. There is a strong focus on visual control at the Cast House. There are, as presented earlier, screens that visualizes the current status at the Cast House. Also, there are painted guidelines for where employees should walk. Up to date operational goals are displayed in computers, which are accessible at the entire plant. At the Cast House, *Kanban scheduling (physical cards), visual work instructions, quality ratings, and productivity* measures are present. However, as I have argued earlier OEE is not used as productivity measure. By using OEE one could display the productivity better. I rate this category as *above average (7),* because the Cast House has strong visual management practices. However, there exists improvement potential. A line driven back to chapter 6.3 (*Lean tools*), shows how the Cast House have improvement potential concerning Visual Control.

6.8.4 *Category 4:* Scheduling system

Goodson (2002) describes how the plants rely on what he calls a “single pacing process”, that is, all upstream activities are controlled based on the demand from the next process. This is what I have referred to as a *pull system (kanban system)* earlier. Goodson (2002) argue that plants using a central scheduling system, nearly always will have some kind of over- or under production.

The production of billets is not scheduled in a “single pacing process”. The billet production is scheduled centrally. A “single pacing process” would in the billet production mean, that the production at the Casting processes would be triggered by the demand from the saws, rather than the upstream processes pushing billets through the production line. This causes the saws to wait for billets from the upstream processes, which have a negative effect on the OEE.

As I have mentioned earlier, there are not an appropriate amount of inventory in-between the processes. However, these inventories are FIFO-based, which is the preferred type of inventory in a production line. On the other hand, the production of liquid alloys to BAF definitively follow this type of “pacing process”, where it is the end customers that decides the actual pacing of the production of the product. There is one production line that follows a single pacing process and another that does not, but uses FIFO-inventories. Based on this I rate the scheduling system at the Cast House as *above average (7)*.

6.8.5 *Category 5:* Use of space, movement of material and product line flow

In Category 5, Goodson (2002) presents the ideal use of space, movement of material, and product line flow. He highlights the importance of efficiently use of space. Ideally, materials should only be moved once and over the shortest possible distance. Tools should be kept as near as possible to the machines, and the production material should ideally be stored at line side, rather than in separate storage areas. The plant should be structured in a continuous product line flow, and not in shops. Free space is considered a valuable commodity in plants, free space can be used in new value adding activities. (Goodson, 2002)

The material in the billet production follows a continuous product line, conveyors and FIFO lines are used in between the processes in the billet production. Therefore it can be said that the materials are only moved once, as Goodson (2002) argues to be the ideal way.

The material that is necessary in the different processes are stored line-side, and not in separate inventories. Most tools and setup equipment are stored in the immediate proximity of where the work is executed. However, there is one problem with the current situation of the equipment. The workshop that maintains the molds for casting, are located at the opposite side of the plant, while the storage of the molds is located by the casting process. This loss was presented in Table 9 (*human efficiency losses*), as an example of *logistic loss (number 12).* A solution to this problem would be to move the maintenance shop closer to the casting process. The fact that there is a large amount of inventories (FIFO ques) in-between the processes at the Cast House, make the amount of free space on the shop-floor limited. As Goodson stated, space is a valuable commodity in any plant. My analysis rates this category as *excellent (9)*. However, there is a possibility of removing inventories that take up unnecessary amount of space.

6.8.6 *Category 6:* Levels of inventories and work in process

According to Goodson (2002), internal operations seldom require high level of inventories. Therefore, the total number of observable parts is a good measure of a plants leanness.

The levels of inventories in the billet production is, as I have stated several times already throughout the thesis, is higher than necessary. There is some need for inventories in-between the processes because of the batching nature of the technology that is used at the Cast House. However, I believe that the amount of inventory in-between processes is unnecessary and hide problems (the water level analogy). As I discussed earlier, this may be one of the reason for the bad performance factor in the OEE. I rate this category as: *above average (7).*

6.8.7 *Category 7:* Teamwork and motivation

Category 7 presents the teamwork and motivation among the employees as important factors in reviewing a plant´s leanness. Goodson (2002) state that in the best plants, there is a consequently focus on the goals for productivity and quality. He also highlights the importance of teamwork, and how this can be spotted by looking for posters or charts that describe problem-solving and employee empowerment procedures.

As I stated in chapter 6.5 (*The learning environment*), the degree of employee engagement at the lower levels is limited, and the strong culture seems to make the employees little open for changes. There are no team goals that ensure that the different teams can pull in the same direction, and no defined performance indicators for the teams. Team-goals could have made it easier for them to know how they work aligned with the company´s overall goal. The fact that there is no visible ongoing problem-solving, show how the work-teams are not involved and engaged in ongoing problem solving. The employees at the lower level do not seem committed to continuous improvement. The overall impression is that the teamwork and motivation at the Cast House is *average (5).*

6.8.8 *Category 8:* Condition and maintenance of equipment

Category 8 brings forth the condition and maintenance of equipment and tools. Goodson (2002) focuses on the importance structured maintenance work. The best plants post their maintenance records. This detailed work can ensure that the workers know more about the equipment and this way plan for preventive maintenance. However, more important, this work sends out a signal to the employees that the management cares about the product and the work the employees do. Based on this, he argues that posting a preventive maintenance timetable will lead to increased moral at the factory floor. Goodson (2002) also states that equipment purchased long ago, but looks new and runs smoothly, indicates that the plant is taking care of its investments.

There is no timetable posted that shows future preventive maintenance tasks at the Cast House. This can be considered as an improvement potential regarding the maintenance at Cast House. This could lead to both an increased moral among the workers, and it could ensure that the workers know as much about the equipment as possible and they can plan for preventive maintenance.

Based on the conversations I had with maintenance personnel, and other key people at the Cast House, the overall maintenance program at the Cast House seems efficient. For example, much of the equipment at the Cast House are old, still working efficiently, which according to Goodson (2002) is a sign of good maintenance practices. Costs of maintenance and downtime at the Cast House is low. Maintenance is considered necessary to be efficient, and not an expense. Based on this, and the lack of a preventive maintenance table that is posted, I rate the condition and maintenance of equipment as *excellent (9)*.

6.8.9 *Category 9:* Management of complexity and variability

In Category 9 Goodson (2002) judges how the organization manages, controls, and reduces the complexity and variability in their operations. An indicator one can use to judge how the plant performs in this category is to observe how much data that is recorded manually. A typical sign of this is a large amount of key boards. If many keyboards can be observed, and data is collected by hand, this may be an indicator of poor complexity and variability handling. Goodson (2002) states, that the workers at the best plants do not need to keep track of parts in the production. Furthermore, the best plants use the same equipment for manufacturing different products.

There are little data that is collected manual and processed manual at the Cast House. Most data collection and processing happens automatically. This is a sign of handling complexity efficiently.

At the Cast House, most of the equipment can be used to produce all the different billets (products) that they produce. The fact that there are only two main production lines at the Cast House, indicates that they handle complexity well. The production line themselves, are also structured in a simple way. A reminder back to chapter 6.7 *(Rules in use),* shows that through ABS the Cast House has developed direct and pre-specified *pathways*.

Goodson (2002) gives an example of a visit to a Toyota plant, where he observed how they handled complexity by using built-in-tests. ABS incorporates the same type of concept, and the Cast House uses such tests to ensure that the workers do their jobs correct. For example, there are a light beam around the saws. If this beam is broken, this automatically shuts down the entire machine. This analysis leads to the rating of the management of complexity and variability to be *excellent (9)* at the Cast House.

6.8.10 *Category 10:* Supply chain integration

According to Goodson (2002), the best plants has a small number of supportive and dedicated suppliers. This leads to low costs and high quality. A plant with a high number of suppliers will most likely not include their suppliers directly in the development process. Goodson (2002) state that the best plants pull the material from their suppliers.

The fact that the Cast House is a part of a bigger plant, makes this category difficult to review. However, as I have described the electrolysis department as an external supplier of the Cast House, and this is the main supplier of the Cast House, I rate the degree of supply chain integration as *excellent (9).* This is based on the fact that material is pulled to the Cast House through the electronical kanban system.

6.8.11 *Category 11:* Commitment to quality

Goodson (2002) state that the plants are always striving to improve their quality and productivity. He claims that this is easy spot in a plant, since workers that are proud of their quality program gives the program a name and that they visualize their vision. Goodson (2002) highlights the importance both short- and long-term goals for the plant and teams. Again, as in Category 3, he underlines the importance of visualizing production schedules, work instruction, quality and other KPIs. Goodson (2002) highlights the importance of visual continuous improvement. He refers to an example where Toyota chose their supplier based on the high degree of visualization of continuous improvement.

Quality is as I described under "Quality Maintenance" built into the product, and the Cast House do a good job in doing this. That is, optimal process parameters are established and there is a visual inspection in the billet production that is communicated downstream from the casting. Goodson (2002)state that good plants call attention to scrap rather than hides, the Cast House continuously highlights the scrap on the screens that are spread out over the plant. When the amount of scrap drops below the standard the it is clearly visualized by making the numbers red.

However, I rate the commitment to quality as *average (5).* This is based on the fact that there are no short- or long-time goals for the work teams at the Cast House, and the lack of visible commitment to continuous improvement fact that employees do not seem committed to continuous improvement. Improvement suggestions for increasing the score in this category is to visualize ongoing problem solving (e.g. as Fibo does at screens and on white boards at the plant), and define a vision and team goals.

6.8.12 Conclusion (Results of RPA)

Table 14 show all the 11 categories, and their associated score from the analysis conducted above. With a score of 87 points, out of a maximum score of 121 points, the Cast House places itself among the top three plants in Figure 52.

Table 14 Result from RPA

Categories	**Score**
1. Customer satisfaction	Excellent (9)
2. Safety, environment, cleanliness, and order	Best in class (11)
3. Visual management system	Above average (7)
4. Scheduling system	Above average (7)
5. Use of space, movement of materials, and product line flow	Excellent (9)
6. Levels of inventory and work in progress	Above average (7)
7. Team work and motivation	Average (5)
8. Condition and maintenance of equipment tools	Excellent (9)
9. Management of complexity and variability	Excellent (9)
10. Supply chain integration	Excellent (9)
11. Commitment to quality	Average (5)
Total score for 11 categories: *(max 121 points)*	**87**

RPA Data for Plants with at Least 10 Tour Reports Each

Manufacturing operation	Category ratings mean	Category ratings standard deviation
A	97.8	3.6
D (2001)	89.0	1.0
B	86.4	10.2
C	82.0	11.0
D (1999)	71.0	13.5
E	65.5	12.2
F	56.5	13.0
G	52.0	12.5
H	49.8	10.5
I	45.5	10.0
J	36.9	7.1

Figure 52 Data collected by Goodson and his students (Goodson, 2002)

The analysis highlights several improvement opportunities. The opportunities that was identified should, as Goodson (2002) suggests, be improved to increase the leanness of the plant. Further, I will approach the different improvement suggestions that was identified in analysis of the categories. Several of the improvement suggestions has already been discussed earlier in chapter 6.

Under Category 1, *Customer satisfaction,* a clear improvement potential was identified. The fact that there are no customer ratings displayed at the Cast House, makes this an easy category to improve. The plant can for example visualize the degree of customer satisfaction on the screen that are spread out over the Cast House. They can also use this number in the combination with the 24-hour meetings. By using this performance indicator, greater awareness of the end customer could be achieved. Based on the fact that they already score high in this category, this is can be seen as an easy improvement.

The improvement potential regarding *visual management* was in category 3, as in chapter 6.3 (*Lean tools*), highlighted. Based on this, the Cast House would benefit of improving some of their visual management practices.

Category 4, *Scheduling,* indicated that the Cast House should consider making the billet production line more *pull-based.* This means that the downstream processes should trig the production in the upstream processes. In this case this means that the saws, that is the last internal customer, should regulate the production.

Concerning the *use of space, movement of materials, and product line flow* (treated under Category 5), the Cast House gets a high score. However, two improvement suggestions were identified. By moving the maintenance mold shop closer to the casting process, this would decrease losses concerning movement and transportation. Further, the Cast House could benefit on removing inventories that take up unnecessary amount of space. Category 6, *Levels of inventory,* also brings forth improvement potential concerning the amount of inventory. The level of inventory is higher than necessary, and could with benefit be decreased.

Category 7, *Teamwork and motivation,* stands out as one of the categories that shows the biggest improvement potential in the *RPA analysis.* This potential has been highlighted earlier under chapter 6.5 (*The learning environment*), therefore it will not be further discussed under this chapter. The other category that received a low score was category 11, *commitment to quality,* this correlates with the score in category 7. This is because there are a lack of visual problem solving, and a lack of visual and defined team goals and vision.

Condition and maintenance of equipment and tools, treated under Category 8, shows a need for visualizing maintenance records at the Cast House. This could affect the moral among the workers in a positive way.

7 Improvement suggestions

7.1 Introduction

Chapter 7 will present and discuss possible improvement suggestion for the Cast House at Alcoa Lista. These improvement suggestions are based on the findings from each of the subchapters´ conclusions in the analysis.

Based on the analysis, the following areas were identified as improvement possibilities:

- An *improvement suggestion system* made for creating a culture of continuous improvement
- Visualizing important KPIs by using white-boards
- Autonomous maintenance and visualization of planned maintenance and records
- Ensuring that everyone is pulling in the same direction
- Creating an organization of scientists
- The billet production line
- Standardization

By implementing the following improvement suggestions, the Cast House may deliver closer to what Turnbull (2003) describes is the ideal for all suppliers in Alcoa, and that is to supply their customer: on demand; defect free; in batches of one; immediately; safely; with no waste.

1.1 An *improvement suggestion system* for creating a culture of continuous improvement

Under chapter 6.2 (*Relevant projects*), one particular improvement potential was highlighted. This regarded the number of improvement suggestions made by the workers at the plant. Based on only 18 improvement suggestions the last 7 months, it was stated that there is not a culture for continuous improvement, and that this system does not catch all improvement.

An implementation of a better system for registering improvements could be a solution to this challenge. This could lead to a more accurate KPI on *morale.* For example, the *wish-list* (at the 24-hour meetings), the scientific problem solving made by maintenance personnel (discussed in chapter 6.7: *Rules in use*), and improvements made based on the HSE-deviation system (discussed under chapter 6.2: *Relevant projects*) should all be registered. This system could also facilitate for a culture of continuous improvement at the Cast House.

Based on the case study of Fibo, and their success of implementing an effective improvement suggestion system, I recommend that it should be set a target for number of improvement suggestions in a month. If these targets are met, team members should be rewarded with compensation that builds the morale of the team. This can be seen as a better solution than the current practice, where single persons are rewarded for their improvements.

As I stated in the literature study, the idea of *continuous improvement* is based on the fact that it is easier to make many small improvements, rather than few large ones. As the system is structured today, it focuses only on the *lowest hanging fruits*. This makes the system neglect all the small improvements, which are the basis for continuous improvement.

Creating a designated software for this purpose, or/and using simple suggestion lists at the workstations, could in my opinion affect the numbers of employee suggestions in a positive way. The current practice is to send an e-mail of the proposal to the person that is responsible for evaluating the proposals. To succeed with this system, it is essential that it is easy to use.

1.2 Visualizing important KPIs

Chapter 6.3 (*Lean tools*), identified and discussed the various tools used at the Cast House. From this, the following tools were identified: visual control, 5s, standardization, A3, 24-hour meetings, kanban, and SMED. This shows that the Cast House has come a long way in the use of Lean tools. However, the following improvement potential was identified: they do not use a white-board in their visualization of KPIs in the 24-hour meetings. To meet the need for using a white board in the visualizations, I have developed a proposition that now will be presented.

The use of OEE as an KPI should be present at the 24-hour meetings, and KPIs concerning employee suggestions should be visualized in some way. Both of these are important performance indicators in Lean and TPM. A suggestion for a KPI-white board for the 24-hour meeting was developed in Figure 53. This white board contains OEE as an KPI for all the process critical equipment in the billet production at the Cast House: *casting*, *conties*, and *sawing*.

The only loss identified concerning the liquid alloy production to BAF, was energy use. Based on this, I have included this as a performance indicator in my proposition. As discussed in chapter 6.6, (*The production processes at the Cast House*), there are energy losses in the production of liquid alloy to BAF. As shown in Figure 7, Spear and Bowen (1999) state that if a supplier can respond to an request immediately, this may be a sign that the supplier is idle, waiting for request. Based on this, I integrated a KPI of the energy use as a part of the suggested white-board.

The Cast House´s plant performance was also included in the white-board suggestion. This is because more awareness will be created by physical having to write the number on the board in either red or green, rather than visualizing it on a screen, as the current practice is today.

As uncovered in chapter 6.8, (*Rapid Plant Assessment*), there is a need for displaying customer satisfaction at the Cast House. Therefore, customer satisfaction was included as a KPI in the suggested white-board in Figure 53. As the saying goes *"if you can´t measure it, you can´t improve it"*.

24-hour meeting white-board: Cast House												
Day	Casting		Conti		Sawing		Liquid metal to Benteler		Plant Performance			Customer satisfaction
	OEE (85%)	Comments (losses)	OEE (85%)	Comments (losses)	OEE (85%)	Comments (losses)	Energy use (kW H) / Tons of metal delivered		Tons produced	Number of Defects	Comments	Days since last complaint
Monday:												
Tuesday:												
Wednesday :												
Thursday :												
Friday:												
Saturday:												
Sunday:												
Last Week:												

Figure 53 Suggestion 24-hour meeting KPI white-board

As I identified as a problem in the OEE calculation in chapter 6.6, (*The production process at the Cast House*), the number of defects at the saws are not logged. By using a white-board at the work station, the quality (number of defects) can easily be logged as they occur. Based on this, and by calculating the OEE of the saws, the performance of the operators can be measured and visualized. In this way, it is possible to improve the efficiency of the work. Also, the reason for bad performance should be described. A target for OEE and quality should be set, and as in the 24-hour meetings, this should be visualized by using red or green markers.

By describing the reason for KPIs that is under the standard, the equipment losses can be identified, and in this way be solved to root-cause through scientific problem solving. The problem solving should preferably include the operators in this work. In this case they are the lowest possible level, which Spear and Bowen (1999) stated, is where the problem solving should happen. This will further be discussed under chapter 7.6 (*Creating an organization of scientists*). An example of a KPI white board for overlap meetings are presented in Figure 54.

Date	Shift	Wrong Length	Quality (100 %)	OEE (85%)	Comments (7 losses)
23.05.2017	A	5	99 %	50 %	(4) Empty magazines
23.05.2017	B	0	100 %	30%	(3) Changing of sawing blade and Empty magazines
23.05.2017	C	0	100 %	85 %	No comment

Figure 54 White-board for overlap meetings

1.3 Autonomous maintenance and visualization of planned maintenance and records

The analysis in chapter 6.4 (*The Eight Pillars of TPM*), identified that the operators executes some maintenance tasks on their equipment today. However, the analysis brings forth a possibility of improving the current Autonomous Maintenance practices. I believe that more maintenance tasks, such as lubrication, cleaning and inspection, can be assigned to the operators. This would engage the operators more by empowering them, which could have a positive effect on the workers moral.

To execute the implementation of an autonomous maintenance practice, I recommend to use an autonomous maintenance implementation process. By using such a method, the implementation can be done in a structured way. The chosen method is the *seven steps of autonomous maintenance* (Nakazato, 1994a). This method contains sevens steps for assuring a successful autonomous maintenance. The seven steps are as follow:

1. Perform initial cleaning
2. Address contamination sources and inaccessible places
3. Establish cleaning and checking standards
4. Conduct general equipment inspection
5. Perform general process inspection
6. Systematic Autonomous Maintenance
7. Practice full self-management

Regarding step 4, I will recommend using a planned visual control system for autonomous maintenance tasks on the different work stations, as they have in Fibo. This regards both on the existing autonomous maintenance tasks and future autonomous identified maintenance tasks. By using this method, you can ensure planned maintenance, however, still being flexible enough to make it fit the daily operations.

In the *Rapid Plant Assessment,* analyzed in chapter 6.8, indicates a need for visualizing maintenance records at the Cast House. This was also identified as a factor that affect the moral among workers in a positive way. Based on this I recommend visualizing maintenance records and planned maintenance.

7.5 Ensuring that everyone is pulling in the same direction

Chapter 6.5 (*The learning environment*) identified the need for team- and personal goals at the Cast House. Later, in chapter 6.8 (*Rapid Plant Assessment*), this need was highlighted again. The plant has today no specified team goals and no defined performance indicators for the teams. Thus, there is a risk for the different teams working against opposing goals.

As depicted in Figure 55, goals and KPIs should come from the leadership (top-down). In return, the leadership receives results (bottom-up). A possible solution to this challenge, regarding the lack of team goals, can be found by looking to Fibo. They connect all the teams' goals with the overall goal/vision of the factory. By connecting all employees to the overall goal of the Cast House, it is possible to align improvements, and ensure that all employees and all teams are pulling in the same direction. Having these goals visible at the current workstations could be an effective way of implementing this way of thinking.

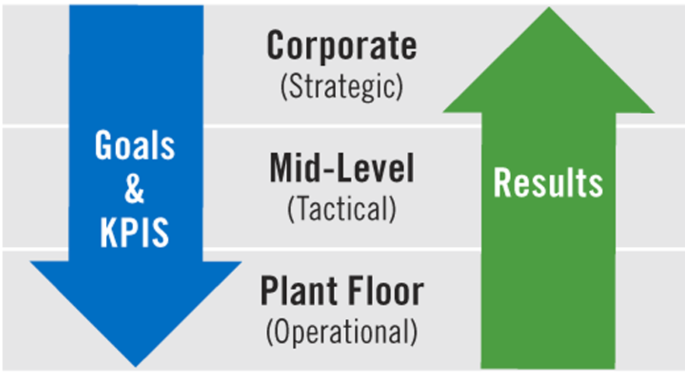


Figure 55 Goals and KPIS delivers result in return (Vorne, 2017a)

7.6 Creating an organization of scientists

In chapter 6.8 the *RPA analysis* highlights that there is no visible ongoing problem-solving at the plant. This indicates how the work-teams are not involved and engaged in ongoing problem solving. Both the lowest scores in the analysis, category 7 (*Team work and motivation*) and 11 (*commitment to quality*) were attributed to the lack of visual problem-solving in the work-teams.

As was identified in the literature study, creating an organization of scientists is the essence of Lean. This has repetitively been identified as an improvement potential throughout the entire analysis. A3 is the main tool for scientific problem solving at the Cast House. Therefore, all employee should be involved in using this tool, as problem solving should happen on the lowest possible level of the plant.

As stated in chapter 6.4, (*The Eight Pillars of TPM*), there is a need for educating the workforce in Lean and TPM. To successfully involve the low-level employees in problem solving, there is a need for a training and educating program at the plant. In order to achieve commitment to continuous improvement, it is important that the workers know the basic ideas of Lean.

To achieve an organization of scientist, the scientific problem-solving mindset has to become embedded in the employee's mindset, in other words, become the way that the employees think. This type of mindset needs to be taught, and it is here Kata-method (recall that this is translated to a routine) can be the possible solution for the Cast House. When problems occur, the Team-leaders should not come up with the solution right away. They should rather let the employee that has encountered the problem, solve it. By using the five questions in Kata, the problem solving can be done in accordance with the scientific method, and the operators will ultimately learn the routine and think this way by default. Rother (2014a) also state that the learning must come from the Team leaders/Operation managers, not the lean-staff. Because the learning is a continuous process, that should be practiced every day. If it is the lean-staff that is responsible for the learning, it become periodical.

As identified in chapter 6.5, *The learning environment,* there is a clear difference between the non-operators and operators concerning employee engagement. The employee engagement could be increased by using the employees at the lowest level in the organization in the improvement work, and teaching them to solve problem through the scientific method (A3, Toyota Kata, or any other PDSA tool). It is the operators that know where the "shoe pinches". The Kata method is especially applicable for increasing the engagement, since it activates the learner while the coach play a more passive role. This was identified by Hess (2014) in the literature study as a good learning methods. I believe this solution would affect all the questions answered by the work-force (operators) in the questionnaire used in chapter 6.5. As stated before, employee engagement and organizations performances are correlated.

This improvement suggestion is not a quick fix, but a mind-change concerning the nature of how problems are solved at the Cast House. By engaging all employees in the problem-solving, many small improvements can be made. Together, these improvements can move the Cast House towards their desired future state.

7.7 The billet production line

Based on the talks, observation, agent based simulation, and the OEE analysis, it is clear that *saw 3* fail to perform as optimal. Based on this, three improvement suggestions to the billet production was developed. Alternative 1 relates to the *line organization loss*, alternative 2 is based on the *Muda of inventory* loss, and the third improvement suggestion is a long-term combination of the two alternatives. All of these improvements will concern the processes down-stream from the *casting,* because of the limitations of this thesis. In the value stream maps in this chapter, the number of operators will not be presented, as it is difficult to understand the need of operators before the improvements are made.

7.7.1 Alternative 1: Line organization losses

As identified in the analysis, one of the saws (*saw 3*) have an OEE on approximately 33 %, and the agent based modeling analysis indicated that it would be sufficient to use only one saw with the current production level. Based on these analysis and observation made of the saws, the main losses in this case can be attributed to *line organization losse*s, that is, there are an overcapacity at the sawing operations. This causes the saws to fail to deliver on their full potential.

A possible solution to this *line organization loss*, is to try cutting the use of two saws to one. This will lead to an improved OEE, due to the fact that material shortage will not affect the performance or the availability as much as before. This will also simplify the pathway (rules-in-use) of the billets. The solution is presented in the value stream map in Figure 56. In Figure 56 one can see how there is only one saw in use (*saw 3*). This saw can pull billets from both magazine F and magazine 5.

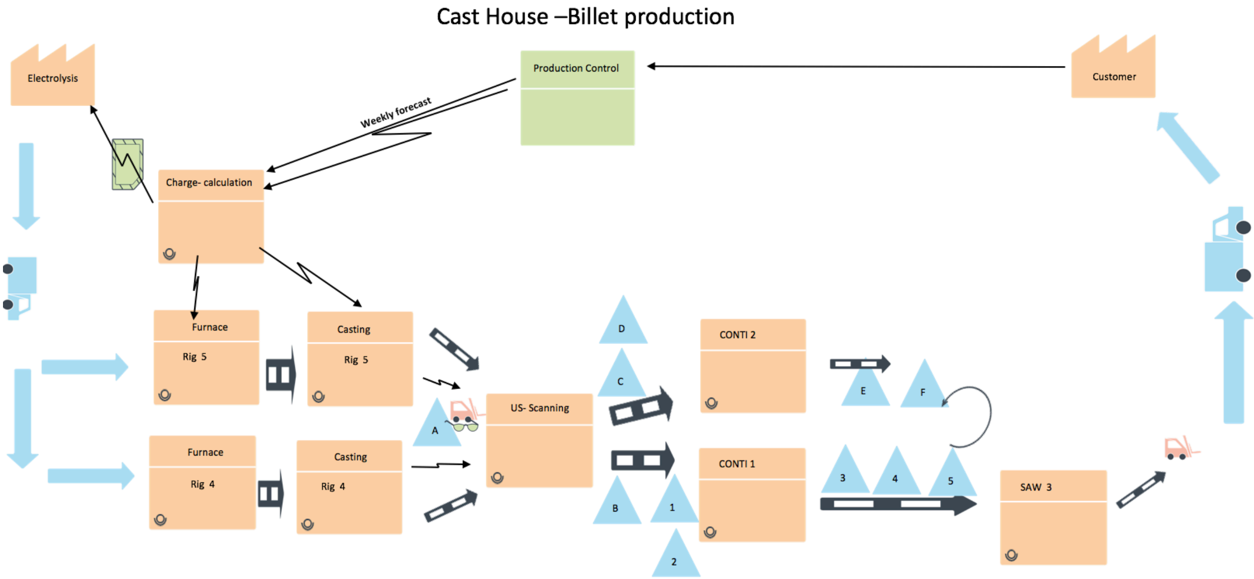


Figure 56 Future state billet production: line organization losses

7.7.2 Alternative 2: Muda of Inventory

The cycle-time (each time a billet exists the *conties*, not an entire cycle that is approximately 4,5 hours) of both *conti 1* and *conti 2,* is greater than *saw 3* and *saw 4*. Therefore the inventory (magazines) before *saw 3* and *saw 4* could be removed. As shown in Figure 57, there is no inventory between the *conties* and the *saws*. This would give the system less flexibility, due to "lowered water levels". By doing so, problems are exposed and thereby removed. This could also have a positive effect on the OEE of the saw, in the way that it forces unresolved problems to surface.

Some of the inventory before *conti 1* and *conti 2* are however necessary, because of the casting technology that produces billets in batches. Fortunately, these inventories are FIFO, which make them the preferred countermeasure for batching. However, as Turnbull (2003) state, ABS do not allow countermeasures to be implemented permanently, but only temporary until the technical boundaries of the production can be resolved. Therefore, the goal should in the long-run be to remove these inventories as well. This will force the Cast House to solve these problems to root-cause. In this way, improve their production.

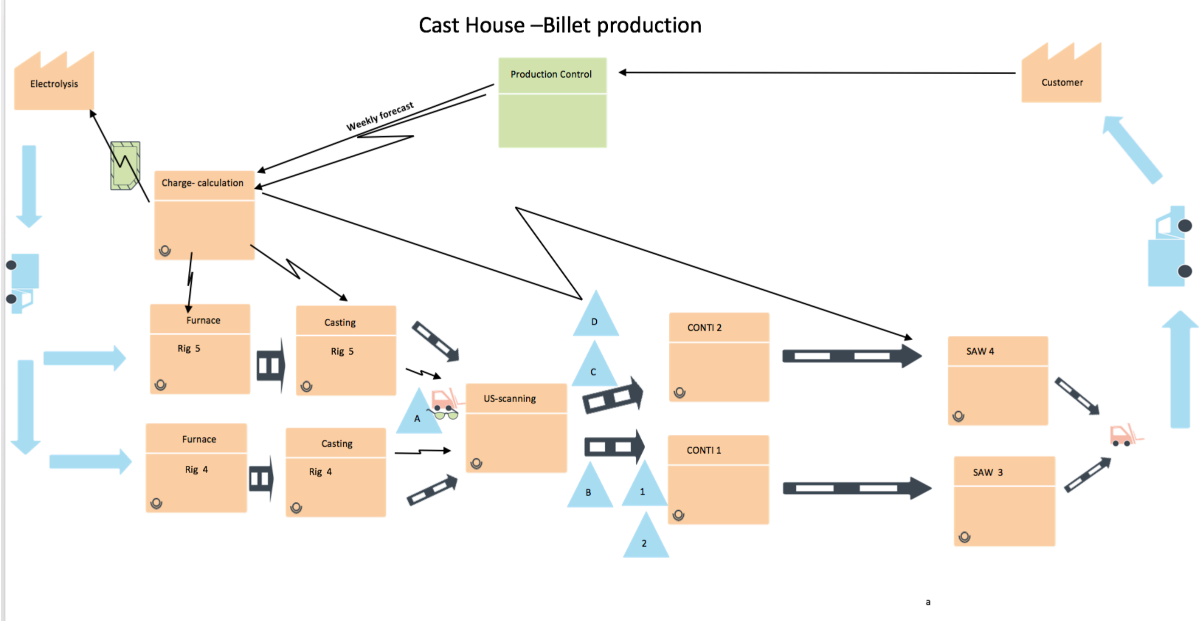


Figure 57 Future state billet production: muda of inventory

7.7.3 Alternative 3: CONWIP system (creating a pull system)

The value stream map in this alternative is based on the value stream map presented in alternative 1 (Figure 56), however, this improvement suggestion would also be applicable for the current production value stream.

The analysis in chapter 6.8 (*Rapid Plant Assessment*) indicated that the Cast House should consider making the billet production line more pull based. This means that the last internal customer, the *sawing process*, should regulate the production. Because the Cast House constantly produces different products in the same production line, a traditional kanban-system would be difficult to use. If a kanban-system was to be used, this would only lead to more inventory between the Cast House and their billet customers. This is because they then would have needed to have “stock-products” in the kanban supermarkets, while they today have *no* stock products.

A solution to the need for a pull based system is to use a CONWIP- (Constant Work in Process) system. This system can be considered a generalized type of kanban, and is an alternative type of *pull-system.* A CONWIP-card (electronical or physical) is not associated with a certain type of product, as a kanban- card is, but the quantity of products that exits the production. The type of product is assigned at the beginning of the production line, based on the urgent need. Also, the CONWIP-system limits the Work In Process (WIP), that is, the number of WIP is limited by the number of CONWIP- cards. Because the Cast House constantly produces different products in the same production line, using a CONWIP-system is more favorable than a kanban-system. (Spearman et al., 1990).

By using a CONWIP- system, the billet production can go from a *push-* to a *pull- system*. This means that WIP would be limited, that is, less inventory in-between processes and increased value for the customer. Instead of using the scheduling-software that is used today to schedule the production, it could be used to prioritize the production sequence that is triggered by the CONWIP-cards.

A CONWIP-card can be sent from the *sawing processes* to the *charge-calculator* each time an entire batch, or a pre-specified number of billets, has been cut and bundled together. This would then start the production of the next product in the scheduling system, and metal would be ordered from the *Electrolysis*.

By using a CONWIP system, the last production process would become the pacing controlling process. This would increase the score in chapter 6.8 (*Rapid Plant Assessment*), category 4 (*Scheduling system*), which was identified as an improvement possibility in the RPA-analysis.

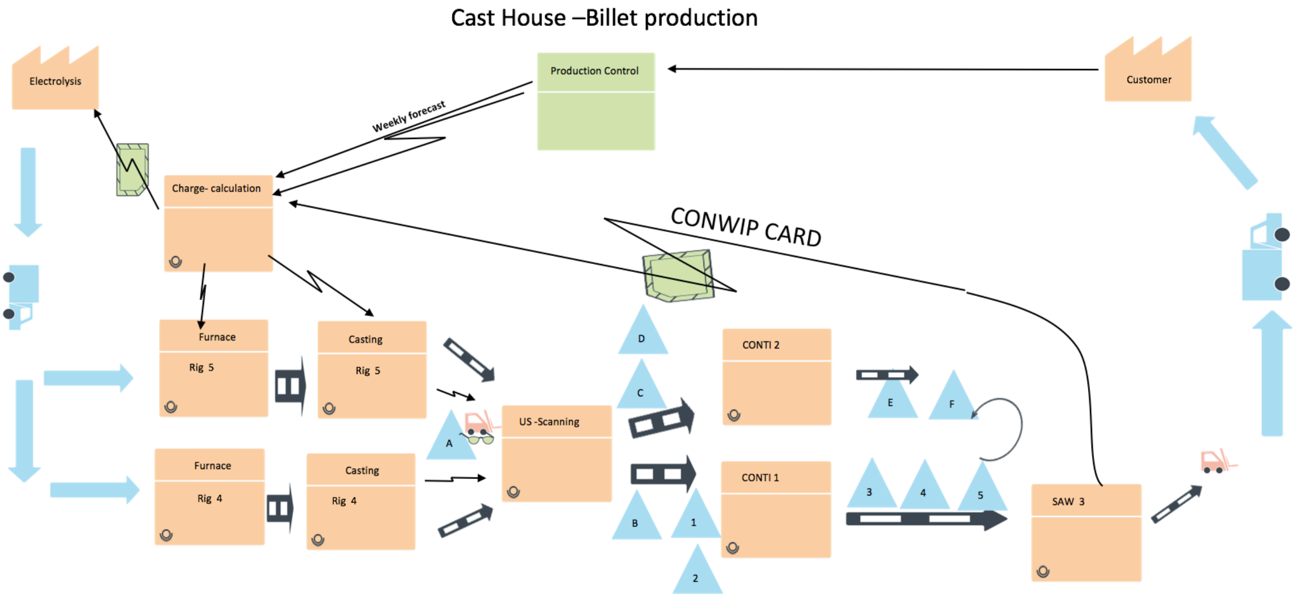


Figure 58 CONWIP pull system in the billet production

7.7.4 Alternative 4: Reorganizing the production line

The fact that the floor plan at the Cast House consists of large equipment that is difficult to move, makes the layout of the factory challenging to change. However, an improvement suggestion has been developed to illustrate the possibility of restructuring the current value stream sequence at the Cast House. This improvement suggestion demands that *saw 3* is moved from its current location, and some modifications of equipment and magazines.

Figure 59 illustrates the possible new value stream sequence. In this value stream map, *saw 3* has been moved prior to the *homogenizing furnaces* (*conti 1* and *conti 2*). This is because, by cutting the billets before they are homogenized will lead to less *energy losses*, as less material homogenized. After saw 3, there is a need for some inventory (FIFO-magazines) as a countermeasure for the batching nature of the billet production. This is because *magazine A* is not big enough for doing this. After the homogenizing furnaces, the billets needs to be bundled together. For this purpose, the bundling system at *saw 4* can be used. This saw has an automated bundling system, which would demand less motion by humans (one of the losses).

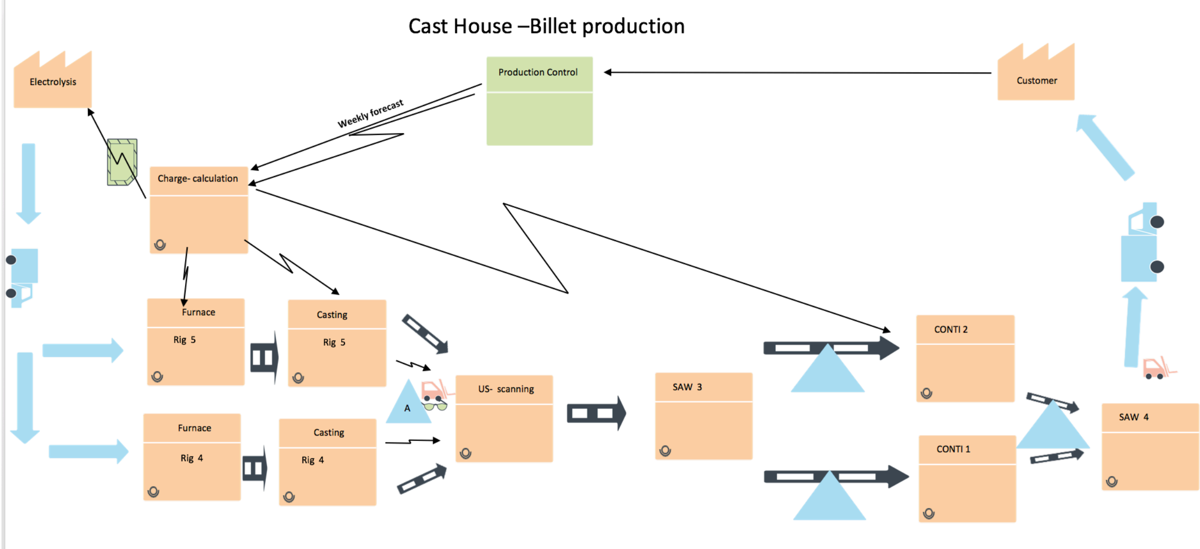


Figure 59 Restructuring the sequence in the billet production

Figure 60 shows how this new value stream sequence could look like in practice. The green arrows indicate where all billets move in the same direction. The blue arrows show the flow of the billets that are homogenized in *conti 1* (C1), and the red arrows indicate the flow of the billets that is homogenized in *conti 2* (C2).

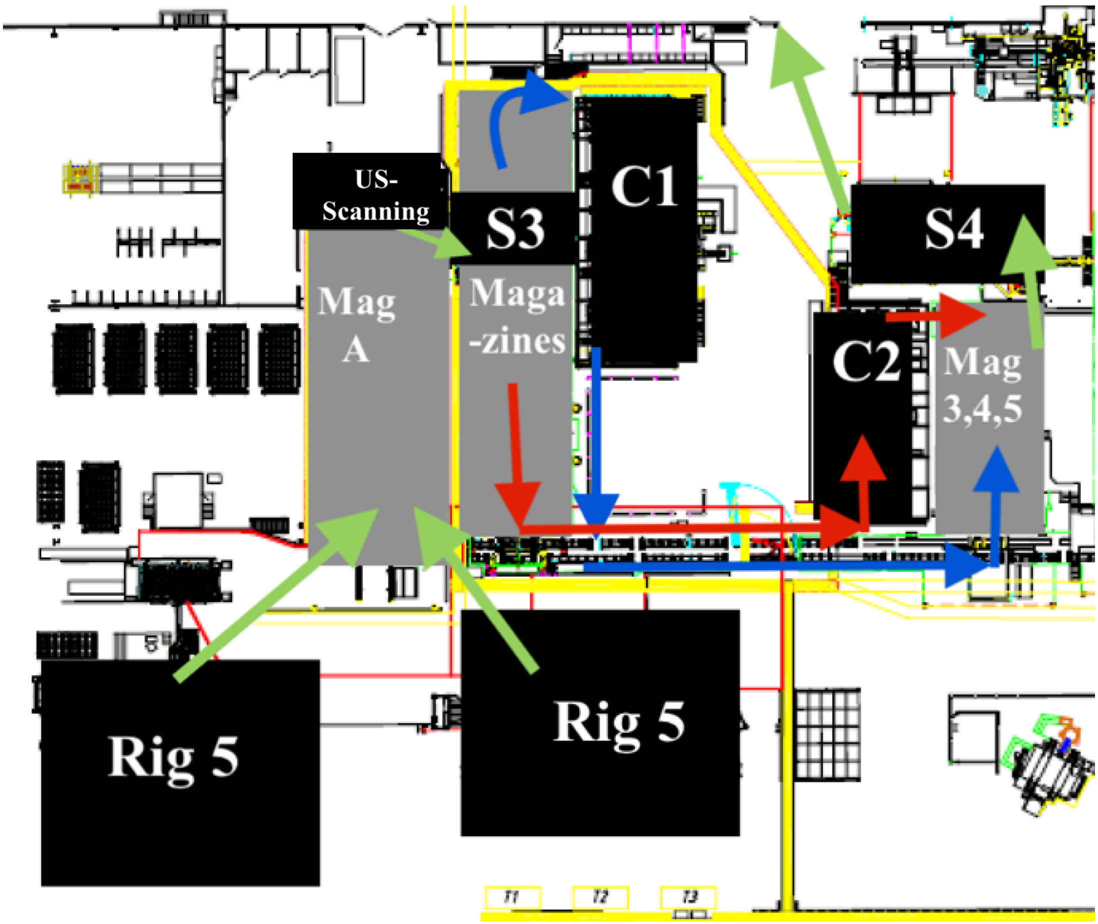


Figure 60 Floor plan of the restructure of the sequence in the billet production

The economic benefits of this restructuring are quite visible. If one assumes:

- that a common homogenizing furnace uses 210 KWh per ton homogenized aluminum (Hertwich, ND);
- the average electricity prize in Norway is 0,35 NOK per KWh;
- there is approximately produced 115 000 tons of billets at the Cast House in a year;
- approximately 5 % of the billet is cut of

Equation 6 Cost savings of restructuring the billet production value stream

$$(210\ kWh)\times\ (0{,}35\ NOK)\times(115\ 000\ tons)\times 5\ \% = 420\ 000\ NOK\ a\ year$$

The economic benefits of using the value stream described in this section would give a, under the given circumstances, result in a cost saving of approximately a half a million NOK a year.

7.8 Pre-specification and direct connection *(Rules in use)*

As concluded in chapter 6.7, *Rules in use,* the Cast House has an opportunity for improvement regarding standardization. The work of operator “b”, who chooses the billets´ *pathways*, can be improved. The way the pathways are chosen today do not lead to the most efficient pathway through the value stream. The *activity* of when the billets are “pulled” from magazine B to either magazine 1 or 2 (in the value stream map of the current billet production), are also not pre-specified. In both the rules *pathway* and *activity,* the need for higher degree of pre-speciation of the work of operator “b” is needed.

Chapter 6.7 also concluded that there is a need a more direct connection between the operator “b” (the operator of the ultra-sonic (US) scanning process) and the operators at the “casting process”. I recommend implementing a more direct connection between these processes. This would make it possible for the casting operators to know how and when to improve their work

8 Discussion

This thesis is built around Lean and TPM practices in an industrial context. The chosen industrial context was primarily the Cast House at Alcoa Lista, this to get a deeper understanding of how Lean and TPM practices can be used in an industrial setting. Also a case study of Fibo was included, this to show how some of these practices have had a positive effect in an manufacturing plant.

During the work of this thesis, I have been enriched with much knowledge about the chosen subjects. Both knowledge about Lean and TPM- theory, how theory can work in practice, how the practices presented works together, and how the Cast House and Alcoa Lista already has come a long way. The work with this thesis gave med a deeper understanding to see that there is no such thing as "a perfect Lean industry", there are always room for improvements. When analyzing the current status at the Cast House, I learned that Alcoa has come a long way in implementing Lean in their daily work. However, several improvement suggestions were identified. By reweaving an industrial company with long traditions within Lean, it demanded a deep understanding about the concepts of Lean and TPM.

As I started the work of this thesis, a natural part was to look at the visual practices, that is, the relevant projects and the Lean tools used at the Cast House. Further, it was natural to take a look into how they perform in The Eight Pillars of TPM. The use of the RPA- analysis, gave an overview of the use of the leanness at the plant. All this work brought up a need for a deeper analysis of current topics. To truly understand how lean works and Is used at a plant, it was necessary to look into the learning environment at the plant, and to review their use of their own business system. This to see if it the practices matches the theory.

The goal of Lean is to flow value to the customer (Rother and Liker, 2014), therefore an analysis of the value creating processes at the Cast House was needed. These processes are the production of billets and liquid alloy.

Future study

As mentioned before, Alcoa Lista has come a long way in implementation Lean philosophy in their organization. Is it recommended that they continue their journey, and take the next step of creating an organization of scientists (the "fourth" rule in *Rules in use*). The idea behind scientific problem- solving is learning. The findings in this thesis, show a need for implementing a culture of learning and embracing the concept of continuous improvement. It is recommended that learning becomes a part of the daily work of all employees.

It is also recommended that they take a closer look into how their maintenance practices are done and the possibility to make the whole production based on a pull-system.

9 Conclusion

The conclusion attempts to answer the objectives set for this thesis in chapter 1.3 (*Objective*). The purpose of this master's thesis, was to make a review of Lean and TPM practices in an industrial context, this context was chosen to be the Cast House at Alcoa Lista. Based on the presented literature and case studies, the current situation at the Cast House were analyzed and discussed. Here, both positive and negative aspects of the current Lean and TPM situation were highlighted. Improvement possibilities were identified, and furthermore, the thesis presented possible improvement suggestions based on these findings.

When reviewing leanness at the Cast House at Alcoa Lista, one can see that the plant has come a long way of implementing Lean as a part of their organization and mindset. The analysis showed that the Cast House uses many Lean- tools to a high degree in their operations. Visual control, 5s, standardization, A3, 24- hour meeting, kanban, and SMED were all identified.

Through their business systems (ABS) and long traditions, tools and practices are embedded into the core of the organization. Their *pathways* are simple, the *connections* are direct and most *activities* are standardized, making the overall leanness of the plant high. *The Rapid Plant Assessment*- analysis substantiated this claim, by giving Alcoa a high score in rating their leanness. Especially, the category regarding safety, environment, and order were given a high score. This category received the score "best in class", a score that should only be awarded one plant in each industry. Also, the fact that their employees are empowered through a flat organizational structure, can be seen as a positive aspect.

Another positive finding in this thesis is connected to their production processes, where "pull" is an idea that is represented in many aspects of their production. The Cast House pulls their material from their supplier through an electronical kanban-system. Also, one of their key customers are included in an electronical kanban-system, making the Cast House deliver their product just-in-time.

At last, the improvement suggestions were presented. The Cast House could, in my opinion, benefit on making a few changes. First of all, there is a need for an improvement system that facilitates a culture of continuous improvement. The use of standardized white- boards in visual control at the Cast House, should be implemented. The review uncovered a need for the implementation of the powerful TPM performance indicator, OEE. Further, there is a possibility of improving the current maintenance practices and the moral among the operators, by empowering them through the TPM-pillar, autonomous maintenance.

Clearer goals, for both the plant and teams, and associated performance indicators for how to reach these goals, should be specified. Thereby ensuring that every worker is working towards the same goal, the Cast House´s main goal. Regarding the billet production, there exist *line organization* losses and *Muda of inventory* losses. This can be improved by simplifying the pathways and lowering the amount of inventory in between adjoining processes. Some pathways and activities could benefit from higher standardization. Also, some aspects of the production can benefit of becoming more pull- based, rather that push-based.

As the essence of Lean is to create an organization of scientist based on solving problem through scientific method on the lowest possible level, this have been devoted much focus in this thesis. The fact that the operators are not included in scientific problem solving, can be seen as a clear weakness considering the reviewing of leanness at the Cast House at Alcoa Lista. Through learning, in this case problem solving, the performance of the Cast House can be increased, both due to, continuous improvement and an increased employee engagement. These two aspects are both proven to increases the performance of an organization.

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11 Appendices

Appendix A: Questionnaire on the Learning Environment

Hva slags stilling har du ?	
1. operatør	•
2. Ikke-operatør	•

Har du deltatt i problemløsning med A3?	
1. ja	•
2. nei	•

HPLO:

	Uenig	Delvis Uenig	Verken enig/ eller uenig	Delvis enig	enig
På jobb har jeg mulighet til å gjøre hva jeg gjør best	(1) •	(2) •	(3) •	(4) •	(5) •
På jobb virker det som om meningene mine betyr noe	•	•	•	•	•
I løpet av det siste året har jeg hatt mulighet til å vokse og utvikle meg.	(1) •	(2) •	(3) •	(4) •	(5) •
Noen på jobb oppmuntrer og legger til rette for utviklingen min	(1) •	(2) •	(3) •	(4) •	(5) •
I løpet av det siste halve året har noen gitt meg feedback (tilbakemeldinger).	(1) •	(2) •	(3) •	(4) •	(5) •

Appendix B: The calculation of OEE on saw 3

	Instruction for input	Billet size 1	Billet size 2	Billet size 3	Billet size 3	Billet size 4	Billet size 5	Billet size 6	Billet size 7	Billet size 8	Sum:
Planned run time (min)	Subtracted scheduled downtime										1440
Average saw speed	Read of PI (software)										6639,4
Availability (%)	Average saw speed/std saw speed										0,655872765
Actual run time (min)	A*B=C										944,4567816
Cycle time (min)	Measured once only	0,977	1,0	1,15	1	1,1	1,2	1,15	1,6	1,023	
number of cut per product	Measure in PI			195		427	72	241			935
Number of products	G/2	0	0	97,5	0	213,5	36	120,5	0	0	467,5
Performance	(sum(E*F))/D	0	0	112,26	0	234,8	43,2	138,7	0	0	0,56
Number of Defects	Insert manually	0	0	0	0	0	0	0	0	0	0
Quality	F/H										1

	OEE
	1440
Availability	0,66
Performance	0,56
Quality	1
OEE	0,37

Explanation of colors:

- Data inputted
- Data that can be inputted, but is currently not (e.g. no defects)
- Measured only once, or calculated automatically
- Bellow standard
- No relevant numbers

Appendix C: Result questionnaire on learning environment

Question	Operators	Non-operators
1	66%	75%
2	55%	92%
3	30%	75%
4	39%	79%
5	50%	79%