FACULTY OF SCIENCE AND TECHNOLOGY

MASTER THESIS

Study programme / specialisation:
Risk Analysis and Governance

The spring semester, 2022

Open / ~~Confidential~~

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Thesis title: Ports' congestion factors: Applying risk analysis as a problem identification tool to figure out the interrelated complex factors that contribute to the problem by assigning weights and probabilities to each factor

Credits (ECTS):

Keywords: port congestion, congestion factors, Bayesian network, port productivity

Pages: 62

+ appendix: 7

Stavanger, 29/05/2022
date/year

Abstract

Ports' congestion is a recurring problem that is caused by several factors. There are several past attempts to resolve ports' congestion by applying governing and constructional reforms. Due to divergence and instability of congestion causal factors, the available studies and solutions are specific to individual ports. The main objective of this master thesis is to apply risk analysis as a problem identifier to figure out the interrelated complex factors that contribute to the congestion problem by assigning weights and probabilities to each factor.

The research is based on qualitative data from secondary sources to gather all available information about the causal factors for ports' congestion. A structured questionnaire was carried out and sent to various ports' managers to figure out the most effective causal factors globally, as a means of validation for the secondary data and to ensure that the data reflect the current congestions causing factors from the port's users themselves.

Congestion's factors can be human, technical, or organizational with different magnitudes based on the port's features and capabilities. They are vulnerable to sudden and quick changes due to their interrelated and complex structure. Bayesian network (BN) is a risk analysis tool that fits the complex and changing scenarios of the congestion problem. It can incorporate the newly received information into the pre-established network of causal factors for port congestion.

BN managed to reflect the cause-and-effect relationship between the causal factors and by means of appropriate software, the effect of any new event on congestion occurrence is visualized. Furthermore, the application of BN needs to be integrated into the port information management system as a permanent warning system that predicts the congestion and virtually shows the results of applying suggested solutions before applying it.

Keywords: port congestion, congestion factors, Bayesian network, port productivity

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Introduction

Seaports worldwide are the gateway through which cargo and passengers pass to enter or exit the country (Meersman et al., 2003). They handle around 80 % of the global trade by volume and more than 70 % of the global trade by value (Review of Maritime Transport, 2018). The port's management always seeks the right decisions that ensure the smooth flow of cargo starting with (a) the uninterrupted flow of the vessels that transport the cargo, (b) the loading and unloading of cargo, (c) cargo processing, and finally (d) the movement of trucks carrying the cargo within the port and passing through the port's gates.

The importance of the port's management role comes from the port's position in the supply chain, as Goss (1990, as cited in Meersman et al., 2003) pointed out, "any improvement in the economic efficiency of a seaport will enhance economic welfare by increasing the producers' surplus for the originators of the goods being exported and consumers' surplus for the final consumers of the goods being imported". Therefore, enhancing the port efficiency enhances the whole supply chain efficiency and increases the rate of flow of cargo in the whole supply process.

The scheduled arrivals and departures of ships are managed by the port's authority through sharing of information and coordination of work with other stakeholders in the port community. Lind et al. (2016) claim that all of the port's actors are always looking for ways to minimize the ship routes and achieve the just in time (JIT) arrivals which are considered a main factor in the competitiveness within the maritime sector. Hummels & Schaur, (2012) assert that the longer the transport times, the more dramatic reduction of trade, and they estimate that the value of each day in transit is between 0.6 % and 2.2 % of the value of the good. The whole supply chain is negatively affected by any delays that occur in the port interface (Everett, 2007).

The delays are magnified, particularly with the economies of scale achieved by the introduction of mega-ships that have excessive cargo capacities. These huge ships acted as a force multiplier for the consequences of the delays in the ships' arrivals. The capacity of a container vessel reached 24,000 TEU (20 ft Standardized Shipping Container), instead of 13,000 TEU in 2013 and 8,000 TEU in 2000. Dealing with such an amount of cargo needs aimed cooperation between the whole port's community and an excessive workforce.

One of the main challenges that face port management, in order to sustain the smooth flow of vessels and achieve the JIT arrivals, is dealing with port's congestion. Congestions, as brought up by Meersman et al. (2012), ruin any gained efficiency from further development of a port or from any reduced costs. Many factors can cause a port congestion problem, to the extent that only less than half of all container vessels arrive in port on schedule (Bloomberg, 2011, p.82 as cited in Fan et al., 2012). Even development in the shipping industry itself increased the congestion problem. As stated by Saeed et al. (2018, p. 164), the emergence of carrier alliances, such as the 2M alliance between Maersk Line and Mediterranean Shipping Co increased the dependence on mega-ships, which in turn expanded the berth handling time due to increased volumes of cargo per each vessel, which means more waiting time for the other vessels waiting for empty berths.

Port congestion causal factors are diverse and have long-term consequences. One of the long-term unexpected factors is the COVID-19 epidemic that most of the world is currently experiencing. The reduction of the workforce due to the pandemic caused some ports' closures and consequently congestion in many ports worldwide. The impact of congestions has spread far and wide across all industries, leading to business declines, shortages of stores' inventory, customers having to fly certain essential goods by air to reduce shortages, and seasonal goods are facing the threat of not arriving or exporting on time (Manaadiar, 2020). Currently, the increased concerns about Omicron, the new covid-19 variant, are putting constraints on the supply due to the recurring ports' congestions and ports' closures (Drewry Shipping Consultants, 2022).

Mitigating the congestion's causal factors represents a great challenge due to their diversity and instability. Developing sustainable port productivity needs to adopt a tool for port managers that can provide a warning before the occurrence of the congestion.

Risk analysis tools are widely applied within the maritime industry, especially in the fields of safety and security. In general, the focus is to figure out the causes or the consequences of a hazardous event during an operation or activity to reduce the risk. However, in the case of port congestion, the causal factors are complex and interrelated with either a lack of information or rapid change in information. Bayesian network (BN) is one of the risk analyses tools that has specific characteristics that suit the port congestion problem. It was chosen as the modeling technique in this research, making use of its strength in dealing with uncertainties caused by the insufficiency of data. The network also can map the interrelated relations between the factors so that the analyst can easily assign probabilities for their occurrence.

Finally, BN is applied to one of the main ports on the Red Sea to figure out the effectiveness of the risk analysis tool in presenting the relationship between the causal factors and recognising the advantages and disadvantages of applying BN in dealing with the congestion problem. The analysis is based on information collected from a constructed questionnaire about the causal factors for ports' congestion in different regions, information from literature and news sources, and from the author's experience in ports' management. The discussion part compares the difference between the method of applying BN in dealing with congestions and the past research that approached the problem, and the suggested requirements to achieve the best application for the BN in handling the congestion's factors.

Literature Review

Through reviewing and analyzing relevant literature, this section articulates how researchers and experts dealt with ports' congestion on the one hand, and on the other hand, how risk analysis techniques were previously applied in the maritime field of research. First of all, it is important to understand the role of the port and the meaning of congestion. Talley (2006) defined the port as:

> A place that provides for the transfer of cargo and/or passengers between waterways and shores. Alternatively, it is an intermodal node in the transportation network, where cargo and/or passengers change modes of transportation (e.g., from a ship to an inland transport mode and vice versa). (p. 44)

He also stated that ports' congestion occurs "when the port users, the ships, interfere with one another in the utilization of port resources, thereby increasing their time in port" (p. 55). Ports' congestion significantly expands the ship's transit time.

Notteboom (2006) defined transit time as the concept of transport time, which is the number of sailing days from one port to another. Generally, it is the total time on a door-to-door basis including dwell times (waiting time) at ports' terminals and time in the queue to access the port of discharge. Thus, cargo owners are obliged to keep a large inventory to avoid depletion of stock, a condition that comprises more costs due to the unreliable transit time. Production costs may also increase due to late delivery of materials to destination factories. That is why the shipping lines are always keen to meet their ships' schedules as announced to the customers. They also intend to avoid the burden of paying the costs of unproductive vessel time (demurrage charges on chartered vessels) when the ship is neither navigating nor engaged in cargo handling in the port (T. E. Notteboom, 2006).

Ports' Congestion Several Approaches

Researchers approached ports' congestion from different perspectives with different proposed solutions. Notteboom (2006) discussed how ship liners deal with some tradeoffs to manage the time factor as a main consequence of congestions. He presented solutions such as reshuffling the order of ports or canceling some ports from the ship's schedule. Following a similar technique, several software programs for container freight planning were developed to allow clients to switch between different modes of transport to select the best mode, e.g., railway instead of ship transportation. These programs are based on real-time tracking for a shipment and the direct detection of delays in the shipment (*Multimodal Logistics* Scheduling *Software*, n.d.).

There are several studies attempted by ports' authorities to deal with congestion consequences after its occurrence. Saeed et al. (2018) in their approach to ports' congestion, applied a Transaction Cost Analysis (TCA) to examine port congestion mitigation from a governance perspective. They considered three main factors that attribute to the problem, which are the frequency (number and type of vessels arriving at the port), the uncertainty (environmental uncertainty and behavioral uncertainty), and the asset specificity which represents the needed investments to release the congestion. The research presented a governance mechanism that considered the roles of all maritime logistics chain stakeholders, including shippers, carriers, terminal operators, port authorities, shipping agents, logistics providers, and landside providers.

Agostini & Saavedra (2013) introduced the idea of rationing based on the value of cargo rather than on a first-come-first-served. They concluded that in dealing with congestion, the efficient rationing gives priority to containerized cargo (cargo that can be shipped in a container unit), followed by breakbulk cargo (load carried in drums, bags, pallets, or boxes), while bulk cargo (liquid bulk including vegetable oil, chemicals, and liquified natural gas [LNG], and dry bulk such as coal, iron, grain, and sand) in the last place.

Investing in ports expansion is another solution for releasing congestion and reducing waiting times, as concluded by Fan et al. (2012). In their research on the USA ports, they applied an intermodal network flow model to analyze congestion in the logistics system for container imports. They found that most of the US ports face congestion that entails more costs and diverting ships to other routes in some cases as well.

Zhang et al.(2014) approached congestion but not seaports' congestion; they assessed the congestion risk within inland waterways. They provided a case study on the Yangtze River in China using an accident data–based approach. The congestion risk assessment is carried out to analyze the characteristics of the accidents resulting in channels' congestions. In their study, they claimed the presence of a research gap within congestions caused by inland water transport, since previous studies mainly focused on the congestion issues within seaports or dam areas. However, by reviewing the available studies concerning seaports' congestion, most of the focus was either on congestion caused by accidents or on providing a solution for a specific port by analyzing the factors causing the congestion within this port. A good example of this is the research done by Yeo et al. (2007). They applied a simulation program to Busan port to estimate congestion occurrence in 2011, where they suggested internal modifications within the port to prevent future congestions. But the research did not present a solution that can be used as a guidance for every port authority to predict the increasing risk of a congestion due to accumulation of certain factors.

Other researchers analyzed ports' congestions to figure out the factors causing it. Bolat et al. (2020) in their study, determined the factors causing congestion and ordered them with analytic hierarchy process method, where weights are assigned to factors based on experts' assessment. They concluded that the most important main factors for port congestion are documentation procedures, port operation and management, ship traffic inputs, port structure and strategy, and government relations. The study managed to clarify and weight the most important causal factors that can be used by ports' managers to identify areas that need more attention to deal with congestion. However, each port has its unique structure and characteristics that differ from one port to another, which explains why most of the available research concentrated on dealing with the congestion problem specifically in a certain port.

Maneno (2019) looked at the factors causing congestion in the Port of Dar es Salaam in Tanzania by using feedback from various port's stakeholders by means of a questionnaire. He concluded that inefficient handling equipment, lack of information and communication technology, insufficient port area, bureaucracy, and unskilled manpower are the main factors behind port congestion.

In the case of the Nigerian ports, the congestion problem at Tin Can Island Port (TIP) was modeled as a multi-server queuing problem with ten berths. Okoye et al. (2011) in their research, applied the queuing theory in order to enhance the sustainable development of the Nigerian ports. They found out that congestion in the Nigerian ports is not caused by only inadequate berthing space but also by the operational inefficiency of the port management and lack of infrastructural development.

Other researchers approached congestion by applying regression analysis in five African ports to pick out the consequences on logistics and supply chain operations. Nze & Onyemechi

(2018) in their research, stated that typical causes of congestion in African ports are bad weather affecting both ships' arrivals and cargo handling, ships' accidents, strikes within the port, sudden peak in demand, landside's congestion, documentation processing, and infrastructure deficiency. They concluded that curbing congestion within African ports would be through planning, modifying regulations, increasing capacity, enhancing efficiency, or a combination of these.

The global container port business volume increased by 254% between 2000-2018, as noted by Manaadiar (2020). In his article about port congestion's causes, consequences, and impact on global trade, he attributed the reasons for congestion to the rising of demand over capacity, bad weather, labor disputes, war zones, pandemics, slow productivity, limited port's yards space, port's access limitations, port's location, hinterland connectivity, trade wars, and congestion of empty containers in the port's terminals. He finalized his article by drawing the attention towards (a) the several negative consequences of congestion, especially in the global trade, and (b) the importance of digitization, investment in new technologies, and preparation of skilled personnel so that modern ports can handle the modern and large ships. He also presented his solution for congestion in a brief closing statement "Only once containers start flowing smoothly between the ports and the hinterland and vice versa facilitated by all the stakeholders in the chain, port congestion can be contained".

Applying Risk Analysis in The Shipping Industry

The existing risk analysis literature in maritime systems mainly focuses on probabilistic risk analysis arguments, simulation modeling, and statistical analysis of data. Risk analysis techniques are mainly applied in maritime for safety purposes. The International Maritime Organization (IMO) proposed a standardized risk assessment procedure called Formal Safety Assessment (FSA), where the guideline for it was proposed in 2002 (IMO – the International

Maritime Organization, 2022). It is used for assessing the risks related to maritime safety and the protection of the marine environment during the marine operations with the purpose of applying risk reducing measures to deal with the risk source, and to evaluate the related costs and the residual risk after application.

Nguyen et al.(2021) applied risk analysis to quantify uncertainty within container shipping, and the Bayesian network is used to quantify the risk magnitude by calculating the probability of different risk magnitude scenarios in order to identify the critical and the uncertain risks. They concluded that the physical flow of containers is the main source of high-ranking risks, while most of the uncertainty rises from information and financial operations.

Bayesian network was also used by Montewka et al. (2014) to present a proactive framework for estimating the risk in maritime transportation systems, focusing on the consequences of ship–ship collisions in open sea. They evaluated the probabilities of the events following any collision by determining the severity of the collision. BN was used to express the background knowledge together with the sensitivity analysis and the value-of-information analysis for the estimation of the risk model parameters.

Collision risk was approached in another research by Debnath & Chin (2010) by analyzing critical vessel interactions. This approach proactively measured collision risk in port waters by measuring two proximity indicators between any two vessels. They illustrated their method by quantitative measurement of collision risks in Singapore port fairways and validated it by examining correlations between the measured risks with those perceived by pilots.

Ulusçu et al.(2009) in their research, applied risk analysis to analyze the risks involved in vessels traffic in the Strait of Istanbul and provided suggestions to reduce safety risks. The safety risk analysis was performed by integrating a probabilistic accident risk model into the simulation model, and a scenario analysis was carried out to study the behavior of the accident risks with respect to changes in the surrounding geographical, meteorological, and traffic conditions. It also investigated the impact of some factors such as vessels' arrivals, scheduling policies, and pilotage on the risk's profile of the strait.

In the maritime and ports security fields, Bichou (2008) reviewed the development, application, and adequacy of existing risk assessment and management models to maritime and port security. He discussed several analytical tools that are applied within the maritime field with the aim of drawing attention towards the need for further research to investigate mechanisms and implications of the applied security measures on port and shipping operations, including the impact on the whole supply chain.

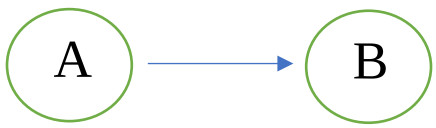
Risk management tools are also used in the maritime financial field as presented by Wang et al. (2014). Since the shipping industry needs excessive amounts of capital investment, it is crucial to evaluate the financial performance of the shipping company. In this study, they assessed the financial performance of shipping companies within three types of cargo in the shipping industry: dry bulk, liquid bulk, and containerized cargo by means of a stochastic frontier model.

Bayesian Network

The BN as defined by Rausand (2011) " is a graphical model that illustrates the causal relationships between key factors (causes) and one or more final outcome in the system" (p. 294). It is a compressive method that sometimes is called Bayesian Belief Network, Causal Network, or Belief Network (Rausand, 2011). Rausland et al. (2021, p. 127) added that, its quantitative analysis depends on the Bayes' formula; that is why it was named Bayesian. They described it as Directed Acyclic Graph (DAG) because cycles cannot be formed, and the network is formed of nodes and directed arcs. In figure 1, node A represents a state, and the arc is the direct influence that affects the other node B. Because of this, BN represents a cause- effect relationship. Each node is represented by a random variable with a discrete distribution of two or more possible states. The variable of the node can be a measured quantity, a latent variable, or a hypothesis.

Figure 1

BN Node & Arc



Note: Node A is the parent node for node B and B is the child node for A, where A and B represent events or factors. All nodes that can be formed on a direct path from A are called the descendants of A and all previous nodes that can be reached from A are called ancestors of A. A node can never be its own ancestor or descendant since BN is an acyclic graph. Each node (factor) has one or more possible states, for example, raining or not raining in the case of a weather node.

The Bayesian network measures the conditional dependence structure of a set of random variables based on the Bayes theorem (Yang, 2019). The Bayes theorem is based on the probabilities of observable events where the probability may change with the introduction of new information (Lunn, 2013, p. 33).

The Bayes theorem: $P(A|B) = \frac{p(B|A)p(A)}{p(B)}$

Where p(A) is the prior probability before taking account of the updated information in B. P(A|B) is the conditional probability of A given the introduction of new information B.

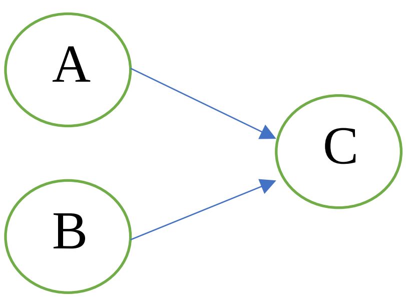
P(B|A) is the conditional probability of B given A.

P(B) is the marginal probability of B, which is a normalizing constant to assure the validity of the value of p(A|B).

Quantitative analysis is obtained by establishing conditional probability tables (CPT). Every node is associated with a (CPT) that represents the likelihood of occurrence based on past experience. Figure 2 shows the formation of CPT for a child node by giving the distribution of variables for the combined condition state of each node as a parent node affecting another node. Rausand (2011, p. 299) stated that, increasing the number of influencing factors and the states increases the complexity of the CPTs.

Figure 2

CPT for a Node with Two Parents



Marginal probabilities of root nodes
Pr(A=1) =0.75
Pr(B=1) =0.35
Pr(C=1) =0.25

Parents		**Pr (C=c| Parents)**	
A	**B**	**1**	**0**
0	**0**	**0.1**	**0.9**
0	**1**	**0.5**	**0.5**
1	**0**	**0.5**	**0.5**
1	**1**	**0.9**	**0.1**

Note: A & B are parents' nodes for event C. Since nodes A&B have no parents, their marginal probability distribution of their variables has to be specified based on experience and past events. Each variable is assumed to have two possible states 0&1 or yes & no. The table represents the CPT for node C where it shows the causal influence of all nodes on the child node C. It gives the conditional probabilities of the states of C given the specified states of the parents A and B.

Rausand (2011, p. 295) also briefed the objectives and applications of BN as follows:

- Identifying the causal factors that can effectively influence a critical event and illustrating the relationship between them in a network.
- Calculating the probability of the event with respect to the causal factors with identifying the most critical contributors.

It is more flexible than Fault Tree Analysis (FTA) and can replace it as it can identify the relationships between the risk-influencing factors in addition to the probability of the top event. The risk analyst assigns conditional probability of each state given their causal connection as it is not limited to only two states as in the Event Tree Analysis (ETA) and FTA (Aven, 2015, p. 80).

Torres-Toledano & Sucar, (1998, p. 3) mentioned the expression of "probabilistic reasoning" where estimates for probabilities of certain variables given other evidence are used for generating recommendations concerning a problem. That is why BN is used in the fields of aviation, aerospace, shipping accidents, medicine, and finance, where there is a need to analyze complex relationships and where more than two actions may influence other action.

The Reason for Using BN

Rausand (2011, p. 297) stated that the main purpose of applying BN in risk analysis is "to model the network of influences" on an event, which are named the risk- influencing factors (RIFs). The RIFs are deductively identified and connected by direct arcs. Conditional probability represents the probability of an event given the occurrence of another event, and the Bayes theorem is based on the fact of how a probability of a hypothesis increases when new evidence is introduced. Moreover, Charniak (1991) stated that the networks can be built of hundreds or thousands of nodes, and that they might be re-evaluated with the introduction of new information.

With new evidence, the nodes' conditional probabilities change, given the changing evidence. In their article concerning applying risk assessment in maritime transportation systems, Montewka et al. (2014) mentioned that BNs have the ability to allow reasoning in both directions under uncertainties making the risk assessment framework a proactive tool by representing the obtained knowledge and updating it to improve the outcome of the model. They also added:

> First, BBNs allow multi-scenario thinking, which not only focuses on an undesired end event (a collision) but also provides insight into the process of the evolution of an accident. Second, BBNs structure reflects the causality in the process being analyzed, allowing further knowledge-based decision-making. Third, BBNs can efficiently handle the uncertainties about variables and the uncertainties about the relations among variables, and represent those in the outcome. (p. 144)

This multi-scenario thinking allowed by BNs suits the problem of port congestion. A port's congestion most of the time is caused by the accumulation of several factors. The number of available factors, their strengths, and the port's characteristics all interact together to eventually result in piling up of vessels in front of the port. Such a case of changing interactions needs a risk analysis tool that can accommodate these unstable changes in a way that can provide the decision maker with a clarification for the impact of these changes on the final outcome. Furthermore, the causal factors for ports congestion, as will be described later, have the features that need to be dealt with by the above three advantages mentioned by Montewka et al., where BNs offer understanding for the evolution process, reflection on the causality in the process, and handling the uncertainties. In addition, this study's focus is not on the end event itself but on the way the event development and the effect of the interaction between the several causing factors at the same time. The factors and their effects are not constant and need an adaptive model that can be updated to enhance its production. Finally, the presence of uncertainties in the causing factors and the relation between them and the final victim, which is the port, requires a method that can represent these uncertainties during the decision-making process.

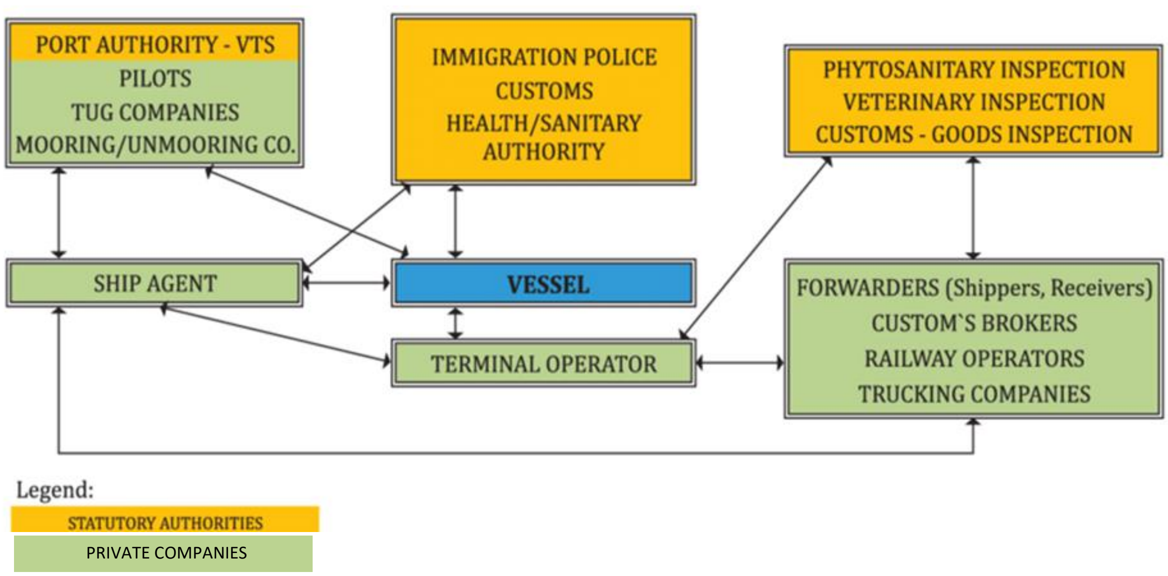
What About Resilience as a Solution? As mentioned by (Aven, 2020, p. 12), improved resilience reduces the risks of undesirable events, especially in complex real life systems that are characterized by huge uncertainties. Aven's point was about the call to shift from risk to resilience; however, constructing a resilient port as a solution to face the consequences of ports' congestion, is a great challenge. Ports' development as stated by (Güler, 2002), involves the construction of a new port / terminal or the extension of an existing port by dredging the port's basins and channels, constructing new yards' areas, and purchasing new equipment attempting to increase the port's capacity, to accelerate the cargo handling processes and to facilitate the ships maneuvers. All developments' activities comprise huge investments that cannot be afforded by many ports' authorities. Therefore, the targeted solution should be an affordable solution that can be applied by the available port's capabilities. The requirement is a solution that provides a sort of warning to the port management, when there is a change from the normal state, and gives a view of what might happen due to this change that can cause congestion; hence the solution is applicable to all types of ports whatever the capabilities of the port are.

Factors Causing Seaports Congestion

Seaports are extremely sensitive, and their activities can be easily disturbed due to the port's vulnerable structure. As shown in figure 3, in a seaport there are several stakeholders, each one with its own prospective and a targeted outcome. Some are assigned to provide services to the ship such as pilots, tugboats, mooring/unmooring, garbage collection, bunkering, etc. and these services can be provided by the port authority or by a private company. Others are security and safety biased, such as the customs, police, and health authorities, where the smooth flow of cargo is out of concern. The final group is responsible for the flow of cargo including the port authority, the terminal operator, freight forwarders where they arrange the movement of cargo through several phases from the ship's loading/unloading, stacking in the port yards, passing through customs, and finally delivering the cargo through the port gates whether by trucks or by railway. Furthermore, there are the ship broker, the ship owner, the shipping line, the cargo owner, and the insurance companies. However, achieving the target of the smooth and quick flow of the cargo is the main function of any port that no one in the port community can disagree upon it.

Figure 3

The Various Stakeholders Within a Seaport

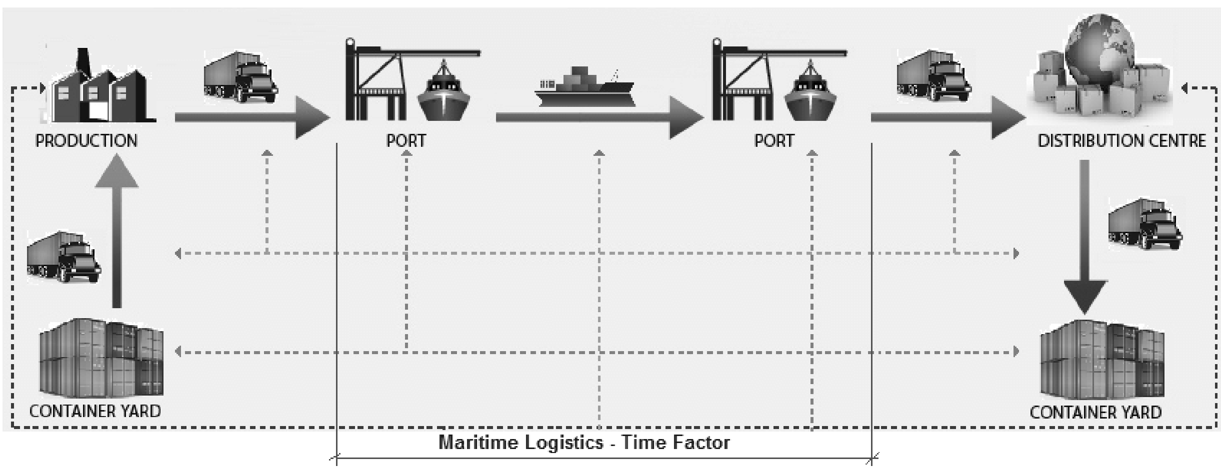


Note: It shows the various stakeholders that are dealing with vessel. From "The Importance of Harmonizing Working Timetables in Seaport Clusters," by J. Karmelić and E. Tijan, *2018,* Scientific Journal of Maritime Research,32, p.117, https://doi.org/10.31217/p.32.1.12. Copyright 2018 by Faculty of Maritime Studies Rijeka.

The consequences of any delay in any phase of the maritime logistics cycle propagates throughout the whole cycle. As shown in figure 4, the port-to-port shipping connects both of the production and the distribution ends together. Therefore, the port's congestion causes disruption in production and distribution activities. The cargo loaded on ships while passing this crucial phase in the supply chain that dominates the mid part of figure 4, is vulnerable to several delaying factors that, if occurred solely or combined, will cause the port's congestion.

Figure 4

The Maritime Logistics Cycle



Note: The maritime logistics cycle shows the cargo flow starting from the production phase until reaching the distribution center via seaports. The focus of this study is the Port-to-Port phase where congestion occurs. From "The time factor in maritime transport and port logistics activities," by N. Florin, A. Cotorcea, M. Ristea, and L. ROMAN, 2016, Scientific Bulletin of Naval Academy, 19, p.73, DOI:10.21279/1454-864X-16-I1-013. Copyright 2015 by Creative Commons Attribution-Non-Commercial-Share Alike 4.0 International. CC BY-NC-SA 4.0.

The causal factors for ports' congestion are so many and can be due to natural or man-made reasons. From the previous studies *(Bolat et al., 2020; Manaadiar, 2020; Maneno, 2019;*

Nze & Onyemechi, 2018; Okoye et al., 2011) and others, about 20 factors were collected and included in a survey that was sent to several port managers worldwide to get a view of the degree of effectiveness of each factor. These factors are briefly defined as follows:

Busy Port's Berths

It occurs when the berth assigned for an arriving ship is still busy with another vessel more than the scheduled period, a case that can occur due to several reasons such as delays in cargos' loading or unloading, documentation processing, port's strikes, and other reasons that will be mentioned next. Arriving vessels start to line up in the port's waiting area causing congestion.

Port's Closure

Many ports are vulnerable to be closed, and both arriving and departing ships have to wait for the reopening and the continuation of port activities. The closure mostly is due to severe weather that prevents tugboats and pilot boats from escorting the ship to/from its assigned berth. After the port's reopening it takes a long time to empty the already occurred congestion starting by releasing the departing vessels, then accepting the arrived ones.

Unscheduled Arrivals

It may occur due to an emergency situation to the ship during its route to its destination port, such as a malfunction of the ship's engine or of any of its equipment that may affect the safe navigation of the ship, dangerous cargo emergency situation, ship accident, or a crew severe health situation. If the port is not prepared to provide the required assistance with the availability of a free berth to deal with such an unscheduled arrival, the scheduled arriving vessels will start to accumulate, and congestion may occur.

Severe Weather

Severe weather affects both the vessel on its route and the port activities itself. During navigation, the ship's captain may increase or decrease the speed, facing severe weather, which may affect the trip duration. Also, severe weather can cause delays in ship departure from a port if it is closed during such weather. Ports also may respond by reducing or stopping cargo handling or halting port services (tugboats, pilots, bunkering) in such a case. In February 2022, the storm Eunice hit UK ports, causing its biggest ports – including Felixstowe, Southampton, and London Gateway – to halt operations and close for a week because of the weather (Macola, 2022).

War Zones

War areas cause disruptions to ship routes to avoid passing through unsafe waters. This may lead to changes in ships' schedules and adding or replacing ports in the original schedule. Furthermore, economic sanctions imposed against the involved governments in the war escalates the disruptions. The current Russian war against Ukraine, as mentioned by the shipping company Maersk, will cause "ripple effects" and "significant delays" across the region (Baschuk et al., 2022). In addition, Jan Hoffmann, the head of trade logistics at the United Nations Conference on Trade and Development, mentioned that "There is no slack in the system, so anything that holds up ships anywhere will lead to less capacity," (Baschuk et al., 2022). The shipping routes are so sensitive to war zones to the extent that it affects the whole supply chain and the global sea transportation of supplies.

Pandemics

The covid 19 pandemic revealed a new ports' vulnerability. In February 2020, the average waiting time for container ships at Zhoushan port in China (the 3rd largest container port in the world) reached more than 60 hours, which is not normal for that port (Manaadiar, 2020). All actions taken by governments facing the pandemic and the related trends and behaviors associated with the pandemic ended up with a negative effect on ports' activities. The stockpiled goods in some ports and terminals due to lockdowns and lowered workforces, the decreasing production due to decreasing demand and the internal manufacturers' difficulties facing the pandemic, and the inefficient operation of several facilities due to regional lockdowns and illness within the workforce caused disruption to ports' activities, where the commercial success is determined by the constant flow of vessels and the smooth flow of goods within ports. Any sudden commercial disruption of ports and terminals exposes them to potential unforeseen risks, which may not be well planned (*Port and Terminal Risks*, 2022).

Slow Productivity

Berth productivity is defined as "the average number of container moves per crane per hour, while a ship is at berth" (*Port Productivity News | Port Efficiency Data*, n.d.). Therefore, productivity relates to the smooth and continuous operation of the cargo handling process that involves both the equipment and the workers efficiency. Drawbacks within equipment's maintenance or sufficiency, and skilled workers' availability are factors contributing to decreased productivity. In addition, lack of digitalization and sharing information technology hinders the process of improving productivity (Kavas, 2018). With decreased port's productivity, berths are kept busy with vessels delayed by cargo handling more than they are scheduled, and newly arriving vessels have to wait more for an empty berth.

Limited Port's Yards Space

Cargo is temporarily assembled within the port' yards after/before their unloading/ loading respectively for logistics, security, and regulatory activities. The problem occurs due to the design and the establishing of the port without a pre visibility study of the port's future market in order to establish the port's yards with sufficient capacity. Furthermore, the introduction of ULCVs (Ultra Large Container Vessels) with extended volumes of cargo is a challenge for any ports with limited yards' areas, since the increase in containers coming off a ship also requires the container yard (CY) to be able to clear the containers with the same speed. Manaadiar (2020) mentioned that in some US ports the CY is unable to handle the increased number of containers, and the movement of containers out of the yard slows down due to saturation of the CY capacities, causing congestion on trucks movement and creating a backlog on the shore side operations that affects the productivity of the port/terminal. The result is longer time for both the berthed ships and the waiting ships in the anchorage area, while other arriving vessels keep adding to the queue.

Port's Access Limitations

Some ports have limited access to their basins that allow only a limited number of operations simultaneously. For example, a port may have a single, long entrance channel that allow the movement of one vessel at a time, or a very narrow channel that requires very slow navigational speeds and more controlling tugboats. Longer entrance and exit maneuvers make it more difficult to release congestions after their occurrence and more risk of port closure during severe weather.

Port's Location

Some ports are located in areas that are confined by nature due to shallow waters, the presence of wrecks, and scattered islands and shoals. Preparing and dealing with these hurdles mostly are difficult and costly. Maneuvers for entering and exiting such ports are slow, and the capacity of receiving a high number of ships at the same time is limited. Such locations make the port more vulnerable to congestions and difficulties in releasing congestions when they occur.

Hinterland Connectivity

Ports are designed with a capacity based on the hinterland they serve. The hinterland is defined as:

> A land area over which a port sells its services and interacts with its users. It is an area over which a port draws most of its business and regroups all the customers directly bounded to the port and the land areas from which it draws and distributes traffic. (T. Notteboom et al., 2022, p. 117)

In the maritime logistics cycle, as shown in figure 4, the operation of the ships and the whole port is connected to the smooth and quick arrival of the cargo to its final destination. In addition, the cargo to be exported needs to arrive port in time from their origin in order to be loaded. Hinterland transportation is carried through intermodal modes, i.e., road, rail, inland waterways, and pipeline. Bottlenecks in any of these modes delay the arrival of cargo to the port causing schedules' disruptions and ports' congestions. In some ports that serve extended hinterland, such as Rotterdam port that serves almost all Europe, the container storage and sorting function is transferred to centers outside the port so that the port entry becomes more close to the market rather than the port in an attempt to increase hinterland accessibility and to avoid cargo congestions within the ports' limits (Visser et al., 2009).

Trade Wars

Ports as a main player in the shipping market are connected to geopolitical differences and demand for commodities. Congestions may be generated in the course of a trade war between countries. In 2020, when China decided to rely on the domestic supply of coal instead of the Australian one, a congestion of vessels lined up in front of the Chinese ports waiting to unload their cargo of the Australian coal (*2021 Port Congestion Report*, 2021).

Congestion of Empty Containers in the Port's Terminals

Containerized cargo puts shippers in the dilemma of the return of empty containers. When the containers are exported loaded with cargo, there is no guarantee for the availability of cargo in the destination port so that the containers can be loaded again and returned backwards to the origin port. Countries like Kenya, Nigeria, Côte d'Ivoire, UK have all experienced ports' congestion due to piling up of empty containers. In the Philippines, Manila port has a lot of full import containers coming in, but not enough cargo to be exported because of trade imbalance; hence empty containers were piling up in the ports and terminals (Manaadiar, 2020).

Landside's Congestions

Congestion also occurs within the trucks arriving and exiting the port, usually at the ports or the terminals' gates. Such congestion will affect the flow of cargo inside the port and the arrival of empty containers that need to be loaded on ships. As mentioned before, when the CYs are full, movement of trucks is disrupted, causing backlogs and delays in the berth operations. Other reasons such as lack of digitalization, scheduling of trucks arrivals, and gates' operations planning can cause landside congestions.

Last Port of Call Delays

The last port of call is the last port the ship visited before arriving at its destination port. Delays that occur in the last port of call, if failed to compensate for by increasing the ship's speed, will cause a delay in the arrival time, and if happened with several arriving vessels simultaneously, port's congestion because of such disruption in the port's schedule occurs.

Route's Disruption

International navigation incubates passing through passageways such as Suez Canal, Panama Canal, and Bosporus strait. Such passageways have their own regulations concerning speed and ordering of entrance, and any disturbance in such schedules will cause disruption in sea trade routes. A good example is the blockage of the Suez Canal in March 2021, by the Ever-Given Ultra Large Container Vessel (ULCV). The Suez Canal blockage lasted nearly a week and caused high levels of congestion as ships queued with more than 300 vessels waiting to pass the major transit zone. The blockage caused congestion at both the Southern entrance (Red Sea) and the Northern entrance (Mediterranean) of the Suez Canal. Even though the salvation operation and the reopening of the canal took only six days in total, the ramifications of the congestion continued until the second quarter of 2021(*2021 Port Congestion Report*, 2021).

Another consequence of the blockage was that many vessels took alternative routes and navigated around the Cape of Good Hope, adding 8 days more on average for a ULCV, costing extra time and fuel. The queues for the Suez Canal at this time transferred the congestion problem to the destination ports after the canal reopening and releasing of the congested ships, as congestion shifted from the canal to the next destination ports such as Rotterdam in Northwest Europe (*2021 Port Congestion Report*, 2021).

Ship's Malfunction

Any malfunction in the ship's engine or navigational equipment can cause delays for the ship, whether due to decreasing the ship's speed for maintenance or for changing the course to enter the nearest port in the case of a situation that may place risk to the safe navigation of the ship and crew.

Labor's Disruption

The movement of cargo within the port is based on the work force of the port who are responsible for operating the cargo handling equipment in the berths, yards, and logistics centers. Also, ships' services such as garbage collection, dockworkers, and bunkering depend on the port's workforce. Strikes by the port's labor negatively affect the flow of cargo and the port operations. In February 2015, labor disputes in the Los Angeles-Long Beach port complex caused congestion of more than 30 ships anchored off the ports of Los Angeles and Long Beach waiting to berth. This port complex on the West Coast of North America handles around 40% of US imports (Associated Press in Los Angeles, 2015).

Insufficient Infrastructure

Ports' infrastructure includes the basins, yards, entrance channels, and service roads. As stated in (*PIANC WG 158, Masterplans for the Development of Existing Ports*, 2014) the 'allowable' berth occupancy for four berths is over 70 % and for eight or more berths over 80 %. Port Authorities should take the right decisions in advance before reaching the allowable occupancies for the port's berths to include such volume whether by increasing the number of basins or by increasing the port productivity by enhancing the labor and equipment performance or increasing the port's working hours. Outdated development plans will finally lead to port congestions since the current port capacity struggles to cope with the increasing number of the incoming vessels and volumes of cargo.

Equipment Shortage/Failure

Limited port productivity may occur due to shortages in handling equipment, whether at the berths or in the yards. The number of the functioning equipment should be compatible with the volume of the cargo received by the port. Cargo congestion within the port's yards and delayed loading / unloading of vessel increases the berth time for the ships inside the port, consequently, causes ships congestion in the port waiting area.

Documentation Processing

Receiving a ship within a port is accompanied with paperwork related to both the ship and the cargo. Each port authority has its own regulations concerning licenses, approvements, and charges. However, the IMO has taken several steps to standardize the procedures and the documents required in each port by adopting the Convention of Facilitation of International Maritime Traffic (FAL). As mentioned in the FAL Convention (2019) "the FAL Convention contains standards and recommended practices and rules for simplifying formalities, documentary requirements and procedures on ships' arrival, stay and departure". Nevertheless, still in some ports, the paperwork may delay the entrance or the departure of the ship to/ from the port.

Cargo Surges

The ports are bonded to the market and the state of the demand within the regions that are served by this port. The decision to establish a new port is based on the market demand in the future. Therefore, any rising of demand over the current capacity of the port that makes its infrastructure and superstructure incompatible with that demand will cause an influx of received cargo causing both cargo and ships' congestion.

Methodology

The research is based on qualitative data from secondary sources collected from published literature and news sources to gather all available information about the causal factors for ports' congestion worldwide. Validation and assessment of the secondary data is fulfilled by using primary sources by communicating with port managers. This validation process is done by sharing a structured questionnaire with ports' managers and ports' services providers in different ports in different regions. The reason for choosing this method is to ensure that the data really reflects the congestion's causing factors from the users themselves. Afterwards, Bayesian Network is applied as a problem identification tool to figure out the interrelated complex relation between the factors that contribute to the congestion problem by assigning weights and probabilities to each factor. Finally, by using a suitable software application, and by the introduction of new evidence concerning a change in the probability of any causal factor in the BN, the induced change in the whole network of descendants' nodes and the impact on the resulted congestion node can be visualized. Thus, a prediction for the degree of congestion can be provided to decision makers.

Congestions' Factors Questionnaire

The questionnaire asked the respondents to evaluate the effect of the known observed congestion factors (the above defined factors) on their ports, how often they occur, and to mention any unidentified factor that was not included. The questionnaire structure is valid as it reflects the real-world problem, and the responses agree with the previously gathered factors. It is partially reliable since some regions are not covered in the respondents list, such as Southeast Asia and the Americas. The answers are consistent as the respondents are from various ports from different countries and kept published for about three months period.

Sixteen respondents from several ports in different regions provided their insights showing a different degree of effect of each factor on their individual seaport (see Appendix A for full survey responses). Respondents' ports are as follows:

- Alexandria port, Port Said East port, Sokhna port, Adabiya port, and Suez Canal in Egypt.

- Bergen Port in Norway.
- Patras port in Greece.
- Bejaia port in Algeria.
- JPDI port in Saudi Arabia.
- Dakar port in Senegal.
- KPA in Kenya.

Application

In this section Bayesian Network is applied to the factors causing ports' congestion. As mentioned in the questionnaire and from the literature review, the presence, and the degree of effect of each factor differs from one port to another. Therefore, the application is applied on Sokhna port in Egypt and the assigned probabilities for each factor to occur is based on (a) the author's experience as a member of Sokhna port management team together with (b) the port's current properties and (c) the historic data about the rate of occurrence of the factors and their consequences.

Bayes theory as mentioned before, is based on using two types of probability distribution, the prior distribution, which here is based on prior information about the probability of occurrence of congestion factors in other ports and historically in Sokhna port, and the posterior distribution that is based on new updates in the situation that may change the probability of occurrence of a factor (Lunn, 2013, p. 2). In the application, the posterior distribution is based on assuming the reception of evidence of the occurrence of new events in the causal factors. Applying this to the Bayes theorem:

$$P(A|B) = \frac{p(B|A)p(A)}{p(B)}$$

where p(A) is the prior probability of the occurrence of, for example, route disruption for the ship before taking account of any updated information about the occurrence of a new event.

P(A|B) is the conditional probability of A given the introduction of new information B. It is the posterior probability of A after the introduction of the occurrence of a new event. In the application, assuming the reception of new information of the occurrence of a blockage in the Suez Canal without knowing how long it will take to be resolved. By taking into account the introduction of this new information, the probability of p(A|B) will consequently increase than the prior p(A).

P(B|A) is the conditional probability of B given A. It represents the probability of the blockage of the Suez Canal with the occurrence of port congestion.

P(B) is the marginal probability of B, which is a normalizing constant to assure the validity of the value p(A|B). Here, it is the probability of the occurrence of Suez Canal blockage in general.

Applying the Bayes theorem can be used with a limited number of factors and changing events. However, due to the presence of several contributing causal factors to the port's congestion, BN is constructed by using a suitable software. By using GeNIe software, a software which is available online, the BN for the port's congestion factors is constructed and run based on the receiving of new information about the factors (*GeNIe Modeler*, 2020).

Constructing the Bayesian Network

1. Specify the end node which is the port's congestion.
2. The congestion causing factors are represented by nodes as shown in figure 5.
3. Identifying the influencing factors (parents). As shown in figure 6, the previously mentioned congestion factors are the parents' nodes to the port congestion node, where they are connected with arcs to show the cause-and-effect relationship

between them and the process is continued to the lowest desired level of resolution to reach the root causes that can be human, natural, technical, or organizational causes.

4. Defining the state of each node with a specified discrete random variable set. (Yes) if the factor event occurs and (No) if the event does not occur.
5. Assigning probabilities to the root nodes (nodes without parents) based on previous events and the port properties.
6. Establishing the CPT as shown in figure 8, by assigning the next level of nodes with the conditional probability distribution given its parents and continuing until assigning the end node. For a full review of the CPT's for all congestion factors see appendix B.
7. Analysing the network quantitively by calculating the probabilities and in most complex cases a computer program is used. As shown in figure 7 and by using GeNIe software, the factors' different probabilities are converted to a bar chart showing the effect of the factors quantitively on each other during the normal conditions of the port.
8. Running the system through the introduction of new evidence. In figure 9, assume that the port authority received evidence of occurrence of a war zone and severe weather at the same time on the ship route to the destination port. Notice that the introduction of new information changed the probabilities in the descendants' nodes until reaching the end node with increasing the probability of occurrence of the port's congestion. War zones and severe weather are parents' nodes to route disruption, so its probability increased from 25% to 92%. The unscheduled arrival

node, affected by its parent node, increased to 65% instead of 30% and the port closure node increased to 42% instead of 29%, affected by its parent severe weather. Finally, port congestion probability increased to 65% instead of 54% due to the change in its ancestors' nodes.

Figure 5

Nodes of ports' Congestion Causal Factors

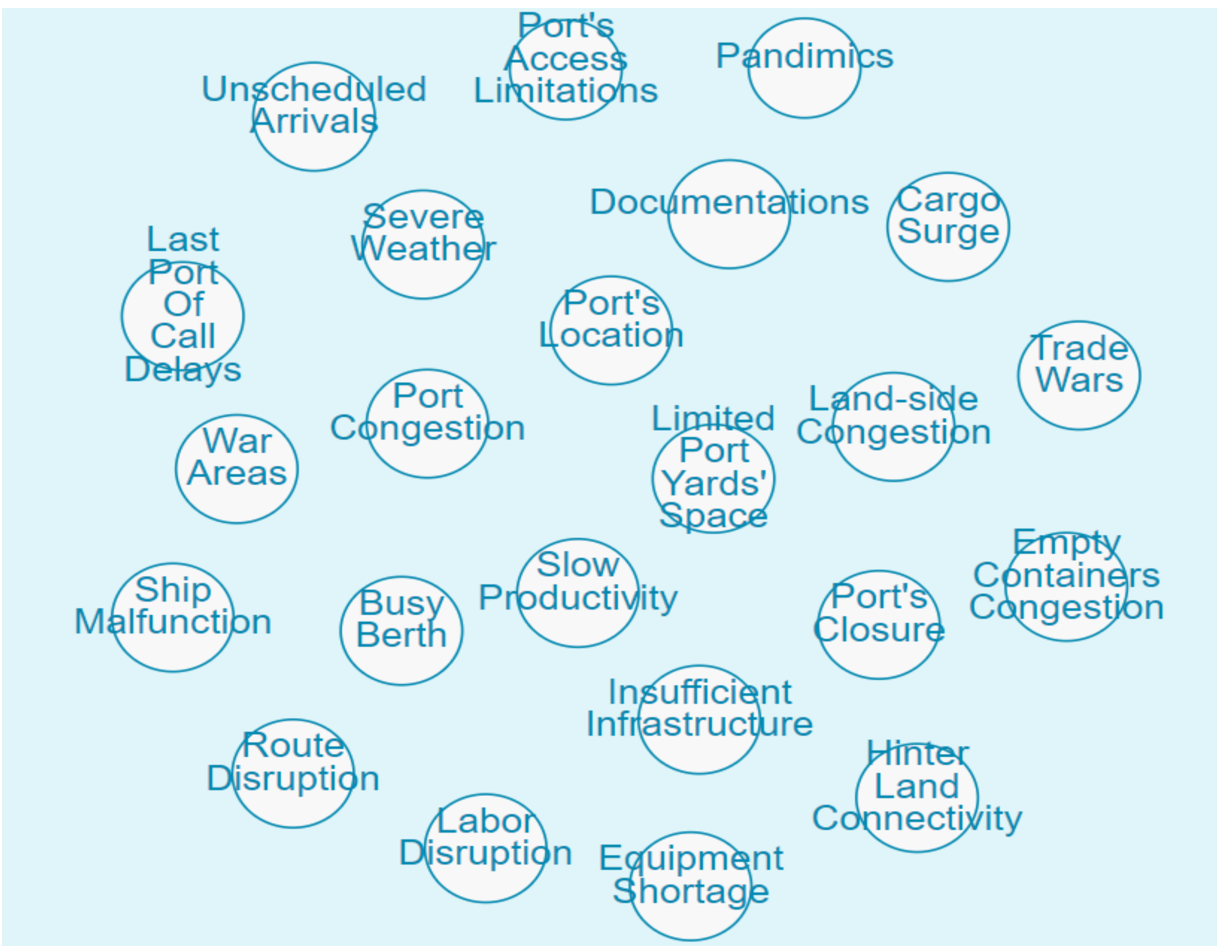
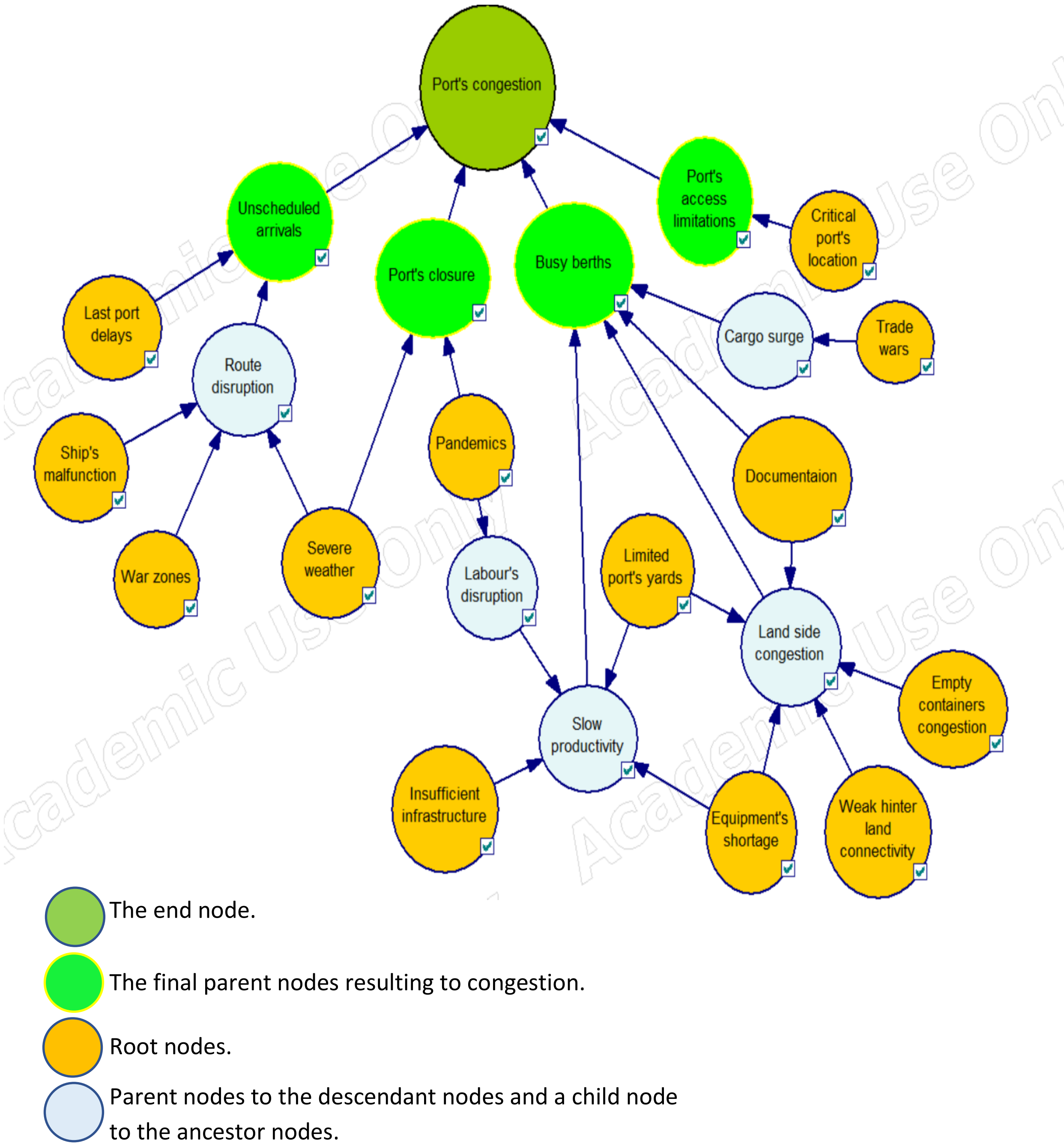


Figure 6

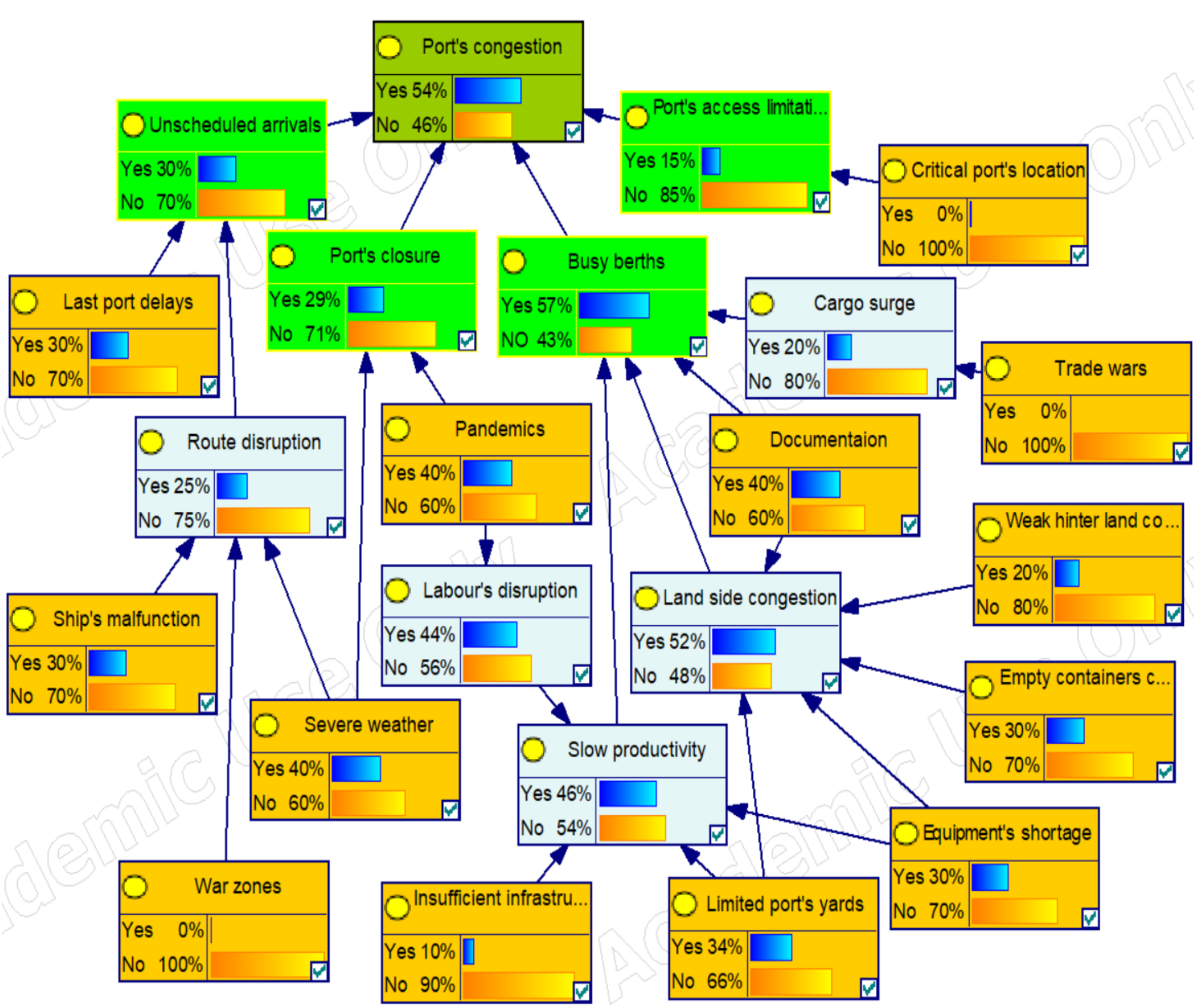
Bayesian Network for Port's Congestion Factors



Note: The congestion factors are connected with arcs to represent a network of cause and effect connecting the parents' nodes until reaching the final consequence, which is the end node representing the occurrence of congestion. In the figure, the root nodes can be natural factors such as severe weather; technical factors such as ship malfunction; human factors such as war zones, or organizational factors such as documentations.

Figure 7

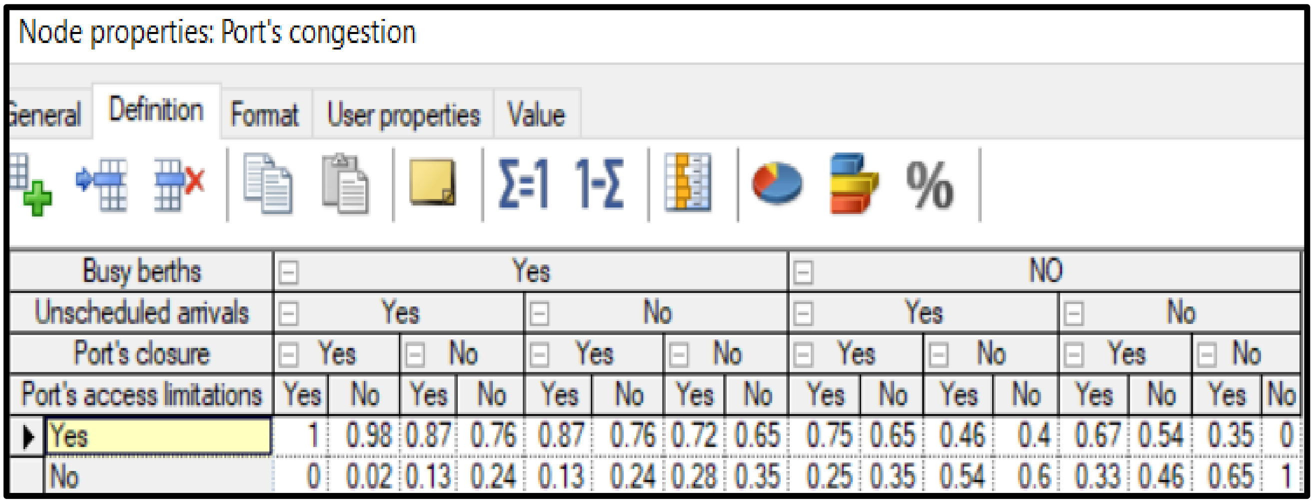
BN for Congestion Factors in Bar Chart



Note: Each node shows the probability of occurrence of the factor given the occurrence of the ancestors' nodes. Probabilities are typical for each port and are based on past events and the experience of the analysis team. In Sokhna port, and based on the history of the port, factors such as trade wars, port location, and war zones are ineffective. Another example is severe weather, about four of ten situations of bad weather situations in Sokhna caused halting of the port operations. By this way, based on the port properties and historic data, probabilities are assigned to each factor.

Figure 8

CPT for Port Congestion

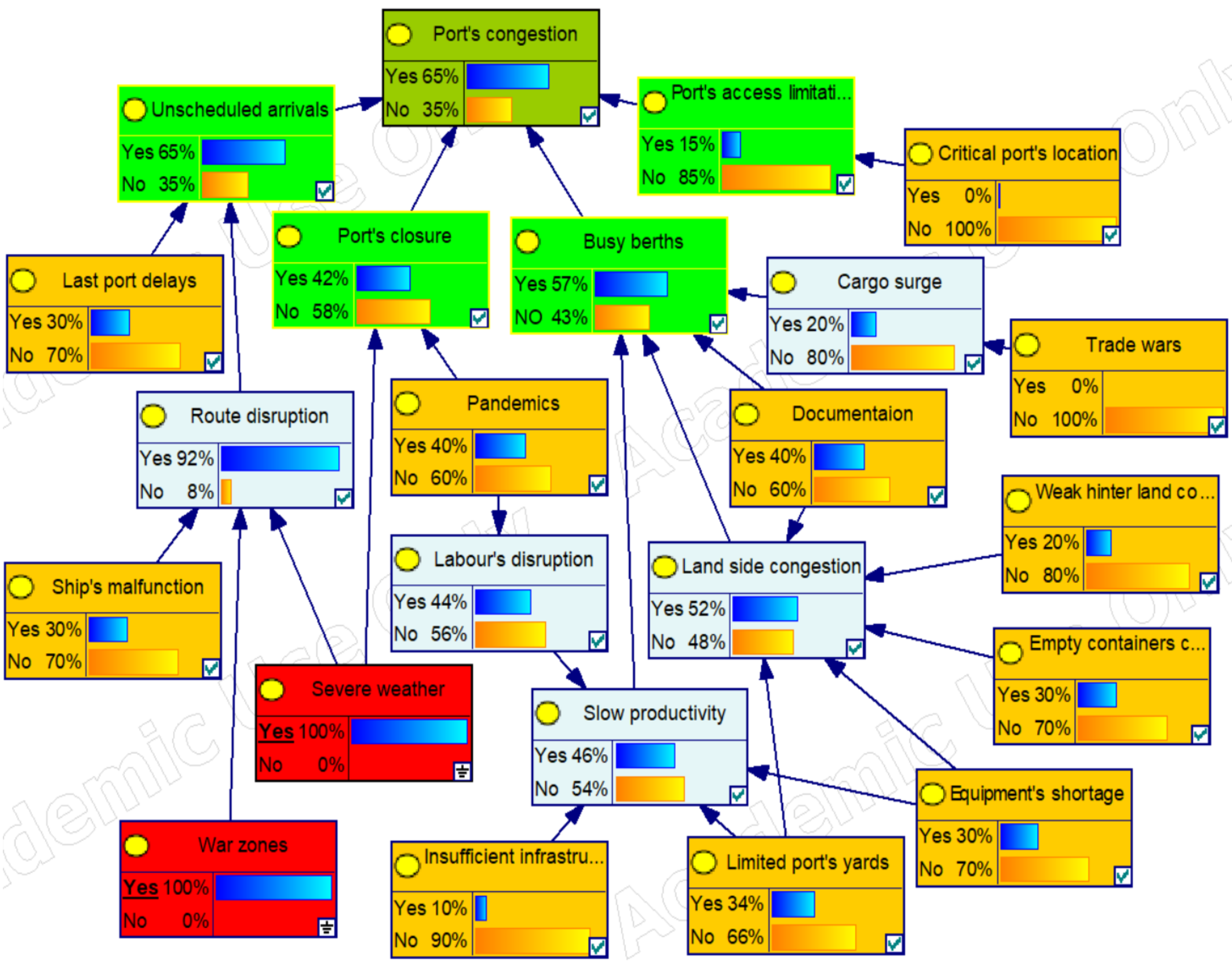


Busy berths	Yes								NO							
Unscheduled arrivals	Yes				No				Yes				No			
Port's closure	Yes		No		Yes		No		Yes		No		Yes		No	
Port's access limitations	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Yes	1	0.98	0.87	0.76	0.87	0.76	0.72	0.65	0.75	0.65	0.46	0.4	0.67	0.54	0.35	0
No	0	0.02	0.13	0.24	0.13	0.24	0.28	0.35	0.25	0.35	0.54	0.6	0.33	0.46	0.65	1

Note: CPT for port congestion given the occurrence of congestion factors. The probabilities of the occurrence of factors are assigned by the port expert based on the port properties, historic events, and the season of the year. Therefore, the CPT differs from one port to another and should be updated from time to time. The CPT shows the probabilities of occurrence of port congestion given the different probabilities of occurrence of busy berths, unscheduled arrivals, port's closure, and port's access limitations.

Figure 9

BN With Evidence of Occurrence of War and Severe Weather



Change in the nodes of War zone and Severe weather based on new evidence.

Note: With the occurrence of war on the route of the ship, together with the occurrence of a severe weather that affected the speed of the ship, probabilities of the descendants' nodes changed. Due to the occurrence of war zone and severe weather, route disruption increased to 92%; unscheduled arrivals increased to 65%; port closure increased to 42% and finally congestion probability increased to 65% instead of 54% in the normal conditions.

Results

The questionnaire showed that there is no pattern that can be drawn about the causal factors. The presence of the factor and its degree of effect is individual to each port. In addition, the questionnaire brought up some other factors that are not mentioned. However, they can be considered as branches from the mentioned factors. The other factors brought up by the questionnaire are as follows: (between brackets is the suggested factor they belong to)

- Poor port management (appears in documentation as a cause node for the slow productivity).
- Some cargo receivers refuse to store temporary on warehouses and request direct transfer from ship to outside the port (landside congestion).
- Price competition between neighbouring ports (trade wars).
- Good implementation of safety and environmental measures in a port may lead to congestion in a neighbouring port which does not follow these measures (unscheduled arrivals).
- Not using artificial intelligence programs for utilizing berthing systems (slow productivity).
- Strikes by some port actors (labour disruption).
- Lack of gangs (slow productivity).
- Lack of good communication between different parties (slow productivity).
- Shipping and loading/unloading companies / transport companies / shipment release procedures (land congestion).
- Seasonal activity such as cruises, highspeed boats, superyachts, pleasure boats, tourism, and ships requests layup (port access limitations).

- The dependence of many incoming commodities on the price on the international stock exchange in addition to agricultural crops export season (trade war).

Nevertheless, the factors proposed by the respondents assured the fact that each port management team should identify the causal factors to the congestion problem in their port of study and identify to what level in the BN they want to reach in the root causes. The identification of the level of analysis is based on the port authority's intention from carrying out the analysis and their capacity and ability to solve the problem. For example, labour disruption can be caused by many reasons, so the authority identifies whether the focus is the probability of occurrence of the disruption or to go further to identify the reasons and the probabilities for this disruption.

Furthermore, the questionnaire confirmed the reliability of the literature review and the congestion factors studied before. The studied congestion factors are general and faced by most ports' authorities, but with different degrees of effect. On the other hand, factors such as trade wars and war zones are not faced by many ports since they are associated with certain locations and certain situations. The same case is with the pandemics, but due to the Covid 19 outreach effect that disrupted the global supply chain for a long period of time, almost no port did not suffer from its consequences. The shipping industry is very volatile and vulnerable to economic and political situations. Therefore, it is important for each port to update the analysis with any change in the global and regional conditions. In addition, some factors are seasonal, such as the weather that differs from summer to winter in many regions, and some activities such as the movement of yachts and cruises are also related to the tourism seasons.

The BN managed to reflect the connection between the different factors in a cause-and-effect network. The network is easy to update by adding or removing a factor with the ability to locate the factor based upon the reason for its occurrence and its consequence. This sort of representation of congestion factors is considered a handful tool for mapping the congestion factors to decision-makers, with the ability to trace the root causes for each factor to the level required by the management.

The BN can be used to differentiate between crucial factors that have the majority of the impact and trivial factors that can be ignored in the case of the prioritization required by port management. Ports' congestion is a complex problem that involves several causal interrelated factors. In the course of solving the problem, causal factors need to be mapped and analysed in order to differentiate and categorize the factors to inform the decision-maker with the most and least effective causal factors. From the application, the BN illustrated that some factors are general headings or collective to be the result of many causes, such as slow productivity and land congestion, which in turn are the main causes for busy berths. On the other hand, the factor of port's access limitations is not an effective factor in this port and is caused by a natural reason which is the port location. From the BN the decision-makers can decide which factors can be approached and how they can be delimited by decreasing the effects of the causal factors. They can also prioritize which factors to start with and by which means, depending on whether the cause is human, natural, organizational, or technical. The decision can be providing training, applying maintenance, or performance development based on the root causal factor source.

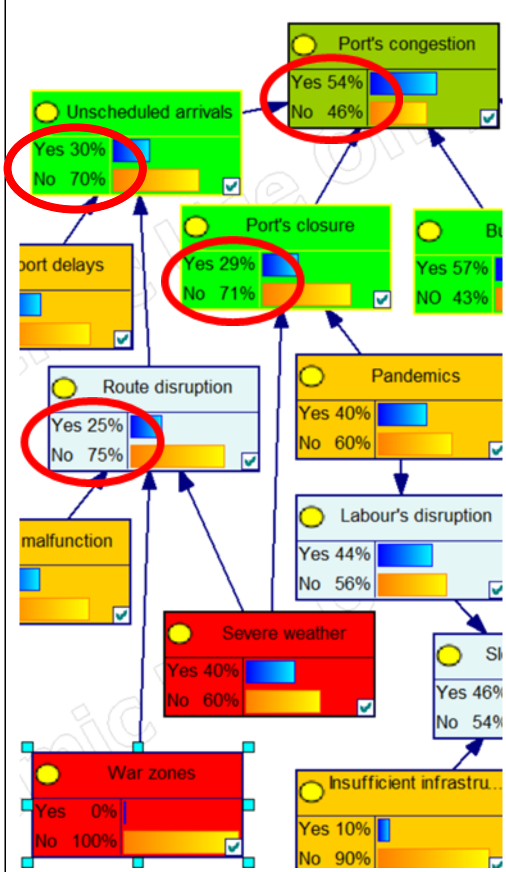
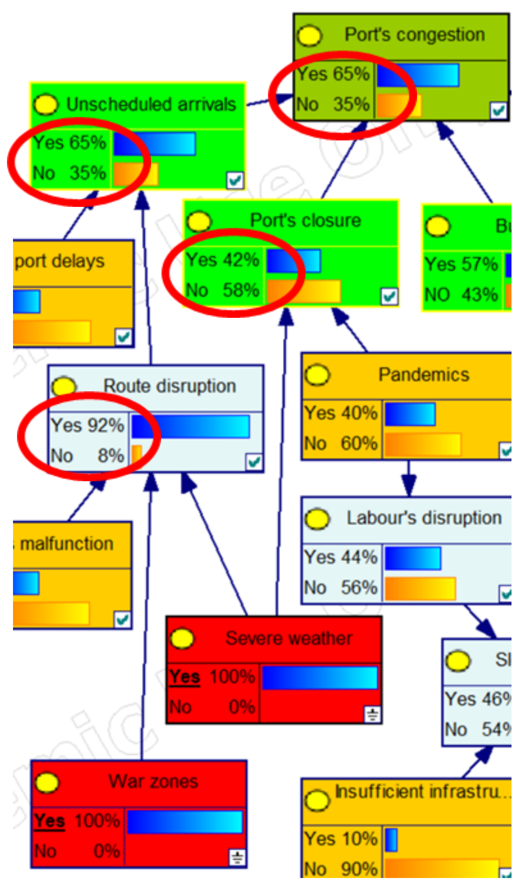
In Sokhna port BN example, the probability of port congestion occurrence is 54% in normal conditions and without any change in the causal factors. Based on Bayøes law, the

$p(A|B) = \frac{p(B|A)p(A)}{p(B)}$, and as stated by Gill (2002, p. 11), by ignoring $p(B)$ then:

$p(A|B) \alpha\, p(A)p(B|A)$, which means that the probability of congestion occurrence given the occurrence of factors is directly proportional to the probability of occurrence of the causing factors. More explicitly, the receiving of information on the occurrence or accumulation of congestion factors; directly indicates the increasing probability of congestion. Therefore, the mapping of factors through the BN is beneficial in the direct and quick indication of the increased risk of congestion. As illustrated in figure 10, by the reception of evidence of the occurrence of a war zone and severe weather on the route of the approaching vessels to the port, all the descendants' nodes (factors) probabilities and finally the probability of port congestion directly increase. BN is considered a quick and easy tool for decision-makers to notice the direct consequences of the changing factors and their effect on the port's vessels' schedules.

Figure 10

Change in Probabilities in Reception of New Evidence

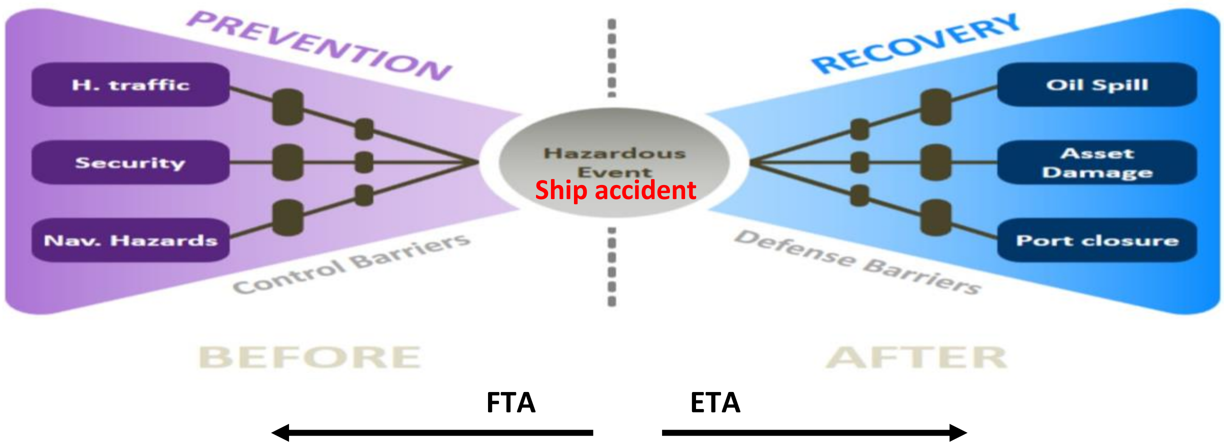
Probabilities of causal factors in normal conditions:	**Probabilities of causal factors with occurrence of war zone and severe weather**:
	

Models are constructed as a tool used in solving complex problems that are induced with a high flux of information. However, such information needs to be specific to be used as an input to ensure the reliability of the model. Therefore, the uncertainties around the input information should be understood and as Saltelli et al. (2019) state, sensitivity analysis (SA) and uncertainty analysis (UA) are the needed tools to explore the uncertainty of the model. In this case, the BN can be applied as a sensitivity analysis tool to identify the degree of effectiveness of each input information both individually and in connection with the other nodes. The analyst can choose which node to be used as a constant and speculate between the different probabilities, starting from the end node with the purpose to figure out the factors' nodes that have the greatest effect on the end node.

Several risk analysis tools are applied in the maritime field as mentioned in the literature review. There is a special concern in the safety field to assess the risks within any sea operation, and also in the security of ships and ports several risk analysis tools are applied to identify the security hazards and evaluate the applied measures. ETA and FTA are used to identify all possible basic events that may result in a critical event in a system or a barrier through FTA and to identify all possible consequences of such events and evaluation of needed barriers through ETA. As shown in figure 11, the integrated usage of FTA and ETA provides a comprehensive risk analysis method where both the causes and the consequences of an event are visualized as it covers the Bow- Tie diagram.

Figure 11

Bow Tie Diagram for Ship Collision

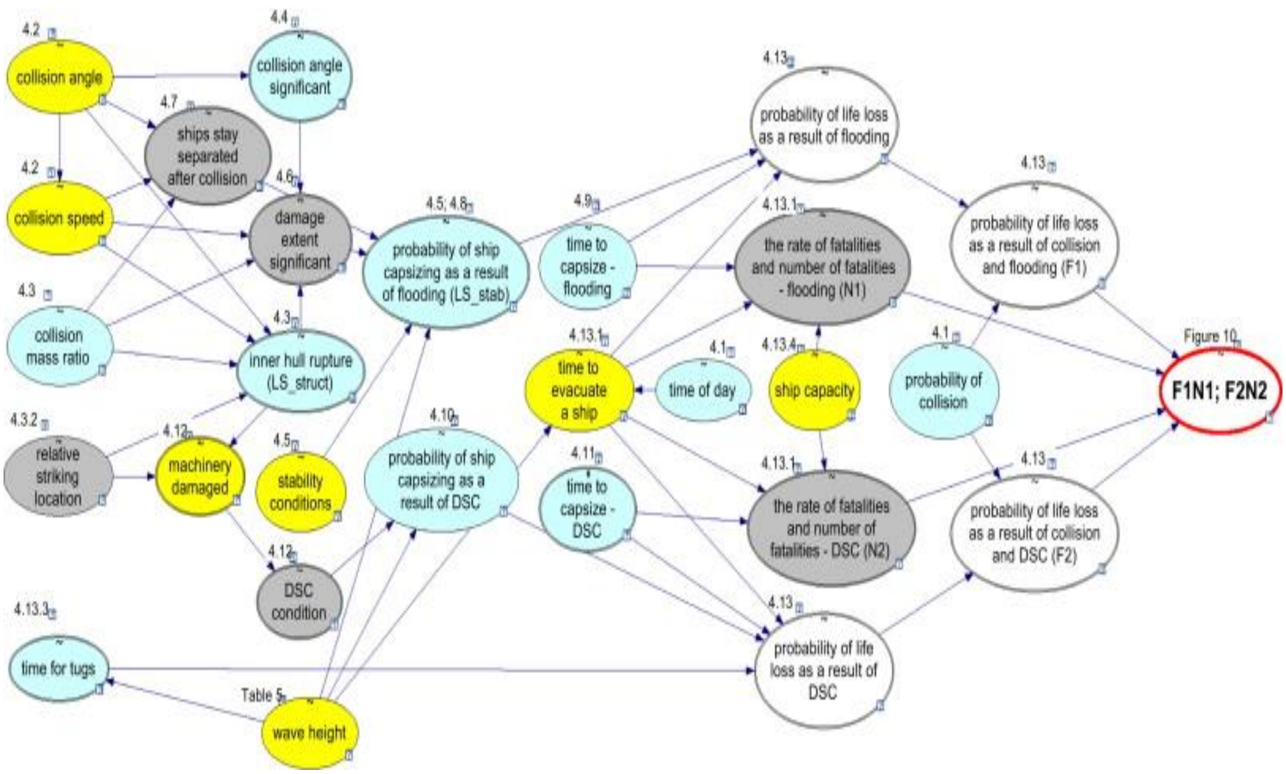


Note: Bow tie diagram for a ship accident, which is the top/hazardous event where the left-hand side is covered by the FTA to study the causes of the event and how to control them while the right-hand side is covered by the ETA to study the consequences of the event and how to defend against them.

Applying BN as a risk analysis tool in the maritime field is not the first time. It is widely applied in complex situations to differentiate between several causal variables. As shown in figure 12, Montewka et al. (2014) presented a framework to construct a logical relation between the causal variables for open sea ship collisions. The framework presented attempts to reflect the causality in the process of open-sea collision that is being analyzed by defining the relevant variables and constructing logical relations between them.

Figure 12

BN for Open Sea Collisions' Causal Variables



Note: the framework consists of four major parts, covering the following areas: (a) collision-relevant parameters; (b) capsizing-relevant parameters; (c) the response to an accident; (d) quantification of the consequences. No need for more details about the application since the example is for showing how BNs are being applied in the maritime field.

In the case of open sea collisions, various variables affect the severity of the collision. The BN applied to allow the analyst to establish relationships among the variables and complex dependencies as well as fast incorporation of new knowledge through the framework.

From the mentioned two examples in figures 11 & 12, it is possible to apply other risk analysis tools such as ETA and FTA in the port's congestion case but with the focus on identifying the causes or the consequences of congestion. Yet, in order to establish the logical relationship between the causal factors, BN is the best solution not only in providing such a network of relationships but also in allowing for the instantaneous updating of the network in the case of reception of new evidence.

The risk picture is given by the cause and consequence analysis as it covers (A', C', Q, K), where A': the initiating event, C': a set of quantities of interest within the consequences C, and Q: a measure or description of the uncertainties about A' and C'. Typically, Q is the probability P, and K is the strength of knowledge judgments (Aven, 2015, p. 13,43).

To construct a Bayesian Network, conditional probabilities are assigned in the CPT tables where it shows the probability of the event to occur given the combined probability of occurrence of other events. Bayesian probability reflects the analyst's degree of belief in the event to occur as he assigns the probability based on his experience and background knowledge (Heckerman, 2008, p. 3). The assigned probabilities can be updated when the assessor gains new knowledge about the event (Zio, 2007, p. 28).

The lack of background knowledge in dealing with the port congestion problem leads to uncertainty in constructing the BN. There are uncertainties in the following areas:

- Probabilities of occurrence in the CPTs.
- The cause-and-effect relations between the nodes.
- The hypothesis of the causal factors.

The reliability of the BN outputs is based on the validity of the assigned probabilities and the established connections between the factors' nodes. As Aven (2015, p. 25) stated, the analyst should qualify the assumptions made, data used, degree of disagreement between experts, models used, and the degree of understanding of the congestion problem in order to provide a reliable risk picture. Therefore, in order to produce an informative risk picture, the analysis team should have a good background knowledge with access to sufficient data to recognize the contributing factors and the relationship between them to formalize a reliable BN and CPT. The assigned probabilities are the analyst's degree of belief about the possibility of occurrence of each congestion factor. Furthermore, due to the volatility of the factors and the vulnerability of their probabilities, the analyst team should be alert concerning the congestion problem and its contributing factors. Any change in the port construction, equipment, services provided, performance, and any renovation that may affect any of the factors' nodes, should be accompanied by updating the BN accordingly.

Environmental accounts

The piling up of ships in front of the port during congestion is a source of increasing emissions. According to the California Air Resources Board report on the congestion that occurred in the ports of Los Angeles and Long Beach in 2021 (California Air Resources Board, 2021), congestion has led to an abnormally high number of container vessels (79 container vessels) at anchor, which use auxiliary engines continuously to run the ship equipment. The report stated that emissions increased by 20 tons per day (tpd) of oxides of nitrogen (NOx) and 0.5 tpd of particulate matter (PM) relative to the normal averages in the same zone, which is roughly equivalent to the total emissions from 5.8 million passenger cars in the South Coast.

Working on a solution for mitigating congestion to reach the Just in Time (JIT) concept, which allows vessels to directly berth on arriving at the port, is considered an environmental solution for preventing increased emissions from the waiting vessels. IMO in its global fight against climate change, has adopted mandatory measures to reduce emissions of greenhouse gases (GHG) from international shipping. It also urges its members to implement and support energy efficiency in the shipping sector (*Initial IMO GHG Strategy*, n.d.). Applying the BN as a proactive tool to prepare for and deal with the congestion problem before its occurrence can help in at least reducing the magnitude of the congestion if occurred by reducing the number of congested ships.

Discussion

Applying risk analysis, as a problem identification tool to figure out the interrelated complex ports' congestion factors that contribute to the problem, can provide several advantages different than those provided by the previous studies. Most of the preceding solutions were reactive. In Notteboom's (2006) solution, port's management should react to the congestion's occurrence by changing the vessels' schedules; solution is taken to make up for the already occurred delays, and it also has a negative effect on the reliability of the liners due to the frequent modifications in the container ships' schedules. On the other hand, applying BN is a proactive approach that can raise the attention of the port's management before its occurrence. Even if the port's management reacted to the BN's method warning by changing the ships' schedules, applying this solution in the early stages helps in decreasing the intensity of the congestion consequences if occurred.

The same reactive approach is presented by Agostini & Saavedra (2013) by prioritizing certain types of cargo ships over others to resolve the congestion after its occurrence, not to prevent or warn against its occurrence as presented by applying BN.

The BN also deals with the uncertainty factor, presented by Saeed et al. (2018). Although their method of TCA was a governance modification method, it can be considered supplementary to the BN solution as it mitigates some root nodes in the BN method. Improving the port's documentation processing and increasing cooperation between the maritime logistics stakeholders resolves some causal factors' nodes, thus decreasing the probability of congestion occurrence in the final node. The same case is with the solution presented by Manaadiar (2020), where he suggested digitalization, the introduction of new technologies, and relying on skilled workers. The BN function of mapping all the causal factors in the form of nodes; helps in applying such solutions by showing the effect of the applied solutions on the root nodes and the descendants' nodes. Furthermore, applying the BN as a sensitivity analysis tool helps in identifying the most effective nodes to be prioritized first, to eliminate the congestions' causal factors.

Applying BN in dealing with a port's congestion is different than other solutions that require more investments in port expansion, as presented by Fan et al. (2012) and Yeo et al.(2007). Ports' expansion solution is inevitable for some ports' authorities to absorb the continuous growth of ships and cargo volumes; nevertheless, the discussed factors can cause congestion even in ports with large capacities. Increasing port capacity does not deal with the uncertainties related to congestion causal factors, since they are formed from a large number of variables due to the nature of the maritime industry itself. The maritime industry involves various stakeholders, such as the ship owner or charterer, the cargo owner, the port authority, the cargo handling company, the shipping company, the customs and tax authority, and the security authority, which all contribute to the variability of the maritime field together with the vast regions that the ship covers. The factors can be unexpected and a number of them always occur simultaneously increasing the probability and the severity of congestion. In addition, not all port authorities have the capacity to invest in port renovation and expansion. There is a need for a solution that can provide a warning before congestions occur; so that the port authority can start mitigating the problem or working on decreasing its consequences in advance. The BN method can provide this solution since the contributing factors are mapped in the form of a network showing the different probabilities of occurrence of each one of them.

The BN is also systematic, proactive, and transferable. It utilizes the network as a medium to express and propagate the background knowledge that is available about the congestion problem from the previous events and the current situation.

In the application, the updatable function of BN is used in a different way. As mentioned by Aven (2009, p. 153), the BN is a tool that always reflects the available information, as it updates the result of the risk analysis before and after the operation, i.e., the difference between the planning and application phases. On the other side, applying BN in analyzing the factors of port congestion, is not about the difference between the planning and the execution phase, it represents a continuous reflection of the ongoing situation that provides a 24/7 tracking of the changing causal factors and their effect on each other and on the final congestion that may occur.

One of the challenges in applying BN as a warning tool for ports' congestion, is the need for a port-configurable causal factors map that includes all relevant factors for each port and to develop an easy way of keeping it updated. The reliability of the tool depends on the accuracy of the causal factors assigned by the port's team. The responsible port's team should be aware of all the expected congestion's causal factors and their degree of effect on the port. They should also be familiar with the regional and the international situation that may impose changes in the causal factors or may generate other types of factors. The team's experience and awareness of the situation will also affect the precision of the assigned probabilities in the CPTs.

Considering the update of the network, so far, it can be done manually by the port's team. Some factors can be done automatically, such as the weather update since most of the ports have sensors and software that can be connected directly to the system to update it regularly. The update process is connected to the degree of digitalization of the port and the connection with other ports and stakeholders in order to develop an automatic updating system.

Further research is needed to study the importance of ports' digitalization in the field of building a database for the congestion factors and the digital information sharing between stakeholders with the aim to develop a systematic reliable way of updating the network regularly.

Another challenge in the study, is the outcome of the used questionnaire. The questionnaire intended to get feedback from various ports, covering different regions to get a full picture of the congestion problem causal factors. Only 16 ports responded to the questionnaire; since many ports' authorities had reservations about responding to social media sources, and several ports' authorities expressed excuses that it was confidential information. However, the received responses agree with the author's experience in ports' management and with the gathered information from the available sources. This point ensures the importance of not taking the mentioned congestion factors as constants that are compatible with all ports. They are considered as guidance and there will always be differences, especially in the root nodes' factors, but the middle parent nodes' factors are general problems that present in several ports, such as the low productivity and the busy berths nodes.

One more challenge facing BN application, is the black swans' causal factors. While applying BN in dealing with the congestion's factors, the black swans may appear in three cases as presented by Aven (2014)):-

1. The evolution of a new congestion causal factor that is not mapped in the BN (unknown unknowns).

2. The occurrence of a factor that is not mapped in the BN due to ignorance of the port analysis team but may present in other ports' analysis (unknown knowns – unknown events to some, known to others).
3. Factors that the analysis team judged to have a low probability of occurring. It can be detected by the sudden increase in the probability of a factor, such as the consequences of the Covid pandemic and the blockage of the Suez Canal, where their marginal probabilities p(B) suddenly increased after being considered very low for a long period of time due to their past occurrence rarity.

The first case is unpredictable and unthinkable where the factor occurs for the first time. This case is very rare in the shipping industry but cannot be neglected because of the continuous development in the industry and the involvement of several stakeholders that may lead to the emergence of new unknown factors. The probability of the occurrence of the second and the third cases can be decreased by increasing the analysis team's proficiency and their awareness of the past and current maritime supply chain situation and the congestions' causal factors in different ports globally.

Applying BN as a tool to face congestion problems in its basic state is not costly but the idea is to develop the application to be a software included in the Port Information Management System (PIMS). The PIMS is a software system that is used by the port control team (responsible for tracking and controlling the ships' operations from their arrival until departure). The PIMS inputs are formed from all information about the port, visiting ships, weather parameters, and cargo, while the outputs are different types of reports considering the rate of cargo handling, statistics for ships and cargoes, and the ships' plans and schedules for berthing and disembarkation.

The next step for this research is to integrate the congestion causal factors into the system with its different probabilities. With the reception of new evidence and feeding it into the system, it can automatically transfer the effect on the next factors and finally shows the expected affected operations within the port, the affected vessels, and the affected time plans. Furthermore, the system can provide a medium for testing the effect of suggested solutions on dealing with the problem. In other words, to run the system in advance by applying solutions such as informing coming vessels to reduce or increase speed or deviating their course to another port, and to see the effect of this solution on the resulted congestion probability before it occurs. However, transforming the BN application into a software application requires investment in modeling and then integrating it into the software system.

In addition, the BN method needs to be applied by several ports to test its practical validity in warning the port authority against congestion increased probability and to measure the improved performance of a port by applying such an approach over time.

Conclusion

Ports' congestion is a recurring problem that is caused by several factors. Risk analysis can provide a tool as a problem identifier to figure out the interrelated complex factors that contribute to the problem by assigning weights and probabilities to each factor.

The smooth flow of cargo passing the ports as a gateway for coastal countries is crucial in the supply chain. There are more than 20 factors that can result in congestion of ships and consequently disrupt the flow of cargo globally. The type and magnitude of occurrence of such factors are various and unstable to the extent that they affect even the highly developed ports worldwide.

Risk analysis has been applied in the maritime field especially in dealing with security and safety. The BN is a tool that gives both qualitative and quantitative representations of the problem. The DAG provides a structure of causal dependence between nodes which is the qualitative part of causal reasoning in a BN; thus, the quantitative part is given by the CPTs showing the relations between variables and the corresponding states. In the study, BN managed to cover three main features for ports' congestion causal factors, which are: mapping the interrelated complex connection between factors; showing the cause-and-effect relationship between them; and dealing with the uncertainties within the variables and their occurrence.

The ports' congestion problem involves several complex factors that cannot be resolved by a simple Bayes theorem. A suitable software such as GeNIe software is used to construct (a) the DAG for the congestion factors nodes and (b) the CPTs with the assigned probabilities for the occurrence of all factors. The software also can be run with the updated information to show the consequential effects on the next level of factors' probabilities and the probability of the port congestion.

Although applying BN to the port congestion problem managed to reflect the interrelated connection between the factors and their effect on the congestion occurrence, it still needs to be integrated into the port information and management system to provide a 24/7 warning system that anticipates the congestion and acts as a test medium for the solutions suggested from the port management to deal with the newly occurred change in the factors. More attention is required towards the port analysis team's experience and punctuality in establishing the BN in order to minimize the effect of Black Swans and to assure the validity of the method in achieving its purpose of providing an early warning before congestions occur.

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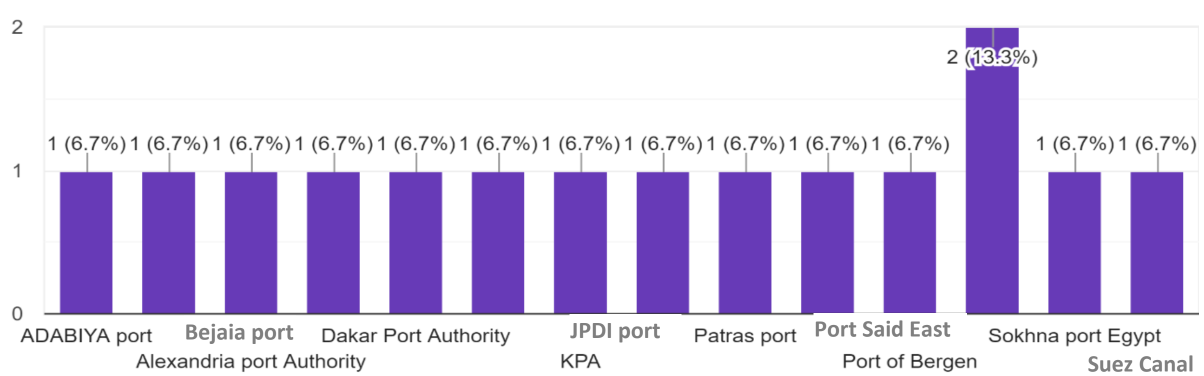
Appendix A

Causal Factors Questionnaire

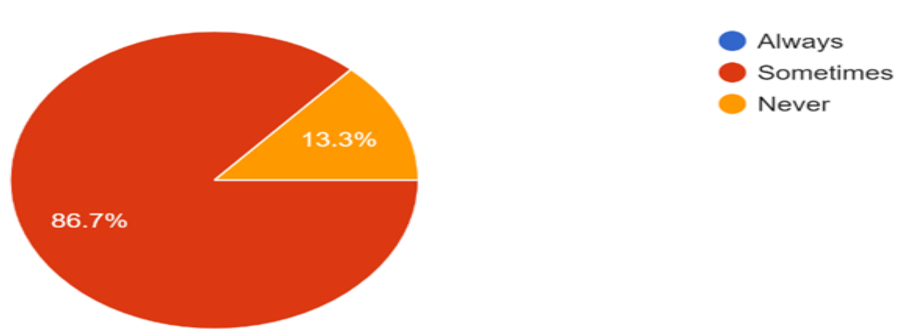
Your position **14 responses**

Deputy GM
General Manager
Port General manager
Port Deputy manager
Head Division
Branch Manager
VTS officer
Logistics officer
Head of Procurement department
Commercial manager
Manager
VTS Supervisor and manager
Pilot
Chief of vessels movement centre

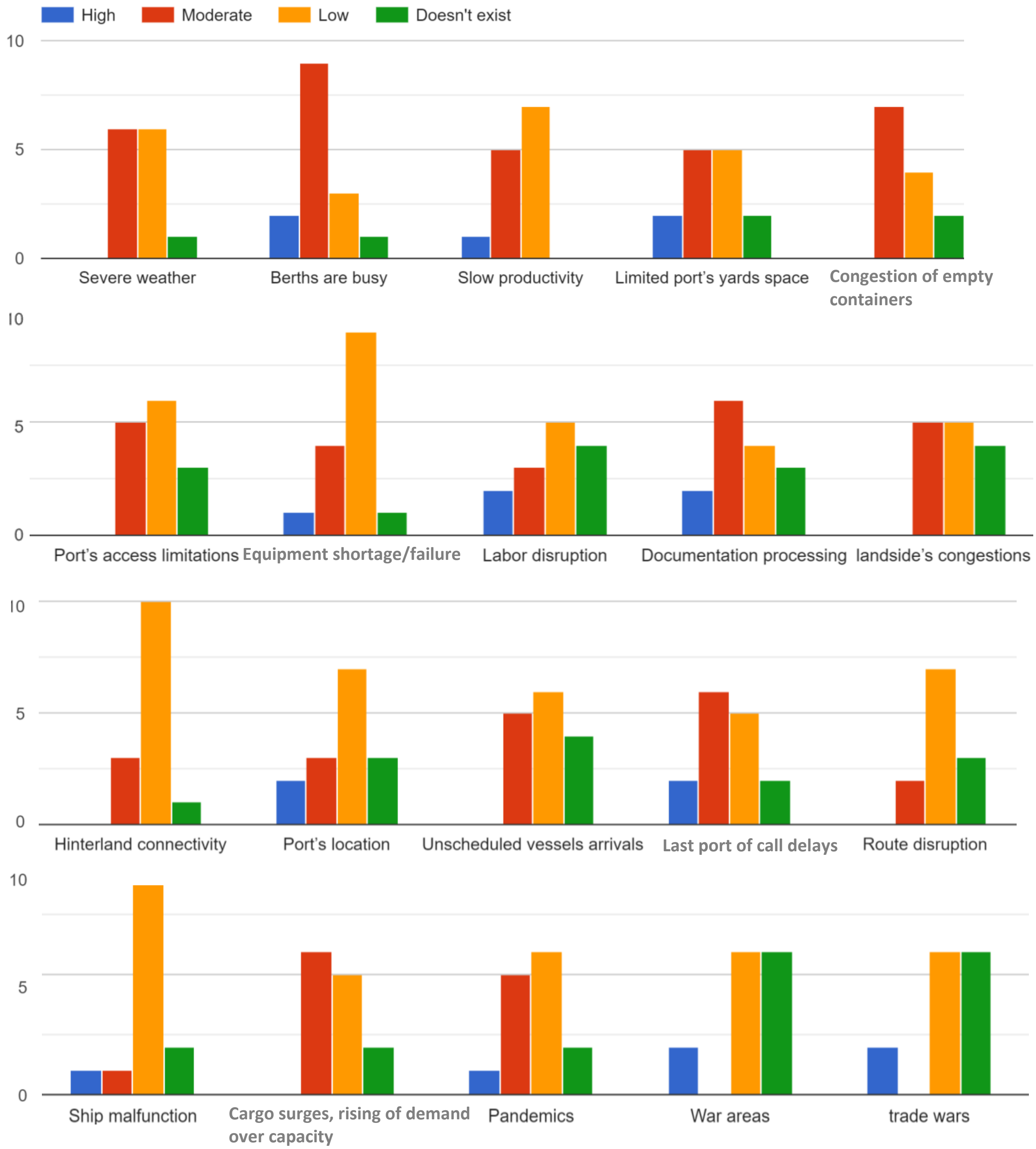
The port's name **15 responses**



How often does congestion occur in your port annually? **15 responses**



The following are observed causal factors for ports' congestion. Assign the degree of effect for each one of them on your port



What are other factors from your perspective can cause ports' congestion?

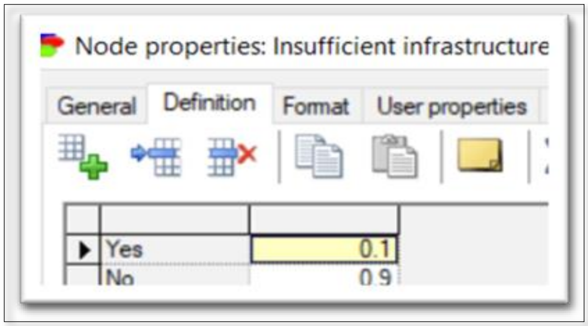
8 responses

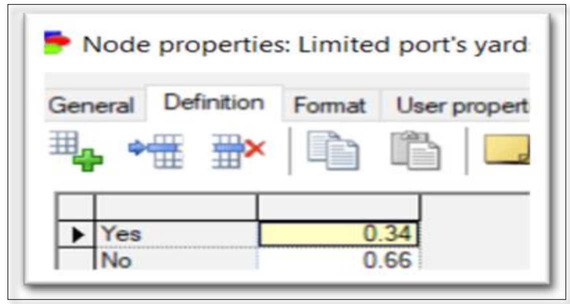
- Poor port management
- Some Cargo receivers refuse to store temporary on warehouses and request direct transfer from ship to outside the port.
- Price Competition between neighbouring ports
- Good Implementation of safety and environmental measures in port may lead to a congestion in a neighbouring port which don't follow these measures
- Not using artificial intelligence programs for utilizing berthing systems
- Strikes by some port actors
- Lack of gangs
- Lack of good communication between different parties
- Shipping and unloading companies / transport companies / shipment release procedures
- Seasonal activity (cruise, highspeed boats, super yachts, pleasure boats, tourism), bad weather and pandemic (ships wants layup)
- The dependence of many incoming commodities on the price on the international stock exchange in addition of Agricultural crops export season

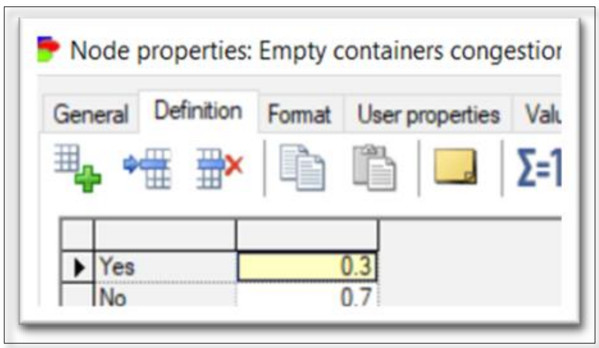
Appendix B

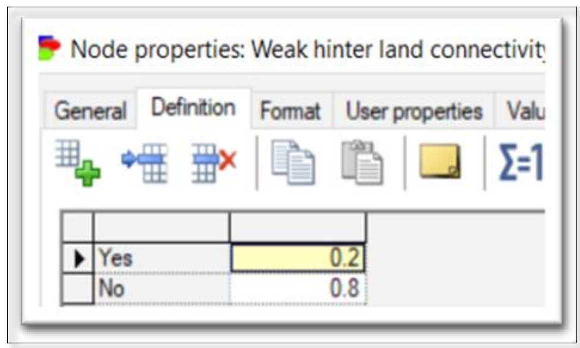
Conditional Property Tables

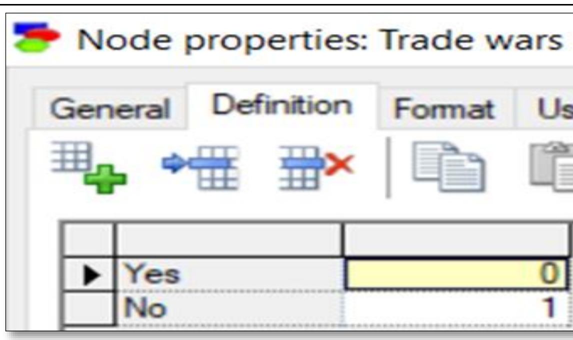
CPT's for root nodes

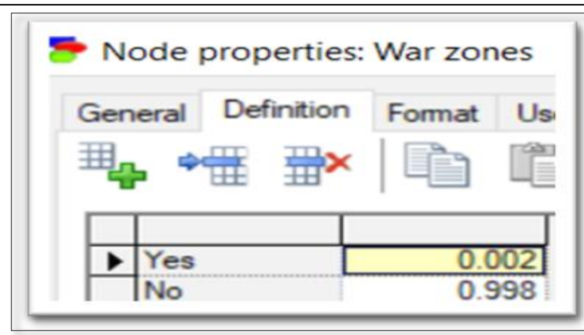


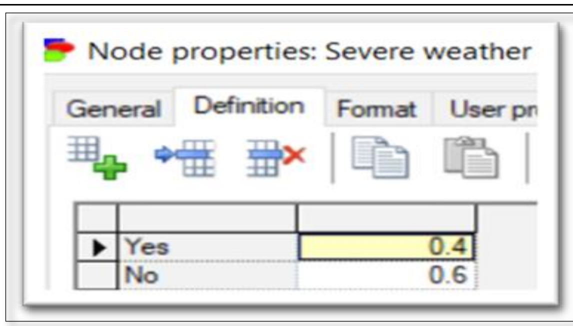


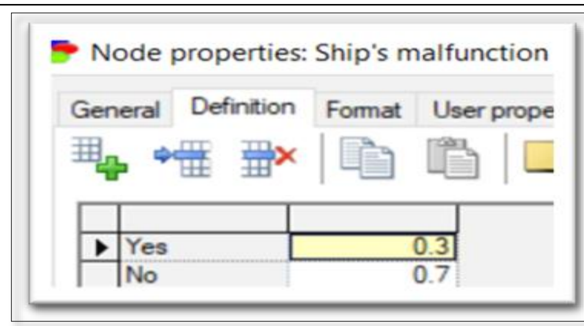


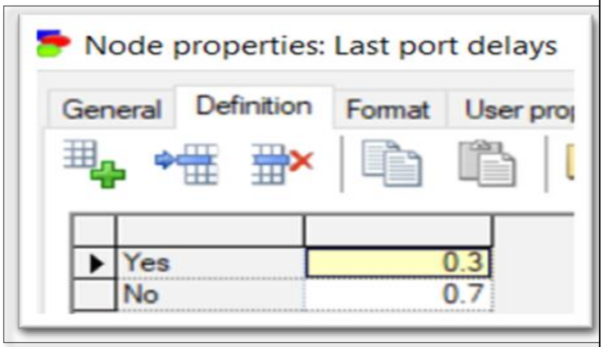


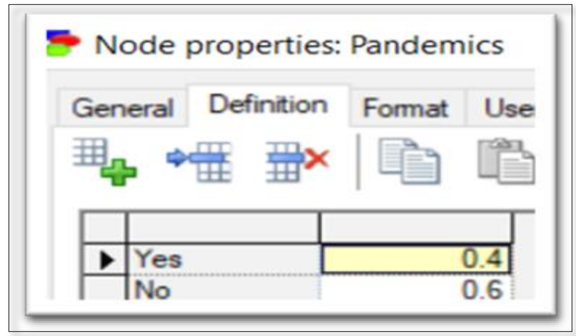


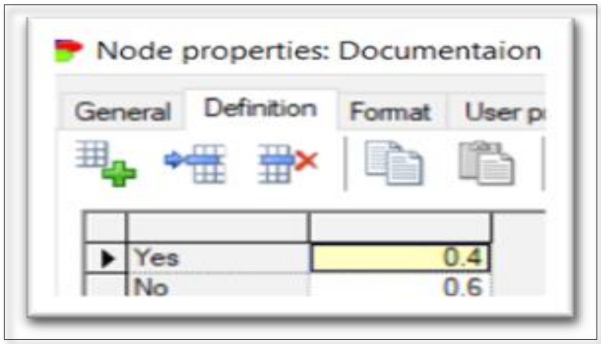


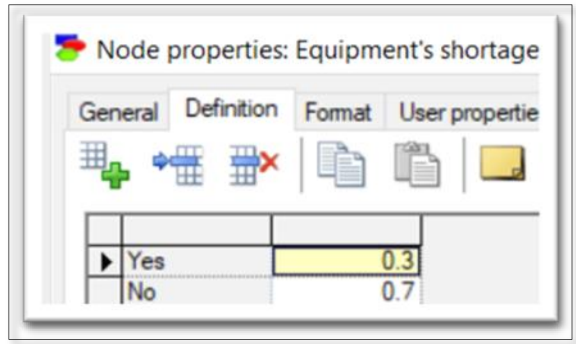


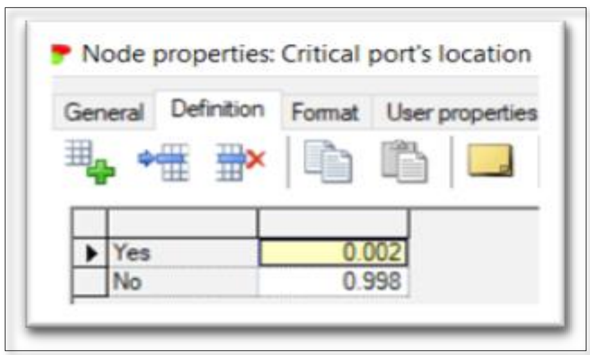




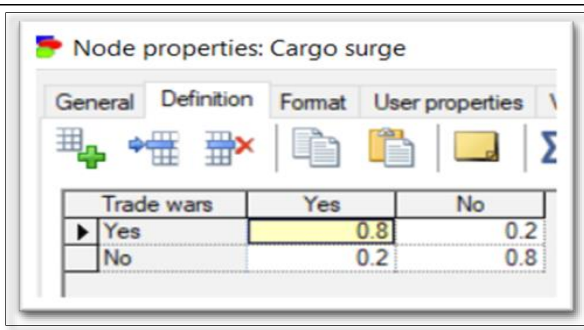


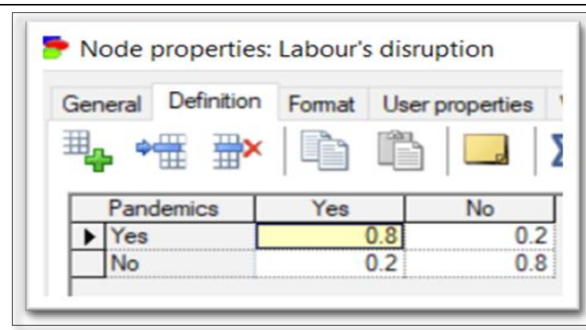






CPT's for anscestors' nodes to port congestion





Node properties: Route disruption

General | Definition | Format | User properties | Value

Ship's malfuncti...	Yes				No			
War zones	Yes		No		Yes		No	
Severe weather	Yes	No	Yes	No	Yes	No	Yes	No
Yes	1	0.9	0.89	0.3	0.89	0.75	0.3	0
No	0	0.1	0.11	0.7	0.11	0.25	0.7	1

Node properties: Slow productivity

General | Definition | Format | User properties | Value

Labour's disrupt...	Yes								No							
Equipment's sh...	Yes				No				Yes				No			
Insufficient infra...	Yes		No		Yes		No		Yes		No		Yes		No	
Limited port's y...	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Yes	1	0.89	0.8	0.7	0.87	0.7	0.76	0.67	0.8	0.7	0.65	0.6	0.34	0.2	0.2	0
No	0	0.11	0.2	0.3	0.13	0.3	0.24	0.33	0.2	0.3	0.35	0.4	0.66	0.8	0.8	1

Node properties: Land side congestion

General | Definition | Format | User properties | Value

Documentaion	Yes															
Empty containe...	Yes								No							
Weak hinter la...	Yes				No				Yes				No			
Equipment's sh...	Yes		No		Yes		No		Yes		No		Yes		No	
Limited port's y...	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Yes	1	0.9	0.8	0.78	0.87	0.76	0.7	0.67	0.78	0.67	0.64	0.63	0.62	0.61	0.6	0.59
No	0	0.1	0.2	0.22	0.13	0.24	0.3	0.33	0.22	0.33	0.36	0.37	0.38	0.39	0.4	0.41

Documentaion	No															
Empty containe...	Yes								No							
Weak hinter la...	Yes				No				Yes				No			
Equipment's sh...	Yes		No		Yes		No		Yes		No		Yes		No	
Limited port's y...	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Yes	0.58	0.57	0.54	0.56	0.58	0.59	0.62	0.6	0.61	0.62	0.62	0.63	0.6	0.57	0.54	0
No	0.42	0.43	0.46	0.44	0.42	0.41	0.38	0.4	0.39	0.38	0.38	0.37	0.4	0.43	0.46	1

CPT's to parents' nodes to port congestion node

Node properties: Port's access limitations

General | Definition | Format | User properties | V

Critical port's lo...	Yes	No
Yes	0.78	0.15
No	0.22	0.85

Node properties: Port's closure

General | Definition | Format | User properties | Value

Severe weather	Yes		No	
Pandemics	Yes	No	Yes	No
Yes	0.6	0.3	0.5	0
No	0.4	0.7	0.5	1

Node properties: Busy berths

General | Definition | Format | User properties | Value

Cargo surge	Yes								No							
Documentaion	Yes				No				Yes				No			
Land side cong...	Yes		No		Yes		No		Yes		No		Yes		No	
Slow productivity	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Yes	1	0.89	0.88	0.85	0.81	0.78	0.77	0.67	0.85	0.78	0.67	0.6	0.65	0.45	0.35	0.1
NO	0	0.11	0.12	0.15	0.19	0.22	0.23	0.33	0.15	0.22	0.33	0.4	0.35	0.55	0.65	0.9

Node properties: Unscheduled arrivals

General | Definition | Format | User properties | Value

Last port delays	Yes		No	
Route disruption	Yes	No	Yes	No
Yes	0.89	0.6	0.6	0
No	0.11	0.4	0.4	1

CPT for the end node "Port Congestion"

Node properties: Port's congestion

General | Definition | Format | User properties | Value

Busy berths	Yes								NO							
Unscheduled arrivals	Yes				No				Yes				No			
Port's closure	Yes		No		Yes		No		Yes		No		Yes		No	
Port's access limitations	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Yes	1	0.98	0.87	0.76	0.87	0.76	0.72	0.65	0.75	0.65	0.46	0.4	0.67	0.54	0.35	0
No	0	0.02	0.13	0.24	0.13	0.24	0.28	0.35	0.25	0.35	0.54	0.6	0.33	0.46	0.65	1