Improving the logistics and collaborative sensemaking during a disaster relief effort using a flexible floating and modular seaport

Investigating humanitarian logistics using a mathematical optimization model and a complex interaction research

TU Delft

Lenny Bakker. 2022

The above cover picture represents a possible design of a floating, flexible and modular seaport (Souravlias et al., 2020). The lower cover picture shows the damage to the international seaport of Port-au-Prince, Haiti, after a devastating earthquake in 2010 (Kneen, 2010).

Improving the logistics and collaborative sensemaking during a disaster relief effort using a flexible floating and modular seaport

Investigating humanitarian logistics using a mathematical optimization model and a complex interaction research

by

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Preface

Cycling past an asylum center and a school for disabled children on my way to my internship at the ministry of finance it grasped me. Nothing is more rewarding then helping people in need. Making this world a better place. At that moment the internship was my last step before I could start with my master thesis. One thing was sure. I wanted to contribute with my thesis to the world.

After some discussions and orientation the subject of using floating, flexible and modular seaports in order to improve humanitarian relief operations was defined. I knew right on, that this was the subject I would love to work on during my thesis. Finishing this thesis was a bumpy ride. With a lot of ups and downs. Motivation was not always as high as at the start. But I could always put my own struggles into perspective with the horrible circumstances that people affected by disasters have to deal with. I genuinely hope, that the insights in this thesis already can make 0.01% difference for them. In that case, it was all worth it.

Next to that, I am happy that I learned some new things during this thesis. I learnt how to grab complexity. How to interpret complex situation. Step into a complex situation full of noise and come back with the important relevant factors of that complex situation.

This thesis is the final product to obtain my master degrees in Mechanical Engineering as well as in Science Communication at the Delft University of Technology. During my time in Delft I did get the opportunity to develop myself in many ways. On top of that, I have made friends for life. Now I am ready to close this chapter in my life and I am really looking forward to the next chapters.

However, before I can start that next chapter I first have to thank a lot of people which helped me during this thesis. Firstly, I want to thank my mentor team of four: Mark Duinkerken, for being critical about my work, take the time to read my work and give elaborate feedback, for asking questions you don't want to hear to in the end improve the quality of the project, for thinking along with a student which need to combine two different subjects; Maarten van der Sanden, for brainstorming together, asking questions about what I want to reach instead what other expect me to reach, for feeding me with new insights; Dingena Schott, for keeping an overview, for keeping the process in mind; and Steven Flipse, for helping me putting the results into perspective, for the feedback on the theoretical part of this research.

Then, I really want to thank my family and the family of my girlfriend. Thanks for your continued support, trust and love. A special thanks to my parents for their patience and for allowing me to study this extensive amount of time. A special thanks to my sister Lisa for creating the cover of my thesis.

I want to thank all my close friends. Providing the relaxation necessary. I enjoyed every single beer (sometimes more then a single beer), dinner, soccer event and gaming session.

A last word of thanks is for Sanne. I know that I asked quite some patience from you. Despite that, you continued supporting me. Without you I would never have finished this thesis. I am really happy that I have shared my whole student life with you. I wouldn't miss it for the world.

Lenny Bakker, Delft, March 2022

Summary

It is strongly believed that two factors increases the frequency and impact of natural disasters in the coming 20 to 30 years. Climate change has and will increase the frequency and intensity of extreme weather events. Next to that, the impact of natural hazards also increases due to the concentration of population in urban area's. Logistics play an important role in effective disaster response and relief.

However sometimes logistics is also a bottleneck. Lack of seaport handling capacity leads to problems during disaster relief efforts. To deal with that problem a flexible, floating and modular (FFM) seaport is proposed. This seaport is stored all around the world and when necessary it is shipped from those storage facilities to the disaster area in order to help with the disaster relief effort. The goal of this research is to create the conceptual design which enables such a FFM seaport to reach its full potential to help during humanitarian logistics. From a communication perspective as well as from the logistics perspective.

When looking at it from a logistics perspective this research shows that the FFM seaport is of most help for disaster relief operations on islands bigger then 265,000 inhabitants. With regards to a timeline, this research concludes that the FFM seaport is not necessary within the first fourteen days after a disaster. The logistics goal of this research is to determine the place of storage facilities and amount of seaport handling capacity stored at those facilities.

With respect to the communication part this research concludes that collaborative sensemaking during disasters is the construct which holds the most potential for improving. Improving this construct leads to improving different other important processes in humanitarian logistics. One of the major improvements is that collaborative sensemaking improves the way of working together.

The FFM seaport helps during disaster relief efforts by creating more handling capacity to transfer goods from ship to shore. In order to maximize help it is important that the FFM seaport takes the costs, speed, appropriateness and uncertainty into account. The costs aspect shows that the costs have to be minimized while determining the conceptual design. It is allowed for a demand point to be helped by multiple facilities to keep the costs low. With regards to speed of transport there is a maximum service distance. This is the maximum distance between a storage facility and a demand point for which a storage facility can service that specific demand point. Appropriateness shows that (1) enough handling capacity must be stored to help every demand point and (2) every demand point needs to have a storage facility within their maximum service distance. With regards to uncertainty, the FFM seaport has to deal with (1) the uncertainty about the exact striking area and (2) with the fact that multiple disasters can happen simultaneously.

Note that it is possible to model these factors in a mathematical optimization model. In this research a mathematical optimization model is created in order to determine the logistical conceptual design. Before it is possible to use the created mathematical optimization model, three prepossessing steps needs to be performed.

The results of these preprocessing steps are several of more inputs for the mathematical optimization model. This model determines the storage locations and amount of handling capacity stored at those locations while minimizing the costs. The mathematical optimization model is solved multiple times with different input configurations. Every input configuration gives a conceptual design which is the best option cost based to deal with that specific input configuration. The input configurations differ with respect to the exact disasters happening and with respect to the amount of handling capacity necessary per demand point.

In total there are 12 different input configurations and thus also 12 different results of the mathematical optimization model. Comparing the outcomes of these input configuration shows that the more facilities are opened, the higher the average amount of facility locations needed to help a demand point is. This resulted in a higher the total distance travelled and a higher the average distance to reach a demand point. The results also show that it is possible to reach every single demand point when opening just two facilities. One in Kuala Lumpur and the other in Algiers.

With respect to the amount of handling capacity stored the results show a very large amount of capacity is stored. The exact number depends on the input configuration, but the amount of handling capacity stored is in every case more than the handling capacity of the current fifth largest seaport in the world. When considering the yearly cost it shows that financial wise it is possible to realize the FFM seaport. The different actors which need to invest in such a seaport are financially able to do so.

The best logistical conceptual design from a financial view point is very dependent on the exact disasters that will happen in the future. This means choosing the best design is about choosing which input configuration the decision maker favours.

However, when looking at the most applicable design, it can be argued that the best way to go is to place facilities in Kuala Lumpur and Algiers. This can be beneficially combined with the total amount of handling capacity stored in the run which scored the most favourable with respect to the average costs to help one person. This results in a configuration with Kuala Lumpur opened and storing 1,950 TEU/h and opening Algiers with a storage capacity of 812 TEU/h.

Next to the logistics contribution the possible usage of the FFM seaport also influence the communication process of actors involved in a disaster relief effort. As described collaborative sensemaking in disasters is important. A construct consist of concepts which consist of variables. Measuring these variables gives a picture of the construct of collaborative sensemaking in disasters. In order to find the concepts and variables, a systematic literature analysis is performed.

An emergency simulation role playing game experiment is created in order to evaluate how the usage of a FFM seaport influences the collaborative sensemaking process. Within this experiment, groups are asked to define a plan of action in response to a fictive disaster. The groups have to define this plan of action based on a lot of information. Every participant has different information. Within the process of creating a plan of action some groups are given the use of a FFM seaport. These are defined as the experimental groups. The others, the control groups, could not use a FFM seaport. The groups had to define the plan of action as quick as possible and also had to create a plan which reduced the amount of suffering the most.

It is important to measure the variables in order to analyse how the experimental groups differ in their collaborative sensemaking process with respect to the control groups. Some variables are measured using a questionnaire. The participants filled in a questionnaire after the experiment. The remaining variables are measured using an observer. This person wrote down notes related to the variables.

The hypothesis for this experiment is that the usage of the FFM seaport increases the complexity of the tasks which has to be performed. This increased in complexity leads to less overall performance. This hypothesis is backed up by, among other things, the fact that (1) the experimental group made more external representations (drawings, notes etc), (2) within the experimental groups less participants agreed with the statement that the participants could understand each other quickly and (3) by the fact that participants within the experimental group felt more frustration and fear to make the wrong decision.

The results show that participants in the experimental groups were more quick to start with information sharing than participants in the control groups. They also shared more information at the start of the experiment. On top of that, the amount of information sharing between different participants within the experimental group was less distributed then in the control group.

The quicker start of sharing of information, the larger the sharing of information within the start of the experiment and the more equally distributed participation of the participants is observed. In the experimental group this lead to several positive factors being more present. These are: more emotions shared, more awareness of the role of others, more awareness of the information of others and more agreement on the common goal. However, there is also a negative consequence. Starting earlier with information sharing increased the feeling of an overflow of information and of the feeling of not sharing the right information directly.

The evaluation of the results show a process. This process starts with an increased complexity. Because of that: more equally distributed participation, quicker start of sharing of information happens and more information sharing in the beginning. This increases the emotions shared, more awareness of the role of others, more awareness of the information of others and more agreement on the common goal. Together with more external representations and increased fear to make the right decision this increases a collective sensemaking during a disaster. However, increasing complexity leads to an increased perception of a bad collective sensemaking during a disaster process. This is, among other things, due to an increased feeling of frustration.

The results of the communication and logistics part of this research can be integrated. Two ways are possible. First, using the FFM seaport influences the collaborative sensemaking during disasters. This means that the usage of every design of the FFM seaport will increases the collaborative sensemaking during disasters. The second way is that the collective sensemaking part influences the design of the technology. This can be done by thinking to incorporate aspects to maximize the collective sensemaking process when using the technology in the design phase. When applying this second way of integration into the design of the FFM seaport, example adjustments to the design can be: create a web page or application in which organizations must administrate important information before they can use the seaport, indicating that wrong information can lead to problems or presenting an overview of which organizations are using the seaport.

Another interesting opportunity arises when the hypothesis that adding complexity leads to a better collective sensemaking is true. In that case it is argued that the conceptual design of the FFM seaport has to be adjusted in such a way that it increases the complexity of using it to an extent. For example by opening a lot of facilities at different locations and storing a low amount of handling capacity at those facilities in order to require several different facility points are necessary to help one demand point. This means that defining a plan of action where enough handling capacity is sent to a demand point becomes more complex. This results in a design of opening facilities in Kuala Lumpur (with 1350 TEU/h stored), Algiers (with 356 TEU/h stored), Dakar (with 57 TEU/h stored), Maputo (with 279 TEU/h stored), Berbara (with 35 TEU/h stored) and Corinto (with 332 TEU/h stored).

Note that this design meets the goal of the research. It is a conceptual design which enables such a FFM seaport to reach its full potential to help during humanitarian logistics. It reaches its potential on the logistics area as well as the communication area.

However there are also some discussion points. For example the input parameters for the mathematical optimization model are best estimates. These are mostly based on historical data. The question remains if this inputs mimics the real world data. Next to that there is room for improvement in some aspects of the emergency simulation role playing game. For example: (1) divide every group more equally with respect to age, profession, level of education etc, (2) ask participants about the description of their own role, (3) performing the experiment with humanitarian logistics experts and (4) performing the experiments in the same surrounding.

Also the concepts and variables together forming the collaborative sensemaking in disasters constructs is a discussion point. The exact difference between a collaborative sensemaking process in general and a collaborative sensemaking process in disasters remain unknown. It is argued that the process during disasters contains more factors related to time pressure and emotions.

List of abbreviations

BN	Billions
ERC	Emergency relief coordinator
FFM	Floating, flexible and modular
HC	Humanitarian coordinator
HCT	Humanitarian country team
IASC	Inter-Agency Standing Committee
Limit.	Limited
MT	Metric Ton
NGO	Non-governmental organization
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
P38	Past 38 years
Perc.	Percentage
TEU	Twenty-foot equivalent unit, the cargo volume of a 20-foot-long container
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
USD	United States dollar
UNHRD	United Nations Humanitarian Response Depot
WFP	World Food Programme

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Introduction, background and context (logistics and communication research)

1

Introduction

Homes are destroyed, access roads are impassable and gateways to the disaster area such as seaports and airports are unusable. Injured persons are in need of medical aid while other people have lost their homes. People are in need of food, shelter, water, clothing and hygiene resources. These are the results of a devastating earthquake hitting an isolated country. The consequences would be catastrophic if help is not provided quickly. Imagine you're a disaster relief worker responsible for the logistic part of the disaster relief operation.

What would you do in order to bring the necessary goods to the people as quickly as possible?

Most people with such a task at hand will at some point in the process investigate all available current possibilities and solutions to deal with the hard situation. Collaborations will be started and together decision must be made with regards to the human aid process. This research investigates a new technology which can be used in this kind of situations: a modular, flexible and floating seaport (FFM seaport) and how this technology can lead to a better group decision making process.

Such a FFM seaport can be used when the current port is not able to deal with the incoming disaster relief goods. The FFM seaport is stored somewhere around the world. After a disaster the decision is made to transport this seaport to the disaster area. This FFM seaport provides the necessary handling capacity to transfer the incoming relief goods from ship to shore.

The remainder of this chapter first introduced the Space@Sea project, which is the starting point of this research. After that the chapter outlines the current problems in humanitarian logistics, follows by the research goal and corresponding research questions. After that it gives the outline of the research and it finally presents a reading guide for the remainder of the report.

1.1. Space@Sea project

Flikkema and Waals (2019) introduces the Space@Sea project in their paper. This paper describe that due to the increasing population and rising sea level there is an increasing need for affordable land space at sea. They also state that new developments in offshore activities are calling for new ways of ocean usage such as renewable energy, farming at sea and housing at sea. They conclude that all this activities need sustainable and cost effective land space on water to operate safely at sea. The European Commission has identified this need in their Horizon 2020 research program which, among other things, aims to turn the seas and oceans into an asset for Europe.

Furthermore, the paper of Flikkema and Waals (2019), says that it is possible to create this land at sea by reclamation of a sandy island or by floating concepts. According to them the reclamation technology is a proven technology, accepted by the market but it is limited to shallow waters and it has a significant environmental impact. The advantage of a floating island is that it is suitable for deeper waters, it can be relocated if needed, it can be used for temporary applications and it is more sustainable.

Previous projects on floating island were focused on artist impressions and case studies into the societal acceptance and economic feasibility (Flikkema and Waals, 2019). Technical details and solutions for a large floating island, where multiple activities are combined, are not provided. The Space@Sea project consist, among other things, of a conceptual study to develop a standardized and cost efficient modular island with low ecological impact (Flikkema and Waals, 2019).

Flikkema and Waals (2019) identifies modularity and standardisation as key concepts for the Space@Sea project. They state that interconnecting modular elements, creates a flexible structure. Modulation reduces production and maintenance cost and provides flexible usage. Figure 1.1 shows a couple of this modular elements in a test setting. Space@Sea focuses on four types of applications on the floating blocks: generating energy, living space, farming and maritime transport (Flikkema and Waals, 2019).

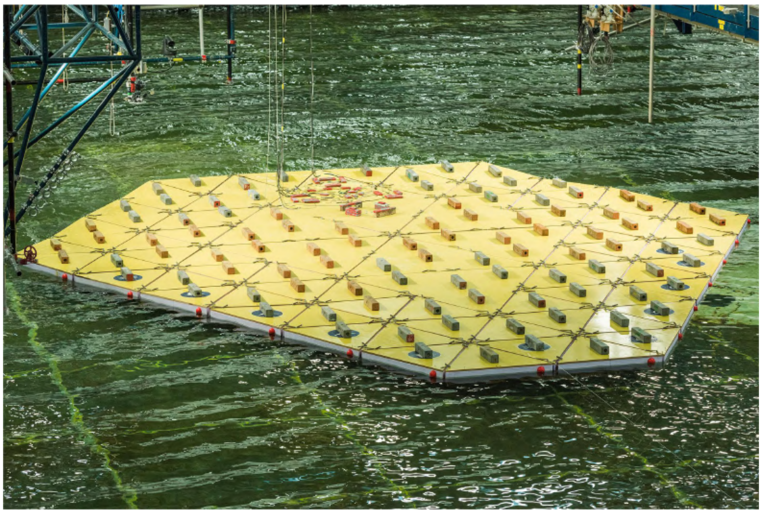


Figure 1.1: Testing the modular flexible elements of the Space@Sea project (Flikkema and Waals, 2019)

One of the deliverables, within the maritime transport application, is a design framework for a floating modular container terminal hub and applying this framework on a floating hub aimed to service the port of Antwerp (Souravlias et al., 2020). This deliverable showed that it is technically and logistically possible to realize a floating container terminal hub. A part of this hub is visualised in Figure 1.2.

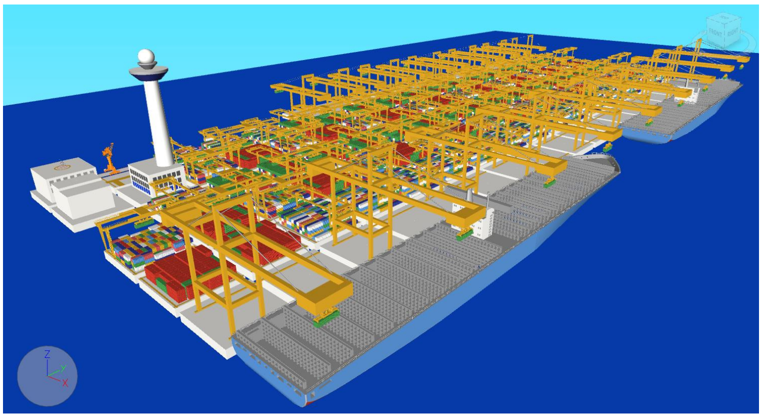


Figure 1.2: Concept of a floating container terminal hub (Souravlias et al., 2020)

Another deliverable of the Space@Sea project is a business case for such a floating container terminal (Dafnomilis, 2020). This business case present a comparison between a floating container terminal hub, a container terminal situated onshore and a container terminal on reclaimed land. The business case mainly focuses on the Port of Antwerp and conclude that cost-wise the floating container terminal hub is a more expensive option to expand then the onshore or reclaimed land options. The business case also briefly introduces another application for the seaport: a time-wise, short disaster relief effort off the coast of Africa. This will result in a floating terminal close to the affected area in order to transship relief supplies from ships directly to the affected area at places where seaports are lacking or destroyed. The results from the business case still not favor this option money-wise as a direct competitor of onshore ports. The business case however describes the potential of the floating container terminal in disaster relief operations were operation cannot take place onshore.

Research to such kind of floating seaports is needed in order to fully access the potential. This observation forms the starting point of this research.

1.2. Problem description

In total 3,751 natural disasters are recorded between 2008 and 2017. An estimated two billion of people are affected and an estimated $1,658 billion have been lost due this disasters (Fisher et al., 2018). The International Federation of Red Cross and Red Crescent Societies (ndb, par. 1) describes a natural hazard as follow: “Natural hazards are naturally occurring physical phenomena caused either by rapid or slow onset events which can be geophysical (earthquakes, landslides, tsunamis and volcanic activity), hydrological (avalanches and floods), climatological (extreme temperatures, drought and wildfires), meteorological (cyclones and storms/wave surges) or biological (disease epidemics and insect/animal plagues)”. It is strongly believed that because of climate change the frequency and intensity of extreme weather events increases. Next to that also the impact of natural hazards increases due to the concentration of population in urban area’s. These two factors increases the frequency and impact of natural hazards the coming 20 to 30 years (Ehrhart et al., 2008; Keen et al., 2003).

Investments in disasters preparedness and response is necessary to deal with the expected rise of the frequency and impact of extreme natural hazards (Ehrhart et al., 2008; Keen et al., 2003). Logistics plays an important role in effective disaster response and relief (Altay et al., 2009; Majewski et al., 2010; Thomas and Kopczak, 2005). It is estimated that around 60-80% of the income of a humanitarian organization is spent on logistics (Tatham et al., 2017). However there are still several problems with the role of logistics in disaster relief operations. Altay et al. (2009) identifies a couple of difficulties in providing supplies to disasters zones. This are among other things: a short time horizon in which people are in need for help, a long distance between the supplies distribution centre and the disaster zone and the fact that transportation infrastructure can be damaged heavily due to the disaster. Others describes the fact that a long time of underestimating the importance of logistics in disaster relief operations creates a lack of operational knowledge and a shortage of investment in technology, communication and in the latest technologies (Majewski et al., 2010; Thomas and Kopczak, 2005). A European Ambassador at a 2004 post-Tsunami donor conference said: “We don’t need a donors conference, we need a logistics conference” (Thomas and Kopczak, 2005, p. 1). Similarly, a spokesman for Doctors Without Borders said: “What is needed are supply managers without borders: people to sort goods, identify priorities, track deliveries and direct the traffic of a relief effort in full gear” (Thomas and Kopczak, 2005, p. 1).

After the 2004 Asian Tsunami more and more organizations became aware of the important role of logistics in disaster relief (Majewski et al., 2010; Thomas and Kopczak, 2005). As Majewski et al. (2010, p. 5) put it: “A whole new field of humanitarian logistics, ensuring the efficient and cost-effective flow and storage of goods and materials for the purpose of alleviating the suffering of vulnerable people, came of age during this tsunami relief effort”. Making the humanitarian logistics a relative new field (Hellingrath et al., 2015). The last couple of years, organizations and scientists performs a lot of research in order to try to bring the knowledge in the field up to date (Majewski et al., 2010). However a lot of research in this field have an reactive approach and focuses on the key humanitarian organisations. This means that most research tries to learn from past mistakes and finding ways to adapt to the changing demands of the key players in the sector. Several researchers highlight the importance of general disaster relief preparedness activities, but little research effort addresses the logistic opportunities that can help in relief disasters (Majewski et al., 2010).

The main objectives of humanitarian logistics is to save lives and reduce suffering. To reach the goals supplies are needed. Airplanes are normally the first choice to deliver these supplies since they are able to quickly reach disaster affected areas. However when large volumes of supplies are necessary, sea transport is the only option (Möhring and Link, 2013). This is why the United Nations World Food Programme charters vessels. These vessels are ably to carry 200,000 - 300,000 metric ton of food (WFP, 2019). Seaports are necessary in order to transship goods from the ship to the shore. The effectiveness of a seaport can be negatively affected in two ways in case of a disaster: (1) direct damage to the infrastructure of the seaport or/and (2) being flood with incoming goods and so exceeding the total capacity (Hellingrath et al., 2015; Möhring and Link, 2013). Due to this two reasons, seaports are often the bottleneck of humanitarian logistics operations (Hellingrath et al., 2015). As an example, the first reason was one of the main reasons of the slow emergency response during the Haiti earthquake in 2010. Due to the earthquake 50% of the port was destroyed and the port could only run at 10% for several weeks (BBC, 2010). Relief organisation stations personnel in seaports to deal with the second consequence. This personnel helps handling the incoming relief goods and makes seaport processes more efficient (Möhring and Link, 2013). Within this research a FFM seaport is proposed as a solution to deal with the seaport being a bottleneck.

At this moment only two systematic programs in the world tries to increase the disaster preparedness of seaports: Get Seaports Ready for Disaster and Port Resiliency Program (Hellingrath et al., 2015; Möhring and Link, 2013). Both programs focuses on training's, self-evaluation, outside expert evaluations, collaborations with local stakeholders and the drawing up of plans in order to cope with disasters. Get Seaports Ready for Disaster is mainly trying to increase the performance of seaports and to expand their handling capacity. The Port Resiliency Program focuses on optimizing the resistance of ports organisations and physical facilities to decrease the impact of damage from natural disasters. Get Seaports Ready for Disaster focuses on seaports in Africa and the Port Resiliency Program on seaports in Latin America and Caribbean (Hellingrath et al., 2015; Möhring and Link, 2013).

Port resiliency improvements is classified in two categories: (1) "hard" resiliency such as structural measures and (2) "soft" resiliency containing of policy, organizational/relationships, procedural, and defensive measures (Link et al., 2014). Current existing resilient programs focuses on the relatively short term and tries to find quick, relatively inexpensive fixes through "soft resiliency" measures rather than through major physical infrastructure changes (Hellingrath et al., 2015; Link et al., 2014). At this moment there is a lack of motivation from ports to improve their resiliency (Hellingrath et al., 2015; Link et al., 2014). This because they do not see any need improving their resiliency, they lack the financial resources and they the lack of guidance (Link et al., 2014; Portstrategy, 2017). Link et al. (2014) proposed a world wide port resiliency certification program with clear, explicit standards, procedures, and documentation that must lead to lowered insurance premiums or preferred treatment on reimbursements for losses.

At this moment it seems like the port resiliency improvements programs are not yet very successful. The sites of the programs (https://www.portresiliency.org/ and https://www.bvl.de/) presents no up to date information and articles on several logistics websites are still highlighting that the motivation for port resiliency is still a problem (Logistics Update Africa, 2016; Portstrategy, 2017).

During the Haiti earthquake, aid organisations have received a lot of critique. Many of the international aid agencies were busy promoting themselves rather than working for the common humanitarian goal. There was no effective common leadership as many non-governmental organisations were competing against each other (BBC, 2010). This lack of coordination and management among the whole humanitarian logistics chain is still a big issue (Logistics Update Africa, 2016; Richey et al., 2009).

Bealt et al. (2016) concludes that humanitarian logistics improves by setting up a collaboration between humanitarian organizations and logistics service providers. Thomas and Kopczak (2005) describes the limited collaboration between different relief organizations as a core challenge in humanitarian logistics. It is hard to achieve this collaboration due to the complex situation. On top of that there is competition in funding between organizations. This results in logistics departments not working together and not knowing that the other organisations face the same challenges. Rodríguez-Espíndola et al. (2018) points out that little research is performed about collaborations in humanitarian logistics.

Holguín-Veras et al. (2012) identifies the different research needs regarding humanitarian logistics. One of them is the decision making structure and another one are decision support tools. In humanitarian post disaster logistics the decision making structure is complex: non structured, highly dynamic, often informal, improvised, far from unified and involves thousands of independent decision makers (Holguín-Veras et al., 2012). Thomas and Kopczak (2005) describes the fact that logistics experts are not involved in the decision making process during relief operations as a core challenge in humanitarian logistics. They state that the program staff controls the budget and determines the amount and sort of supplies that need to be delivered in order to provide relief services. After the decisions are made they inform logistics telling them logistics is responsible for the transport of this certain amount of goods to the disaster area.

The above conclude the following problem description: *The humanitarian logistics field is relatively new and not a lot of research is performed towards the logistic opportunities that can help during a disaster relief operation. Decision making in humanitarian logistics is an important area which needs further research. Seaports are an important link in the chain of humanitarian logistics but also often the bottleneck in disaster relief operations. To manage this bottleneck several programs tries to make seaports more resilient for disasters. This programs are trying to find quick, relatively inexpensive fixes through "soft resiliency" measures rather than through major physical infrastructure changes. A lack of motivation prevents this programs from being successful.*

1.3. Research goal

This research focuses on two different aspects of the role of seaports in humanitarian logistics. The first aspect focuses on dealing with seaport resiliency. The inspiration of this idea comes from Hellingrath et al. (2015). They propose to make a fleet of retired naval amphibious-capable ships to deliver supplies to any coastline regardless of the availability of a seaport. This, out of the box, idea bypasses the problem of inadequate, damaged, or destroyed ports. This research investigates if it is possible to bypass the inadequate, damaged or destroyed ports by using the Space@Sea seaport. This results in a FFM seaport, which can be sailed to any coastline and be connected to the mainland of the disaster area.

The second aspect focuses on the decision making process. Bypassing the current seaports during disasters makes it less important to motivate the current port authorities to deal with resiliency of their ports. An organization or alliance must be in the possession of this seaport and therefore has a major role in the decision making process during the disaster. Next to that they can control the amount and sort of supplies. The organisation needs to work together with a lot of other organizations involved in the humanitarian relief effort. It is necessary to exchange knowledge and information in order to operate in the most efficient and successful way. Exchanging knowledge and information leads to a sense-making activity (Müller-Seitz and Macpherson, 2014), As Wenger (2000) states this sense-making activity is a consequence of participation in a complex social learning system. The success of the disaster relief effort depends on the ability to successfully design such kind of a social learning system. Studies into the (social) learning aspect on a human level during crisis are rare (Müller-Seitz and Macpherson, 2014). Next to that, (Yaqoob et al., 2014) state that little studies research the effect of a new technology on the decision making process in disasters. Smith and Dowell (2000) conclude that a lack of coordination in disaster response is a problem, partly because of conflicts in the decision making process.

The goal of this research is *to create the conceptual design which enables such a modular, flexible and floating seaport to reach its full potential to help during humanitarian logistics*. A conceptual design is the result of the preliminary design phase. It gives the outline of the design so that the basic principles and engineering features can be evaluated by the essential design requirements. On basis of the above, two sub goals are introduced to scope this main goal:

1. To design the logistical conceptual design of such a seaport. This design comprehend the determination of the place and quantity of stored modular and floating terminal parts, in order to make sure that a sufficient amount of floating terminal parts will be on time at the affected location.
2. To create a framework, which comprehend factors, processes, elements and the relationships between them on how to influence the collaborative sensemaking process in crisis situations. Apply this framework on the conceptual design of such a seaport leads to meeting the main goal of this research.

Note that the first research goal determines the total stored handling capacity at a certain location. A certain amount of modular and floating terminal parts represents this stored handling capacity. It does not comprehend the amount of relief goods stored at a location. However, there is a relationship between handling capacity and necessary amount of goods. The total stored handling capacity of the modular and floating terminal parts at a certain location is determined by the total amount of relief goods necessary at a certain disaster affected location.

This graduation research combines two different master tracks. The two sub goals represents these different study programs. The first sub goal corresponds with the Mechanical Engineering - Transport Engineering and Logistics track. The second sub goal with the Science Communication - Communication Design for Innovation track. Integrating these two goals in one research, leads to integrating technical and social factors in the conceptual design of such a seaport. The research is not limited to investigating how an technological innovation can directly be a solution for a current problem. It also investigates how the innovation helps in setting up a collaborative decision process, in which communication between different people and parties is key. Kaklauskas and Zavadskas (2007) conclude that there are some studies about putting innovation into practice with help of decisions support tools available. However, studies which investigates the secondary effect of using a new technology on the decision making process are rare.

1.4. Research questions

The problem statement and research goals leads to the main research question. This research answers the following main research question:

“How could a modular, flexible and floating seaport contribute to an effective and efficient disaster relief effort?”

To answer this main research question, the following seven sub questions are important:

1. What are the important factors which the conceptual design of the FFM seaport must take into consideration?
2. How are the factors which determine the logistical conceptual design of such a FFM seaport (storage place and necessary handling capacity) be used in humanitarian optimization models until now?
3. What is the best optimization model to optimize the factors which determine the logistical conceptual design (storage place and necessary handling capacity) of the FFM seaport?
4. What is an applicable logistical conceptual design (storage place and necessary handling capacity) of a FFM seaport in order to help with disaster relief efforts.
5. According to literature, which factors influences a collaborative sensemaking process during disasters?

6. How can be evaluated how the usage of a FFM seaport influences the collaborative sensemaking process?

7. What are the factors which improves a collaborative sensemaking process during disasters.

1.5. Research outline

This research integrates two fields: logistics and the collaborative sensemaking processes. Combining those two fields leads to an integrated design of such a seaport. One main research goal and research question guides the research with the help of two research sub goals, one for each field of study, which scoped the research. The aim of the sub goals is to contribute to their respective research field.

Figure 1.3 presents a visualisation of the research outline. This figure visualise the research process for both the logistical as the decision making part. First of all an integrated current situation is given. This part corespondents with the first research sub question. It gives the important factors which the conceptual design of the FFM seaport must take into consideration. Some of the factors are important for both fields, some for the logistics process and some for the collaborative sensemaking process. The next step of the research is to use literature to find how current mathematical optimization models deal with the logistical factors. This relates to the second research sub question. By conducting experiments it is possible to define the conceptual design of the seaport. A computer model experiment of a mathematical optimization model finds the best place to storage such a seaport and the corresponding amount of stored handling capacity. The creation of this model relates to research sub question three. The results of the experiments with the mathematical optimization model leads to the logistical conceptual design, which relates to research sub question four. Note that research question two, three and four are all related with the first sub goal and thus with the logistics part of the research.

After this logistics part, the research continues by using literature to define a theoretical framework about collaborative sensemaking during disasters. This relates to the fifth research sub question. After that an emergency simulation role playing game evaluates the factors which influence the collaborative sensemaking process during disasters. The creation of this experiment relates to research sub question six. The results of this experiments gives the factors to improve in order to boost the collaborative sensemaking process during disasters. This relates to research sub question seven. The final part of this research integrates the results of the two experiments. Due to that it is possible to determine if and how such a seaport can contribute to effective and efficient humanitarian logistics. It gives a conceptual design which improves the logistical capacity as well as the collaborative sensemaking during disasters. This forms the answer to the main research question. The final part of this thesis consist of a conclusion, discussion and reflection and evaluates the research and the final conceptual design.

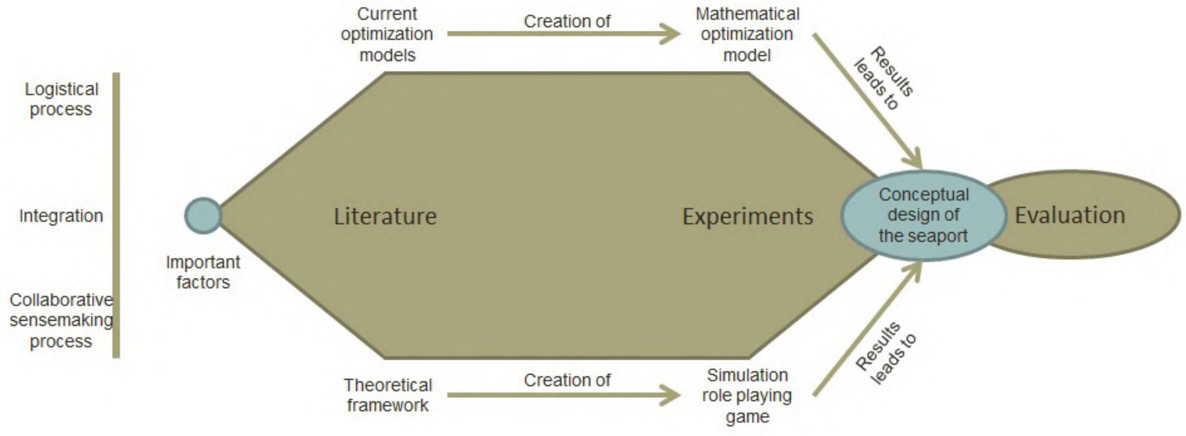


Figure 1.3: Visualisation of the research outline

1.6. Reading guide

This thesis is divided into four parts: (1) introduction background and context, (2) literature, methods and results logistics research, (3) literature, methods and results communication research and (4) discussion, conclusion and recommendations. This research combines a communication and logistics research. Note that the first and fourth part of this research describes content which is related with the communication as well as the logistics part of this research. Part two is related with the logistics research and part three with the communication research.

The first part contains of five chapters. The first chapter introduces the combined research. The second chapter describes humanitarian logistics. The third chapter presents an analysis about all interesting past disaster relief efforts. The fourth chapter describes a big problem in humanitarian logistics: material convergence. The fifth chapter defines the important factors which the FFM seaport needs to take into account. The end of this part answers the first research sub question.

The second part contains of five chapters. Chapter six describes the mathematical optimization models in current humanitarian logistics literature. This chapter gives answer to the second research sub question. Chapter seven describes the created mathematical optimization model. This chapter gives answer to the third research sub question. Chapter eight describes the experimental plan, chapter nine the results of this plan and chapter ten evaluates the results of this experiment. Together these three chapters gives an answer to the fourth research sub question.

The third part consist of four chapters. Chapter 11 describes the systematic literature analysis. This chapter gives answer to the fifth research sub question. Chapter 12 presents the emergency simulation role playing exercise. This exercise gives answer to the sixth research sub question. Chapter 13 presents the results of this exercise and chapter 14 evaluates these results. Together these chapters presents the answer to the seventh research sub question

The fourth part consist of four chapters. Chapter 15 combines the results of the logistics and communication part. Note that this combination presents the answer to the final research question. Chapter 16 discusses the research. Chapter 17 presents the conclusion. Finally, chapter 18 discusses some recommendations and implications.

This reports presents frames with texts at the end of some sections or chapters. These frames contains a summary about the most important points of that corresponding section or chapter.

2

Humanitarian logistics

The goal of this research is to create the conceptual design of a FFM seaport. The first step of this design process is to find out the important factors of humanitarian logistics. This chapter describe the most important aspects of the humanitarian logistics field. The chapter first covers the place of humanitarian logistics within disaster management. Second, it explains the key characteristics of humanitarian logistics. Third, this chapter covers the usual timeline of disaster relief efforts. Fourth, it explains the different actors involved in humanitarian logistics. Finally, the chapter indicates the interesting locations for which the FFM seaport can be of help.

2.1. Disaster management stages

Before describing the characteristics of humanitarian logistics it is good to place humanitarian logistics within the total disaster management field. Disaster management is the process of creating plans, rules, tools, collaborations, codes and so on to optimally deal with disasters (Tomasini et al., 2009). Disaster management consist of several stages which can be represented by a circle. The full circle of disaster management consist of four stages: mitigation, preparedness, response and rehabilitation (Tomasini et al., 2009). Mitigation addresses laws and mechanisms with the goal to reduce or eliminate long-term risk to people and property. For example, building codes and restrictions. Preparedness is the building of an emergency management function to respond to and recover from any risk that society has not been able to mitigate. Response is the actual conducting of emergency operations. Rehabilitation comes after the response and addresses the rebuilding of the communities in order to restore some form of normality. This however is not simply a return to the same old situation. That old situation proves to be vulnerable to a disaster and so improvements must be made. This improvements are made in new laws and mechanism with the goal to reduce long-term risk. In other words it starts a new mitigation phase. This implies continuous improving and due to this disaster management can be seen as a circle. Organization are not only working during a disaster but also between them to constantly learn and adapt to new situations (Tomasini et al., 2009). The role of the different actors is different in every phase of the disaster management cycle. However in every phase non-governmental organisations (NGOs) play important roles (Government of India, 2010; OCHA, 2017; WFP, 2011; Yuprasert, 2016). Figure 2.1 shows the disaster management cycle.

The two sub goals of this research corresponds with the mitigation phase of the disaster management cycle. The logistical conceptual design of the seaport, the first sub goal, defines the storage place and necessary stored handling capacity of a FFM seaport to help in emergency situations. This corresponds with the preparedness phase since it involves the creation of an emergency help tool. The goal of this tool is to deal with the non mitigated situation of not having enough handling capacity available to help the affected people. The second sub goal studies the effect of using such a FFM seaport with respect to the collaborative sensemaking of disaster relief actors. The factors which improves this collaboration are highlighted and used in the conceptual design of the seaport in order to foster the collaborative sensemaking process during disasters. Since these factors are incorporated in the design, this second sub goal also corresponds with the preparedness phase.

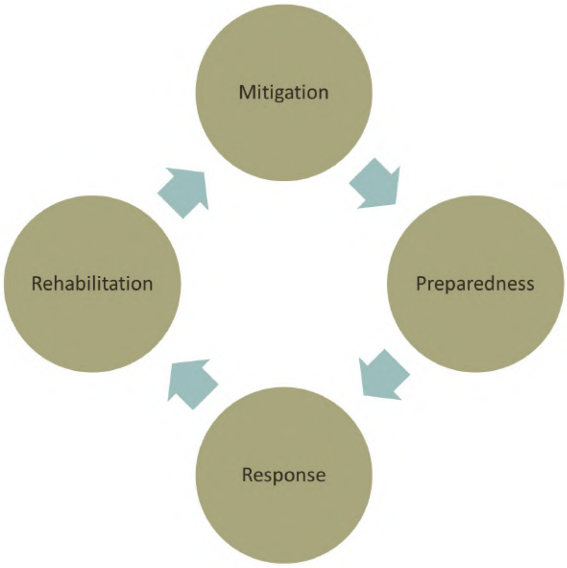


Figure 2.1: Disaster Management Cycle

According to Tomasini et al. (2009, p.44) preparedness is: “the strategy put in place that allows the implementation of a successful operational response”. Bilgen and Ozkarahan (2004) divides planning and decision making in three different levels: strategical (long term), tactical (mid term) and operational (short term). This means that the preparedness phase corresponds with strategical planning since it is a long term plan to prepare for disasters. This relates the conceptual design of the FFM seaport with strategical planning.

Defining the conceptual design of a FFM seaport corresponds with the preparedness phase of the disaster management cycle. The conceptual design consist of the location of storage and amount of handling capacity stored for a FFM seaport. The FFM seaport is shipped to the disaster area from these storage locations when necessary. Creating a conceptual design is one step in preparing for a disaster. The creation of the conceptual design corresponds with strategical planning in the disaster management cycle.

2.2. Key characteristics of humanitarian logistics

Humanitarian logistics means the logistics component of preparing for and responding to disasters and emergencies. It encompasses the management of an entire supply network. The goal of this supply network is to bring goods to the people who are affected by the disaster. Almost every agency that is involved in disaster relief efforts is likely to be engaged in some form of logistic activity. Tatham and Spens (2016); Tatham et al. (2017) estimate that 60 to 80 per cent of the expenditure of relief agencies is spent on Humanitarian logistics. This relates to an expenditure of around $10 billion to $15 billion per year.

There are several factors which characterize and distinguish humanitarian logistics from normal day-to-day logistics (Bilgen and Ozkarahan, 2004):

- Ambiguous objectives. A large amount of stakeholders are involved in a disaster logistic effort. This makes it difficult to assess the level of commitment of the actors and the relationships to each other. Normally, in day-to-day logistics operation, the objective of companies and organization is to make profit. In emergency situations this goal shifts to a speedy and lifesaving response which can lead to ad hoc operations.

- Limited resources. This applies to humans (limited pool of qualified and stand by ready personnel, heavy physical and emotional demands), capital (funds not always available on time) and infrastructure (can be damaged due to the disaster).
- High uncertainty. Disaster logistics depends on the assessment of needed demand. This assessment never leads to a precise amount of needed goods. The amount of needed goods changes over time. Not only the assessment, but also the actual incoming flow of goods varies with respect to quality and quantity. A final uncertainty is that it is hard to assess the amount and quality of supplies that other actors will contribute to the disaster relief effort.
- Urgency. After a disaster happens, there is a huge urgency to start a disaster relief effort. This makes it a high level intensity operation. Actors accomplish a big amount of tasks while little time and resources are available.
- Politicized environment. Politics is involved in every step of the disaster logistics effort. From donations to the distribution in the field.

Also the key performance indicators of humanitarian logistics are slightly different then the normal day-to-day logistics key performance indicators. Normal day-to-day logistics are evaluated using indicators like cost, speed, quality and flexibility. The importance of every indicator changes at different stages of the logistic process (Bilgen and Ozkarahan, 2004). In disaster logistics the indicators changes over time. At the beginning speed is and appropriateness are the most important (Bilgen and Ozkarahan, 2004; OCHA, 2017). Meaning the first few days after a disaster the goal is to supply the right goods at the right place before it is too late for those who need it most (OCHA, 2017). Any improvements in speed also has a significant positive impact on other indicators. A speedy response has a positive impact on the people in need. Making them happy results in positive stories about the disaster relief effort which results in, for example, more donations (Bilgen and Ozkarahan, 2004). (OCHA, 2017) state that later in the disaster logistics operation a balance between speed and cost in the supply chain is pursued. In the first few days after a disaster all processes focuses on speed. Costs take a back seat due to the high urgency and uncertainty. Later, as the operation is up and running, roles are defined and there is a better overview of the necessary goods. The supply chain starts to resemble a normal business supply chain and cost become more important. For example, in the first stage after a disaster all necessary aid will get at the location by airplane. Later the actors will seek cheaper options using road or sea transport (OCHA, 2017).

Literature shows that speed, appropriateness, costs and uncertainty are the key characteristics of humanitarian logistics. The conceptual design of the FFM seaport has to take these into account.

2.3. Timeline

The previous section introduces the characteristics. Based on these characteristics the disaster relief efforts follows a certain timeline. It is important to note that every disaster and disaster relief effort is unique. Due to that not every disaster relief effort follows the same timeline. However it is possible to define some rough stages, steps and rules which applies to every disaster relief effort.

Multiple organisations recognize the importance for speed by using the 72 hours rule. After a sudden-onset disaster the first 72 hours are of utmost importance in order to save a maximum of human lives (Bilgen and Ozkarahan, 2004; Commonwealth of Australia and the Republic of Indonesia, 2015; Dourandish et al., 2007; OCHA, 2017). Important needs in this period are shelter and water and life-threatening injuries and illness must be treat (Carafano et al., 2007). It is impossible for international organization to mobilize an effective response within this short time period. This makes local communities important during this time frame (Carafano et al., 2007). Local communities and government must prepare actions to take care of their own inhabitants in this period (Kloosterboer, nd; O-Canada, 2012).

The 72-hour assessment approach is set up to make sure that directly after this 72 hours international organizations and NGOs can assist (Arii, 2013; Husain, 2018; OCHA, 2017; WFP, 2016). This approach aims to get quickly an overview of the amount and location of people in need. It provides a "good enough, best estimate," snapshot. Continuous updates, revisions and more in depth assessments follows this snapshot over the next few days. Note that, although it is called the 72 hours assessment, it is normal that the very initial assessment is released within 24 hours and this assessment will be updated two times in the remaining 48 hour (WFP, 2016). After this 72-hour assessment relief goods start to arrive at the affected location (Husain, 2018; WFP, 2016).

Most of the NGOs and international organizations that are being asked to help by the government of the affected country deploys skilled staff within hours (OCHA, 2017; The International Federation of Red Cross and Red Crescent Societies, nda). First this staff try to identify with whom they need to work (OCHA, 2017; The International Federation of Red Cross and Red Crescent, 2000). After that they begin to make the assessment of the impact of the disaster. This contains: the geographic impact, the demographics of the affected population, the condition of the affected population, the status of the logistics supply chain, communication infrastructure, local response capacities and available (logistical) resources (Husain, 2018; OCHA, 2017; The International Federation of Red Cross and Red Crescent, 2000). This means that also the status of the port is assessed. Earthquakes, tsunamis, storms and hurricanes are extremely destructive to the port infrastructure and surrounding area. Earthquakes are an extra problem since they also destroy foundations such as mooring facilities, harbour walls and roadways (Think Defence, 2015).

Based on this assessment the different NGOs and international organizations plan their response. Based on this plan different resources (people, equipment and supplies) are allocated and scheduled. During this stage continuous assessments provides extra information and highlights areas requiring further intervention (The International Federation of Red Cross and Red Crescent, 2000). During the assessment phase the high required goods are already provided. Airplanes deliver these goods since in this phase cost is not a primary factor and speed is necessary. Next to that, airplane capacity is sufficient since in this phase normally the least amount of goods are necessary (Wisetjindawat et al., 2014). Later on, cost become more critically and the amount of necessary goods increases (Wisetjindawat et al., 2014). This makes shipping of goods a viable solution later on in the emergency relief response. The typical flow of relief goods is presented in Figure 2.2.

It is hard to find any information about the exact moment when the first ship with relief goods arrives. Humanitarian organizations do not track the performance of the suppliers (Duran et al., 2011). The study of Duran et al. (2011) assumes that humanitarian organisations are able to deliver relief items to a disaster area by ship within two weeks. This is based on personal communications with disaster relief organisation: CARE International.

The emergency relief response can go on for a long time or end relatively quickly. It depends on the disaster and the available resources. Crutchfield (2013) state that it mostly takes something between a couple of months and two years. Normally the quick response unit of the United Nations stops coordinating the effort after three to six months (Jensen and Hertz, 2016). After this amount of time local resources as well as long-term NGOs and United Nations (UN) agencies with programmatic responsibilities take over the clusters activities (Jensen and Hertz, 2016).

2.3.1. Timeline used in this research

The above description induces an overall timeline. This timeline is used in this research and shown in Figure 2.3. Based on this timeline decisions with respect to the conceptual design of FFM seaport are made. Later on, this report presents an analysis of several past disasters. This timeline is in accordance with the results from this analysis. Chapter 3 presents this analysis.

Figure 2.3 shows that goods in the first two weeks arrive by airplane. This gives the FFM seaport two weeks to travel to the disaster area and to get installed. After two weeks the seaport is operational. The FFM seaport helps during disaster relief efforts where (1) the current operation seaports are overflowed

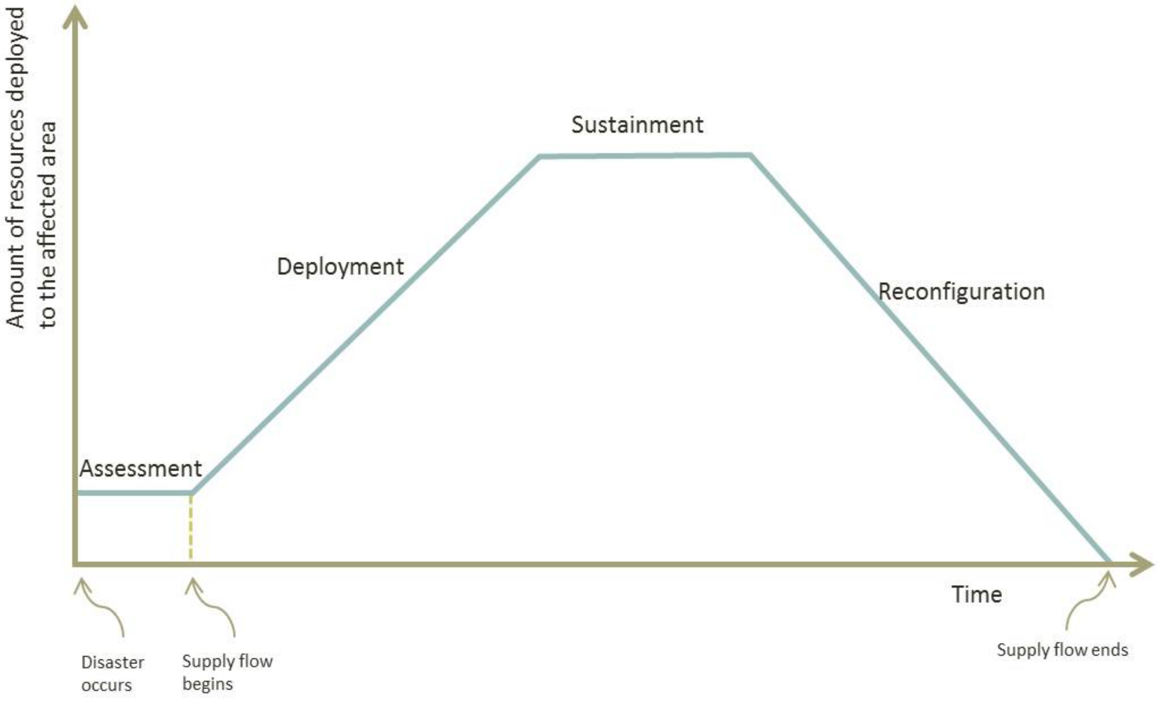


Figure 2.2: Typical flow of relief goods sent to an affected area (Balcik and Beamon, 2008)

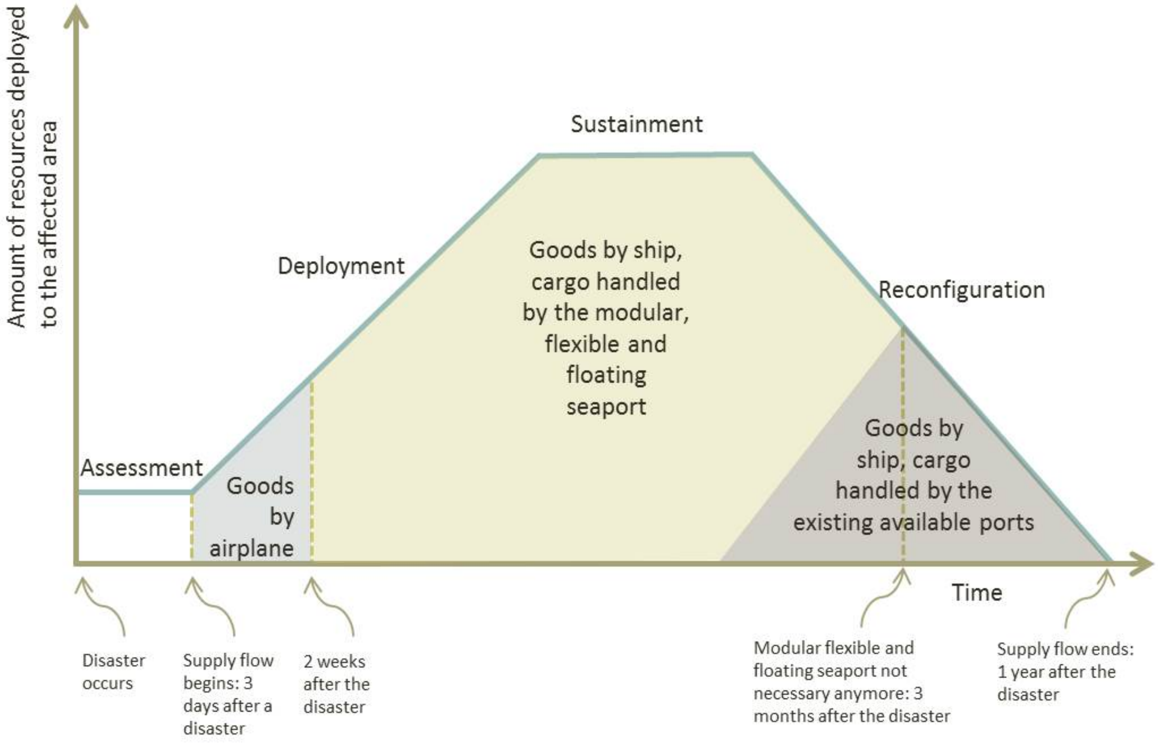


Figure 2.3: Important dates and modes of transport of relief goods as used within this research drawn into the typical flow of relief goods

by goods and (2) where the current seaports are completely destroyed. Within the first circumstance the FFM seaport delivers the extra needed handling capacity. In the second circumstance the FFM seaport delivers all the handling capacity. This makes the second circumstance the worst case scenario. To make sure that the FFM seaport helps in all circumstances, this worst case scenario is used in this research. This means that the FFM seaport delivers the total needed handling capacity of a certain point of interest for at least a certain amount of time. After some time the existing available ports are operational again and are able to handle goods again. Next to that the inflow of goods drop over time. Thus, at some point the existing ports close to the disaster area handles all incoming cargo again. At that moment the FFM seaport is not necessary anymore and travels back to the storage location. Normally this is three months after the disaster. The total supply flow of humanitarian relief goods stops most of the time one year after the disaster.

Note that the choice to focus on the scenario where the current seaports are completely destroyed means that this research focuses on post disaster humanitarian logistics and not slow onset humanitarian logistics. The later type of disasters have mostly a political origin and do not destroy current seaports.

With regards to a timeline, this research assumes the FFM seaport not to be necessary within the first fourteen days after a disaster. It also assumes the FFM seaport to be necessary up to three months after the disaster. This gives a fourteen day time frame for transport of the FFM seaport from the storage location to the affected area.

2.4. Actors

A humanitarian relief operation involves a lot of different actors. In order to get a complete overview about the playing field, it is important to introduce these actors. These actors must taken into account when designing the seaport in order to foster the collaborative sensemaking during the disaster relief effort. This section describe the most important actors.

When a disaster occurs it is the responsibility of the government of the affected country to ensure the safety and well being of its inhabitants. This means the government has to coordinate the work of all different organisations involved in the disaster response (Knox Clarke et al., 2018; PAHO, 2013; The International Federation of Red Cross and Red Crescent Societies, 2000). In the event of a large-scale disaster there are a very few countries which have enough resources to deal with the occurred situation themselves. In that case the international community complements the efforts of the governments (Knox Clarke et al., 2018; The International Federation of Red Cross and Red Crescent Societies, 2000). This international community consists of many different actors: The UN, regional organizations, donor countries, NGOs and the International Committee of the Red Cross (Byman et al., 2003; Knox Clarke et al., 2018).These actors can work together in several coordination structures: affected country leads, The UN leads, coalition leads or another country leads (Byman et al., 2003). When a affected country does not have the resources to deal with a disaster and there are no political reasons for outside powers to intervene decisively, the UN takes the lead (Byman et al., 2003). The UN is involved in almost every disaster relief operation and most of the time the UN leads a disaster relief operation (Maghsoudi et al., 2018; NATO Civil Emergency Planning, 2001). The above shows that the UN is the primal focus point for coordination of disaster relief operation and thus the ideal owner of the proposed FFM seaport.

The UN is an organization with many funds, programmes, departments and specialized agencies. With respect to the disaster relief field the coordination architecture of Figure 2.4 applies. When a disaster happens, the government of the affected country is responsible for the initiation, organisation, coordination and implementation of humanitarian assistance (Knox Clarke et al., 2018; PAHO, 2013; The International Federation of Red Cross and Red Crescent Societies, 2000). In situations where the government is unable or unwilling to fulfill this responsibility the UN sets up a disaster relief effort. The government will ask the UN for help via the Emergency Relief Coordinator (ERC). The ERC is appointed by all member countries of the UN to act as a leader in preparation, coordinating and facilitating humanitarian assistance (OCHA, 2018). Normally the government will ask the ERC for help, but the ERC has the right to intervene without being asked for help (McNamara, 2005).

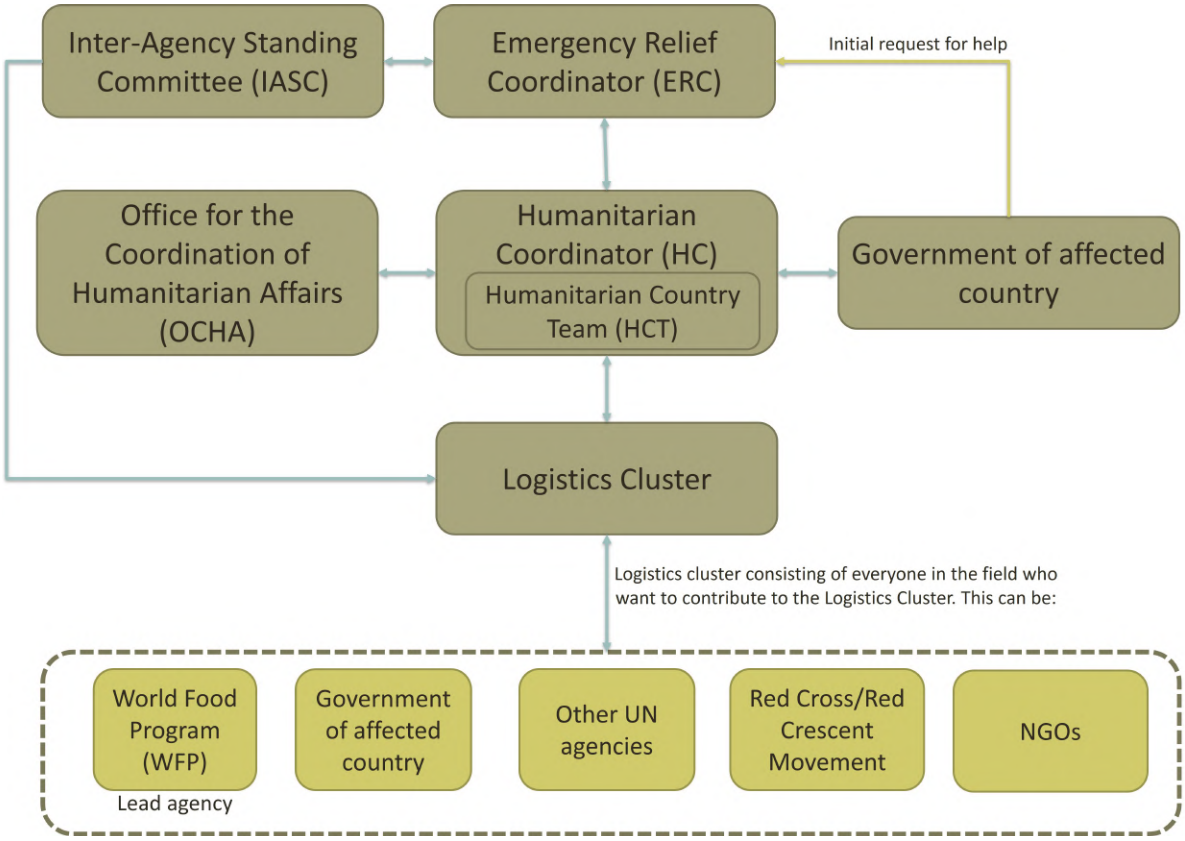


Figure 2.4: Coordination architecture of the different actors involved in the humanitarian logistics. The architecture uses a cluster approach. The figure is based on OCHA (nd)

If a crisis is happening somewhere in the world, the ERC will assign a Humanitarian Coordinator (HC) to lead the response on the ground (IASC, ndb). This HC leads a Humanitarian Country Team (HCT). This team consist of representatives from all different UN, NGOs and the Red Cross/Red Crescent Movement agencies which are providing disaster relief. The HCT is responsible for agreeing on a common strategy for the disaster relief effort (OCHA, nd). The HC and HCT coordinates their actions and communicate with the government of the affected country (OCHA, nd). The Office for the Coordination of Humanitarian Affairs (OCHA) provides guidance and support to the HC and HCT by helping coordinating the disaster relief effort (OCHA, nd).

The ERC is the chair of The Inter-Agency Standing Committee (IASC) (IASC, nda). The IASC is a forum bringing together the executive heads of 18 UN and non-UN humanitarian organizations. If the HC needs extra specialised support a cluster can be request via the ERC at the IASC (IASC, 2007). IASC established and composed this cluster and it consist of a multi-agency group of thematic experts (IASC, ndb). The job of a cluster is to give advice, coordinate and perform actions around one of their specialised themes such as food, water or logistics (IASC, ndb). The HC is responsible to oversee the work of all clusters involved and to keep in close contacts with the lead of the clusters (IASC, 2007)

One of the clusters is the logistics cluster. The IASC appointed the World Food Program (WFP), an UN organization, as the lead agency. They have a lot of expertise with humanitarian logistics (Logistics Cluster, nd). When activated the cluster coordinates, provides information management and facilitates access to the logistics services provided by the WFP and other different partners (Logistics Cluster, nd). The Logistic Cluster has four strategic partners. These are four of the largest global logistics and transportation companies: UPS, A.P. Moller – Maersk, Agility and DP World. Together they form the Logistics Emergency Team (Cluster, 2021). During emergency responses to large scale natural disasters these companies work together upon request from the logistics cluster. However, all humanitarian actors can participate in the cluster community to discuss and work together in short term disaster relief efforts (Logistics Cluster, 2019). A key responsibility of the cluster lead is to ensure that the clusters activities are build on local capacities. This means that the local government is normally part of the cluster (IASC, 2007). Other participating organisation mostly consist of other UN agencies, the Red Cross/Red Crescent Movement and national and international NGOs (Byman et al., 2003).

The logistics cluster proposes solutions when bottlenecks and shortage of supplies occurs which results from a lack of logistics capacity. One of the bottlenecks, material convergence, is seen as the main bottleneck and discussed in more detail in Chapter 4. Solutions to this bottlenecks are primarily sought through the pooling of resources and sharing of assets and information amongst the participants in the logistic cluster. If no effective solution is found the WFP is responsible to provide the last resort. In that case the WFP will provide the logistics service to meet the identified needs of the disaster relief effort (Logistics Cluster, 2019). It is common that the Logistic Cluster creates a transport pipeline which other involved actors can not set up on their own (Jensen and Hertz, 2016).

This study propose that the WFP, as an UN agency, is the owner of the FFM seaport and the storage locations worldwide. As the lead agency of the cluster, they can use this particular seaport when the disaster relief effort asks for it. Within this cluster directly communication with the government of the affected country and all other organisations who are involved in the logistics part of the disaster relief effort takes place. The WFP is already involved in shipping activities. In 2019 the WFP had at any time five ships on the high sea (WFP, 2020). These ships carried 200,000 metric ton of food. 75% of all WFP food travels by sea which represent 3.25M metric ton of food in 61,000 containers (WFP, 2020). In addition the WFP 2019 net asset was $5.87 billion and the surplus was $658 million (Juneja et al., 2020). This mean they can afford to invest in such a seaport.

After consideration the WFP, an UN agency, is assumed to be the best owner of the FFM seaport.

2.5. Locations to help

The past sections describe the key characteristics of, timeline of and involved actors in disaster relief efforts. Now the question arises at which particular affected locations a FFM seaport can be of most help. In order to answer this question, two of the well known disasters where ports played an important role are analysed: the 2010 Haiti earthquake and the 2020 Beirut explosion.

The 2020 Beirut explosion damaged the port of Beirut and plenty of Lebanon's wheat and rice supplies (Bloomberg, 2020). The port of Beirut needed to shut down their operation completely (Bloomberg, 2020). Before the explosion the port of Beirut handled 60% of the food import from Lebanon. After the explosion the port of Tripoli, 85 kilometers north from Beirut, toke over the duty of import the important goods (Bloomberg, 2020; Hand, 2020). Other cargo, which was not directly urgently needed in Lebanon was directed to ports in Italy, Egypt, Turkey and Greece (Bloomberg, 2020; Hand, 2020). It can take up to two years before the port of Beirut is completely restored (Seesing, 2020). This disaster response shows that cargo ships, containing cargo intended for the affected humans, can be diverted to ports even 3,000 kilometers away from the disaster location. Trucks transports the cargo to the disaster location.

Appendix B, describes how military helps in creating seaport capacity during disaster relief efforts. A good example of the military possibilities and limitations is the Haiti earthquake. Appendix B describes the disaster relief effort in response to the Haiti earthquake in more detail. The 2010 Haiti earthquake completely destroyed Port-au-Prince which before the disaster handled around 450 TEU per day, 95 % of the nations total (CSA, 2014; Noel, 2009; Think Defence, 2015). TEU is the abbreviation of Twenty

Foot Equivalent Unit and one TEU represents one twenty foot container.

The Haiti earthquake disaster relief response showed that handling goods with military equipment is difficult and time consuming. The available military resources have a limited handling capacity and can not meet high volume demands. More seaport handling capacity then the military could deliver was necessary in order to deal with the consequences of the earthquake (Think Defence, 2015). This shows that the disaster relief response would be helped if a FFM seaport could be used. In the end something like the FFM seaport was created by using barges. Since the creation of the seaport was improvised, the process was very time consuming. It took a long time until this seaport was realised (Think Defence, 2015). This improvised seaport was needed since no alternative way of transferring goods from ships to the affected area was possible. The island did not had many ports operating. The ports that were operating all reached there maximum capacity very quick (Think Defence, 2015). Since it is an island the amount of ports to divert to are very limited.

On top of this lack of seaports to divert to, the United Nations Conference on Trade and Development (UNCTAD) state that small island states have vulnerable seaports (UNCTAD, 2019). These ports are underdeveloped and not capable to deal with the huge amounts of relief cargo which need to be handled in case of a disaster (UNCTAD, 2019). Next to that islands are extremely vulnerable to climate change. The frequency of disasters on islands will increase (Thomas et al., 2020; UN-OHRLLS, 2011; Veron et al., 2019). The above shows that the FFM seaport is mostly of help in response to disasters affecting islands.

When talking about disaster relief efforts, the military is able to handle a small amount of goods. This means that for smaller islands, the military is able to deliver all the necessary goods. Appendix B describes that the military is able to handle 355 TEU per day. Chapter 3 analysis different disaster relief efforts in order to, among other things, find out how many TEU an affected person needs. The chapter concludes that helping 265,000 people corresponds with a handling capacity of 355 TEU per day. This means that the FFM seaport mostly helps in disaster relief operations on islands bigger then 265,000 inhabitants. The remainder of this research use these locations as focus points.

This research concluded the FFM seaport is of most help for disaster relief operations on islands bigger then 265,000 inhabitants.

3

Disaster relief efforts analysis

The research goal is to define the conceptual design of the FFM seaport. Therefore it is important to look at previous disaster relief efforts. Analysing previous disaster relief efforts leads to an overview of the timeline of disaster relief efforts. This timeline contains, among other things, the amount of time that can pass before a FFM port is needed after a disaster. It tells also something about how many goods are necessary to help all affected persons. This relates to the amount of necessary seaport handling capacity. The analysis also gives information about the susceptibility to disasters of certain areas. This chapter first explains the analysis procedure. After that it presents the findings.

3.1. Procedure

The firs step was to find a database which contain information about disaster relief efforts. Two databases were found: The EM-DAT database and ReliefWeb. The EM-DAT database contains worldwide data on the occurrence and impact of almost 25,000 disasters from 1900 until the present day (Guha-Sapir et al., 2020). The database contains brief information about the time frame, location, type, human impact and financial impact of a disaster. The database sort the data per country, meaning a disaster which hit three countries is counted as and presented as three data entries. ReliefWeb is set up and maintained by the OCHA. This database contains information reports from more than 4000 key sources, including NGOs and governments (OCHA, 1996). The information reports are sorted per disaster and the database contains information about disasters from 1982 till the present day.

Selection criteria were used in order to find the disaster relief efforts of interest. Since ReliefWeb contains only information about disasters from 1982 till the present day only disasters which occurred after 1982 were selected. Next to that, as discussed in Chapter 2.5, islands were selected as the locations for which the usage of the FFM seaport will help in the disaster relief effort. Islands were thus the second criteria.

The third criteria was related to the amount of inhabitants. As described in Chapter 2.5, the military can handle maximum 355 TEU per day during a disaster relief operation. The question arose how many disaster relief goods can be handled with this capacity and how many persons can be helped with this goods. Islands with a maximum amount of inhabitants lower than this capacity can be helped by the military and do not need a FFM seaport. An outcome of this disaster relief efforts analysis gave the exact amount of TEU an affected person need. Beforehand this information was not known. An estimate had to be made in order to find this number. This estimate consist of a quick calculation. The calculation can be found in Appendix C.1. The result is that the disaster relief operation analysis only focused on island with more then 100,000 inhabitants.

The fourth criteria was related to the scale of a disaster. A FFM seaport is only necessary in case of a large scale disaster. This kind of disaster affects a lot of people, their societies and their economics (OECD, 2014). It disrupts the total transportation system (OECD, 2014). A lot of goods are necessary to rebuild the society and economy. The damage of a large scale disaster is minimal 1% of the GDP of a country (OECD, 2014). When the damage was less, it was assumed that an island did not need a lot of relief goods and that the most important infrastructure of the island was not damaged. In that case, help from a FFM seaport is not necessary.

All criteria were applied on the EM-DAT database. First only the disasters which happened after 1982 were selected. Second, only disasters with a damage of minimal 1% of the GDP of a country were selected. This was not straight forward and some problems arose. Appendix C.2 tells how this problems were solved. The EM-DAT database consist of 21,280 recorded disasters which happened between 1982 and 2020. Only 349 were large scale disasters. Out of this 349 disasters the disasters which hit an island with more then 100,000 inhabitants were selected by hand. This resulted in 98 large scale disasters which hit 115 islands with more then 100,000 inhabitants. These disasters were analysed by using the ReliefWeb database to investigate, among other things, the timeline and amount of necessary goods in detail.

ReliefWeb stores a lot of information from various organisations. This disaster relief effort analysis took only documents from the IASC, OCHA and UNDHA (former name of OCHA) into account. This organizations had a complete overview of the necessary relief goods and the disaster relief effort process. The disaster relief effort analysis examined every emergency appeal, situation report and evaluation report prepared by these organizations for the disaster of interest. This three documents gave a complete overview from the disaster relief effort. With this documents it was possible to collect for every disaster, per affected island, the following information:

- The amount of goods necessary to dealt with the disaster. This is expressed by the OCHA and IASC in the amount of money necessary to help the affected people. Later this amount of money was translated to the amount of goods. OCHA and IASC distinguish several areas which are typically in need of relief goods: housing, education, health facilities, infrastructure, food relief, emergency healthcare, temporary water, temporary shelter and agriculture. This information was found in the emergency appeal.

- The timeline of the concerned humanitarian relief effort. This information was found in the situation and evaluation reports. The following moments were of interest: first assessment of damage, final assessment of damage, first arrival of relief goods from international ships, moment that state of emergency was lifted, amount of time international relief goods are necessary, moment that the island is fully recovered and moment that the ports are open again after the disaster.

- If the port was damaged or not. If ports were damaged this was mentioned in the situation reports, evaluation reports and/or the emergency appeal.

- The amount of people which received help during the relief effort. This was mentioned in the situation reports, evaluation reports and/or the emergency appeal.

- The handling capacity of the seaports at the island. The amount of TEU the seaports handled a year before the disaster, the year of the disaster and the year after the disaster is presented. This data was found via the Worldbank Data (World Bank Data, 2020a). If this data was not present in this data bank than this information was not taken into account.

The results of the disaster relief effort analysis is presented in the next section.

3.2. Findings

All found interesting information was ordered in a table. The author of this thesis published this table online (Bakker, 2022). The following things stood out:

- From the 115 times an island was affected by a disaster, 22 times a damaged port was mentioned. This does not mean that only in those 22 situations a FFM seaport would have been beneficial and in other situations not. It is possible that the lack of cargo handling capacity was not mentioned or the damaged seaport was restored very quickly.

- From the 115 times an island was affected by a disaster, 12 times the date of reopening was found. In two instances the port was not damaged, but the port was closed due to weather conditions. In 10 other cases the port was damaged and the port was reopened after repair work was finished. In two cases the seaport was fixed within a day, in four cases within a week and in four cases it took longer, 10 days to more then a month, to repair the seaport. Especially the last cases calls for the help of a FFM seaport.
- It takes some time after a disaster before the first goods arriving from international ships. Sometimes a close by country is sending relief. In that case it took three to five days till goods arrived. At the time of sending goods, the first assessments were not known. This means that this first delivery was a smaller delivery of goods which are always necessary. The longest time necessary to transport the first international relief goods to the affected area was one month. The exact necessary time depended on the time necessary to finish assessments, the moment in time at which a large amount of goods was necessary, the time necessary to bring goods to the ships point of departure, the speed of the ship and the proximity of countries which can offer help. When looking at the available disaster relief effort data, it was seen that on average 14 days after a disaster the first international relief goods arrived. This corresponds with the timeline used in this research as discussed in Chapter 2.3.1.
- Most of the analysed disasters needed three months of international cargo help. Sometimes, with very big disasters, this international cargo help was needed for up to one year. In two exceptional cases international cargo help was necessary for 1.5 or two years. The affected islands of most analysed disasters were completely restored after one year. Note that this information is in line with the timeline used in this research as discussed in Chapter 2.3.1.
- The first assessments of goods was available three days after the disaster had hit the island. The final assessment was most of the time available between two weeks and a month after the disaster hit. These dates are in line with the description in Chapter 2.3.1.
- The difference in throughput of the seaports of the affected countries between a year before, the year of and a year after the disaster fluctuated per disaster. It is not possible to draw conclusions out of this information.
- Sometimes the same disaster hit multiple countries or islands at once. From the 98 analysed disasters, 11 times a disaster affecting multiple countries. seven times the disaster hits two islands, two times three islands, and two times four countries. In all these cases, islands close by each other were affected and all affected islands were impacted on a large scale.
- It happened that multiple different disasters affecting different island around the world within the same time frame. This results in multiple FFM seaports necessary at different places to assists in disaster relief operations. One FFM seaport module can only help one disaster every 3.5 months, since the FFM seaports is used till three months after disaster hits and needs to travel back for 14 days. It was analysed if the timelines of the 98 disasters relief efforts of interest were overlapping each other with respect to the timeline of the FFM seaport. It shows that 16 times only one islands was hit during the time frame, 22 times two islands, 13 times three islands, five times four islands, one time five islands and even two times six islands were hit during the same time frame. This overlapping timelines are presented in more detail in Table C.1 in Appendix C.4.

The disaster relief effort analysis validates the timeline which is used in this research. Next to that it shows that the conceptual design of the FFM seaport must take the possibility that multiple disaster affecting multiple different islands into account. Next to these two conclusions, two other important sets of information are determined based on the results of the disaster relief effort analysis. This are the amount of necessary goods and the different disaster situations.

Based on the results of the disaster relief effort analysis a calculation is made in order to determine how much goods the FFM seaport needs to handle. This calculation shows that on average a person need 0.102 TEU of goods during a disaster relief effort. This means that the FFM seaport needs to handle 0.102 TEU of goods per person in need. The calculation is presented in more detail in Appendix C.3. As described in Chapter 2.5 the military can handle 355 TEU per day. The timeline of the FFM seaport tells that the FFM seaport is in use for 76 days. This 76 days correspondents with three months minus the necessary travel time of 14 days. The military can handle 26,270 TEU within this 76 days. This means that the military can assist disaster relief efforts with maximum 265,000 affected persons. Based on this, islands with more then 265,000 inhabitants are chosen as point of interest for the FFM seaports.

The results of the disaster relief effort analysis also formed the basis of the disaster situation making. A disaster situation consist of the different islands which are in need of a FFM seaport at the same time. Chapter 8.2.3 describes the realization of the situations used in this research in more detail.

The disaster relief effort analysis shows that the possibility of one or multiple disasters affecting multiple different islands must be taken into account. The analysis also determined a person needs on average 0.102 TEU of goods during a disaster relief effort.

4

Material convergence

Material convergence is the problem that during a disaster relief effort a lot of unnecessary, irrelevant and useless goods are sent to the disaster area, while the handling capacity of the infrastructure is limited (Holguín-Veras et al., 2014; Nagurney et al., 2016; Ozen and Krishnamurthy, 2020). This results in crowded seaports which are not able to handle all the incoming goods effectively. In this research a conceptual design for the FFM seaport is created. The design of this FFM seaport helps in dealing with the material convergence problem. In one way by using the physical FFM seaport and by doing so creating as much handling capacity as necessary. In a second way, by incorporating factors in the design which improves the collaboration. This chapter describes the material convergence problem in detail. This chapter first covers a detailed description of the material convergence problem. After that, the role of “working together” with respect to the material convergence problem is explained.

4.1. Detailed description

Material convergence is a complex problem caused by the huge quantity of goods sent to the disaster area and the extremely heterogeneous flow of incoming goods. Many goods arrives in a short time span. The affected area has limited space, resources and personnel to handle the goods and deliver them to the people in great need (Holguín-Veras et al., 2014; Ozen and Krishnamurthy, 2020). Humanitarian actors must meet uncertain and highly dynamic demands, while little information is available. There is no help of stable supporting systems (Holguín-Veras et al., 2014). On top of that the incoming goods are most of the time poorly packed. This creates a major handling effort for the logisticians working within the disaster area (Holguín-Veras et al., 2014). This means that material convergence is one of the most unique, overlooked and poorly understood disaster phenomena (Holguín-Veras et al., 2014). Exact numbers about the material convergence problem are unknown (Holguín-Veras et al., 2014), but multiple examples exist which demonstrate the problem.

The main cause for material convergence is the inappropriate and useless goods which are sent to the disaster area. For example 37% of the medicines sent to El Salvador after the January-February 2001 earthquakes were completely inappropriate and expired (Holguín-Veras et al., 2014). During most disaster relief efforts large quantities of goods come in when they are not necessary anymore. For example after the tsunami in Japan a lot of donors sent blankets to the disaster area. After a week, the weather warmed up and blankets were not necessary anymore. However, still a lot of blankets arrived at the disaster location (Nagurney, 2017).

It is also possible that the total amount of a certain disaster relief item is more then needed. This was the case with water bottles after the Haiti earthquake (Holguín-Veras et al., 2014; Ozen and Krishnamurthy, 2020). After interviews with logisticians involved in disaster relief efforts it is concluded that in every disaster non necessary goods are donated (Holguín-Veras et al., 2014; Ozen and Krishnamurthy, 2020). They estimate it is about 60% of all incoming cargo (Holguín-Veras et al., 2014; Nagurney, 2017). The flood of donated inappropriate material in response to a disaster is often referred to as the second disaster (Nagurney, 2017). The presence of this inappropriate and useless goods means that less handling capacity is available for the really necessary goods and thus the flow of high priority supplies is impeded (Holguín-Veras et al., 2014).

There are multiple reasons which causes the inflow of this huge amount of useless goods. The first reason is the fact that large quantities of goods and equipment are sent to the affected area by thousands of donors (individuals, governments, companies, NGO, faith-based groups etc.) (Holguín-Veras et al., 2014). This large diverse amount of donors have radically different perceptions of the needs on the ground and varied levels of access to supplies (Holguín-Veras et al., 2014). A large amount of donors sent to the area whatever they have on hand. They assume that anything can be of use (Holguín-Veras et al., 2014). The extent of non necessary good which the organisations sent, depends on the situational awareness, the consequences and the general disaster relief effort (Holguín-Veras et al., 2014).

The second cause is the increasing competition for funding among humanitarian organization (Thomas, 2003). The public and donors are not pleased to hear that donations, which are needed in their eyes, are not used.

A third cause is related with the media (Holguín-Veras et al., 2014; Ozen and Krishnamurthy, 2020). When they arrive at the site they make a subjective choice on how they portray the news. They focuses on newsworthy aspects. Multiple examples shows that this can lead to material convergence. For example, after 9/11 on television it was said that most of the rescue dogs burned their feet. This resulted in a tsunami of dog shoes transported to the disaster site (Holguín-Veras et al., 2014).

A fourth cause are the companies which sent non essential goods out of public relation and marketing considerations (Holguín-Veras et al., 2014). Less then 24 hours after the Haiti earthquake a plane loaded with children's toys donated by a manufacturer arrived in Port-au-Prince. A television crew was flying with the plane and after taking pictures and videos they left, leaving several tons of toys which were not used for months. Meanwhile a portable hospital and medical personnel could not land in Haiti because of the congested airport (Holguín-Veras et al., 2014). Another company sent thousand of bottles of a beverage to a disaster site. The problem was that these beverages were pulled out of the consumer market due to low sales numbers. These beverage remained in the warehouses as most who tried it deemed it undrinkable (Holguín-Veras et al., 2014).

A fifth cause is the influence of diplomatic relations. An example is an announcement of the Mexican government after the Haiti earthquake (Holguín-Veras et al., 2014). The Mexican government announced that they would transport all the goods to Haiti that people send to them. This free transportation increased the volume of non essential disaster relief goods tremendously. Mexican Navy ships made 20 trips to Port-au-Prince in the year after the disaster. Eight of them during the first six weeks. Unlabeled boxes of unknown contents and food products not consistent with the dietary habits of the affected people were sent to the port to the great consternation of the disaster relief workers. However, they did not dare to talk to the Mexican government to stop this donations since they could not risk to offend a government of an important country. Other governments are the major donors for every NGO involved in disaster relief operations (Thomas, 2003).

Due to material convergence the disaster relief workers experience a dilemma. Normally they want to thoroughly inspect all the cargo when arrive in the seaport. Due to the huge amount of unnecessary goods this is very labour intensive and delays the shipment of essential goods (Holguín-Veras et al., 2014). This leaves the disaster relief workers two options. The first option is to only accept labeled and document cargo and refuse and sent back all other goods. This can generate accusations of impeding humanitarian aid (Holguín-Veras et al., 2014). The second option, which they normally choose, is to accept all transported goods. This brings other problems. For example it is not known if these goods are safe (Holguín-Veras et al., 2014). Also sometimes it is not known to who or where these goods must be delivered too. When nobody is willing to accept the supplies they are dumped in the open area, resulting in rotting piles of unwanted supplies (Holguín-Veras et al., 2014; Ozen and Krishnamurthy, 2020).

Chapter 2.5 describes that islands will be the main focus of this research. Material convergence is a bigger problem on islands then on land. Islands have a more limited handling capacity infrastructure. It is hard to divert to other resources when necessary. This pleas for the chose made to focus on islands.

Holguín-Veras et al. (2014) concludes that, although the 72 hours needs assessment improved things, material convergence is still a large problem. It is general acknowledged that in order to maximise the disaster relief effort the transport capacity should only be used to transport necessary goods to the disaster site (Holguín-Veras et al., 2014; Nagurney et al., 2016; Ozen and Krishnamurthy, 2020). Holguín-Veras et al. (2014) proposes a couple of solutions. First it is possible to set up information systems which advise on actual needs and gives an overview of the supplies already in transit taken. Next, access control of the incoming cargo can help. With this access control they are able to choose to only accept essential items. Third, it is possible to give priority to goods from large disaster relief organizations. Post-disaster response is a regular task for this organizations and they likely have a solid idea about the actual needs. Finally, a solution is to work together. Holguín-Veras et al. (2014); Jahre and Jensen (2010); Jensen and Hertz (2016); Nagurney et al. (2016); Ozen and Krishnamurthy (2020); Wankmüller and Reiner (2020) all concludes that the humanitarian community must work together to mitigate this second disaster. For example, Nagurney et al. (2016) simulated a disaster relief effort with the help of game theory. It shows that coordination is critical for reducing material convergence. The simulation shows that coordination leads to attracting more donations in comparison with the current competitive situation.

A part of this research is to investigate how a FFM seaports improves collaboration during disasters. Since collaboration is a solution to the material convergence problem, it interesting to dive deeper into this solution. The next section will present this analysis.

Material convergence is the reason why logistics resources are sparse and not able to deal with all the incoming goods effectively. The causes for this problem are diverse. They include limited resources and handling capacity. The FFM seaport can help by creating more handling capacity. It is then also important to consider what is handled. A lot of unnecessary, irrelevant and useless goods are sent to most disaster areas taking up precious handling capacity. A solution is to improve the collaboration between the humanitarian logistics actors to prevent the problem of unnecessary handling.

4.2. Solution in working together

So a solution to the material convergence problem is to work together. There are multiple ways of working together: coordination, cooperation and collaboration (Wankmüller and Reiner, 2020). This section defines these multiple ways. Next, it describes for every way the important factors which plays a role. After that, the logistics cluster approach is analysed with taking the way of working together in mind. This because the logistics cluster approach is set up with the goal of improving working together. Finally, social learning is explained. This research uses this communication theory to analyse deeper how working together is linked with the material convergence problem.

4.2.1. Definitions

Coordination, cooperation and collaboration are broad concepts and widely studied in literature (Jensen and Hertz, 2016; Wankmüller and Reiner, 2020). The definition of these concepts depends on the context. In the context of humanitarian logistics these concepts are not officially defined yet (Wankmüller and Reiner, 2020). Coordination, cooperation and collaboration are used interchangeably in practice and literature (Wankmüller and Reiner, 2020). So every time one of this concepts are used the definition of that concepts differ in, among other things: level of trust, level of commitment, relationship length, quality, closeness of the relationship, level of intensity and willingness to share information (Wankmüller and Reiner, 2020).

Wankmüller and Reiner (2020, p. 256) has introduced a definition for coordination, cooperation and collaboration in the humanitarian logistics field:

- Coordination: “Process of organizing, aligning and differentiating of participating NGOs’ actions based on regional knowledge, know-how, specialization and resource availability to reach a shared goal in the context of disasters”.

- Cooperation: “Process of operating alongside other NGOs towards a common mission, sharing information and adjusting tasks in line with the specifications of the disaster setting”.

- Collaboration: “Process of establishing a close and intensive relationship between NGOs for jointly solving problems where NGOs’ internal standards, guidelines and rules are harmonized in accordance with others and trust is pervasive”.

This definitions are not used officially yet. These definitions are also used in this research, in order to try to reach an uniform definition of these concepts.

Definitions are important. One of the barriers to work together relates to the unknown definitions. When actors are not aware of the definitions, they suppose that working together means a high intensify collaboration (Jensen and Hertz, 2016; Wankmüller and Reiner, 2020). It is possible that they don’t want such a collaboration and thus prefer to not to work together. This while maybe they are open to a less intensify way of working together, like coordination.

So working together helps to avoid the material convergence problem. However, as one can imagine, achieving successful coordination during disasters is hard. The achieved coordination is often insufficient (Jahre and Jensen, 2010; Salam, 2006; Salam and Khan, 2020; Tatham and Spens, 2016; Tatham et al., 2017; Thomas, 2003; Wankmüller and Reiner, 2020; Wedgwood and Read, 2012). After a disaster the humanitarian organisations work under extreme complex and chaotic conditions. Physical infrastructure are destroyed, national and local government are heavily impacted, the size of demand is highly unpredictable, resources can be scarce and transport capacity can be very limited (Salam and Khan, 2020; Thomas, 2003; Wankmüller and Reiner, 2020). During a disaster relief effort sometimes over 400 organizations and 5000 staff members are involved. This makes coordination even harder (Tatham and Spens, 2016). Coordination in humanitarian logistics is described as a ”wicked” problem. Decisions must be made with multiple stakeholders while taking multiple requirements into account. There is no agreement about what the problem consist, let alone about the solution (Jensen and Hertz, 2016).

The next subsections describe per concept the factors which influences coordination, cooperation and collaboration with respect to the humanitarian logistics field.

4.2.2. Coordination factors

Wankmüller and Reiner (2020) defines an effective coordination as aligning the actions of different NGOs to reach a shared goal. An efficient coordination aligns these actions without taking a lot of time and costing to much trouble. Several factors have to be considered in order to ensure effective and efficient coordination between the humanitarian logistics actors. Among other things, these are: tendencies and feelings towards other involved partners, some form of leadership, equal participation of involved actors, incentive to join the coordination, experience in coordination, role framework, commitment, trust, sharing of information and measurements of performance. This subsection continues by discussing information sharing, experience in coordination and role framework in more detail.

Information sharing is seen as the most important factor (Wankmüller and Reiner, 2020). Actors find it hard to share information and data monitoring actions. The play field is highly competitive and information is usually confidential. It requires a high level of trust to share data (Salam, 2006; Salam and Khan, 2020). A solution is to create inter-agency data exchange software/system which will be broadly used (Tatham et al., 2017). When logistics departments tracks goods through the supply chain, data can be stored and analysed to provide post-event learning. Logistics data reflects all aspects of a disaster relief execution (Salam and Khan, 2020; Thomas, 2003).

Humanitarian organizations have a transient nature. This hinders organizational learning and results in limited appropriately experienced personnel. This results in limited personnel with experience in coordination, during emergencies (Tatham and Spens, 2016; Tatham et al., 2017). An ongoing training program at the national and international level would increase the level of coordination (Tatham et al., 2017).

Tatham and Spens (2016) compares the coordination of the Urban Search and Rescue Community and the humanitarian logistics. The Urban Search and Rescue community have achieved successful coordination. This due to, among other things, a clear role framework. The Urban Search and Rescue community has clear guidelines, qualifications, standard and certification. Everyone involved follows protocols. Various roles and responsibilities are predetermined. It is determined which organization is in the lead and which organisation takes the lead when that organization is not on the side yet. An independent audit will evaluate the search and rescue effort when finished. Jensen and Hertz (2016); Tatham and Spens (2016) state that it is hard to directly copy the Urban Search and Rescue way of working to the humanitarian context. NGOs don't want to give up their independence. They want to work following their own organizations belief (Jensen and Hertz, 2016; Tatham and Spens, 2016).

4.2.3. Cooperation factors

Wankmüller and Reiner (2020) defines an effective cooperation as operating alongside each other to reach a common goal together. An efficient coordination means that operating alongside each other does not lead to any problems. these actions without taking a lot of time and costing to much trouble. Several factors are important in ensuring effective and efficient cooperation. First of all, this are the factors described under coordination factors. Since cooperation is more intensive then coordination, additional factors are added on top of these factors. This are, among other things: interaction in the field, logistics perception of different organizations, culture of organization, relationships across organizational boundaries, transparency between organization and relief capacities of organization. This subsection highlights two factors: organization culture and logistics perception.

All disaster relief organizations have different, culture, management styles and administrative structures (Salam, 2006; Salam and Khan, 2020). Every organisation has its own strategic headquarters and strategy to activate the aid process. On top of that, at this moment every organization manages its own logistics (warehousing and transportation). At this moment there is no cooperation in terms of training and exercise (Salam, 2006). The culture of humanitarian organizations hinders change (Wankmüller and Reiner, 2020).

Good cooperation creates shared process and distribution channels between different actors. On top of that, cooperation creates a common vision and logistic perception. This consist of a shared mutual understanding of the situation. Similar concerns are shared. Good cooperation includes a shared humanitarian logistics picture on operational and tactical level (Jahre and Jensen, 2010; Salam and Khan, 2020; Tatham et al., 2017). This is achieved by gathering, monitoring and presenting of data Jensen and Hertz (2016). Tatham et al. (2017) argues that a comprehensive, valid, up-to-date and easily understood ‘picture’ of the logistic response can be made with the help of presenting data in a software program.

4.2.4. Collaboration factors

Wankmüller and Reiner (2020) state that an effective collaboration leads to NGOs adjusting their strategies to others to jointly solving problems. An efficient collaboration means that this adjusting of strategies goes smoothly without to much trouble. Several factors are important to ensure effective and efficient collaboration between the humanitarian logistics actors. Collaboration is more intensive then coordination and cooperation and thus the coordination and collaboration factors must be taken into account. On top of that, among other things, the following factors are important: trust between involved stakeholders, shared risks and costs and a shared cultural understanding and common language. Since trust is seen as the most important factor (Wankmüller and Reiner, 2020) this is described in more detail.

Trust is already important in achieving successful coordination and cooperation. However, it is critical, for establishing collaboration (Wankmüller and Reiner, 2020). Trust is essential for team performance. Without trust, teams cannot work efficiently. Gaining trust is harder in humanitarian logistics then in normal day-to-day logistics. In the humanitarian sector, networks are formed on the spot. In the normal sector there is a lot of time to build relationships. In humanitarian logistics this time is not available. On top of that the level of commitment and relationship intensity is higher in the humanitarian logistics context (Wankmüller and Reiner, 2020).

4.2.5. Logistics cluster

The cluster approach is set up in order to achieve successful coordination, cooperation and/or collaboration (Jahre and Jensen, 2010; Jensen and Hertz, 2016; Tatham and Spens, 2016; Wankmüller and Reiner, 2020; Wedgwood and Read, 2012). The logistic cluster evaluation of Wedgwood and Read (2012) concludes that in general logistics, cluster operations are highly relevant, valuable and effective. Working together in clusters increases the logistic capacity and the coordination, cooperation and collaboration between the participating parties.

However, it is hard to quantify cluster's contributions. This due to the lack of performance indicators and collected data (Tatham and Spens, 2016; Wedgwood and Read, 2012). The Logistic Cluster is very dependant on the willingness of other organizations to participate in the clusters operation. Participation is not mandatory and non-participation limits the cluster's achievement. Many large international NGOs do not participate. Even the cluster lead organization, the WFP, did not coordinate every freight movement with the cluster. Participation in the cluster must be made more advantageous for all organizations in order to cope with this problem (Jahre and Jensen, 2010; Wedgwood and Read, 2012). At this moment actors only get involved with the logistic cluster when the circumstances make this the optimal course of action (Jensen and Hertz, 2016; Tatham and Spens, 2016).

It can be concluded that the Logistic Cluster does not achieve the desired level of coordination, cooperation or collaboration. However, it holds the potential to ultimately reach this level (Jensen and Hertz, 2016; Tatham and Spens, 2016; Wedgwood and Read, 2012). This research investigates how a new technology can be used in order to reach this desired level. By improving coordination, not only the material convergence problem will be alleviated. The lack of coordination also leads to lost information, unstructured relief operations and increased competition between NGOs. This increases the prices of the locally available commodities and services, such as warehouses and vehicle leasing (Thomas, 2003; Wankmüller and Reiner, 2020).

This research uses a scientific communication theory, social learning, in order to analyse deeper how coordination, cooperation and collaboration is linked with the material convergence problem. The theory indicates factors and processes which plays a role during working together. The next subsection will explain social learning.

4.2.6. Social learning approach

The communication part of this research uses social learning to look at working together from a theoretical perspective. Communities of practise are the centre piece of social learning. Humans have always formed communities that share cultural practises (Wenger, 2000). Think about tribes around the cave fire, street gangs or a community of engineers interested in logistics. The logistics cluster can also be seen as a community of practise. In that case the community of practise consisting of different humanitarian actors which want to help with the humanitarian logistics effort. The individual humanitarian actors are part of multiple communities of practise. For example: the community of practise of their own disaster relief organization or government, the community of practise of their hobbies and the community of practice of the country they belong to.

Wenger (2000) explains that knowledge of an individual is formed due to two components: competence and experience. Competence is knowledge present in the communities of practise the individual belong to. The individuals ongoing experience of the world and interaction with other persons (in the context of a given community and beyond) is the other component. When these two are in close tension and the one start to pull the other, social learning takes place (Wenger, 2000).

Wenger (2000) state that the competence of a community is defined by three elements: joint enterprise (collectively understanding of what their community is about), mutual engagement (interaction with one another) and shared repertoire (language, routines, sensibilities, artifacts, tools, stories, etc.). For individuals there are three modes of belonging to a community of practise: engagement (doing things together), imagination (construction an image of our self and our community of practice) and alignment (making sure that our actions are aligned with the rules and context of certain communities of practises). Successful coordination, cooperation and/or collaboration is achieved when the logistics cluster scores high on the three elements of competence and when individuals are able to connect via the three different modes of belonging to the logistic cluster.

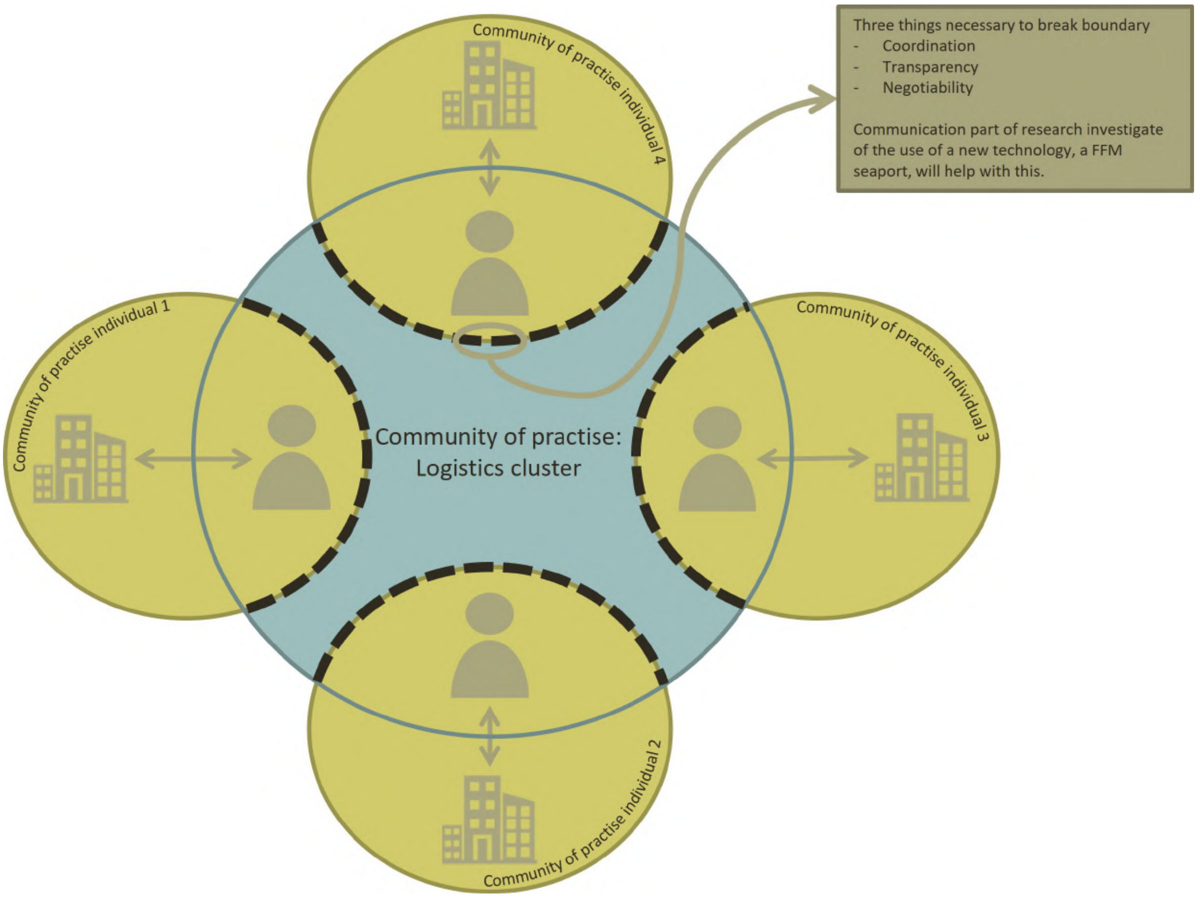
A boundary process take place when disaster relief actors are start to work together during a crisis. A boundary process is a process in which individuals explore and go beyond the boundaries of their current community or practice. Individuals, who did not know each other beforehand, need to work together when the logistic cluster is activated. They form a new community of practise. This community of practise will be established over time by active and dynamic negation of meaning (Wenger, 2010). In boundary processes individuals are learning. They are learning because competence and experience tend to diverge. In boundaries someone experiences another unknown competence (Wenger, 2000). Activating the logistics cluster, can be seen as creating a new community of practise, which can be seen as a boundary process. The different actors of the different organisations which need to work together in the logistics cluster are learning from each other. Among other things about the culture of the others organisations and their view on the disaster and the disaster relief effort.

Wenger (2000) states that a couple of things are required in order to learn by boundary processes. This are: coordination (interpret actions and objects in different practices in a way that enables coordinated action), transparency (give access to the meanings of actions and objects in different practises) and negotiability (provide a two-way connection between practises to make sure that multiple voices are heard). It is important that these three elements are assured at the moment the logistics cluster come together. This elements are necessary in order to create a strong bridge between all the involved actors and their own communities of practise. This bridge can be created in multiple ways: by people who acts as brokers, by objects and by creating a setting to let people interact with each other, like congresses Wenger (2000). This research focuses on the use of an object, the FFM seaport, to act as a bridge between communities of practise.

There are three different forms of boundary objects: artifacts (for example tools, documents or models), discourses and process (Wenger, 2000). The theory in this research is that the FFM seaport acts like an artifact and helps in creating a common language and better shared processes.

Figure 4.1 presents an overview of the social learning theory in relation with the goal of this research. This means that the practical and theoretical factors which influence the cooperation, coordination and collaboration during disasters are discussed. The following chapter builds on this information and indicates the processes involved between those factors and the material convergence problem. In the end this will answer the first research question since it gives the important factors which the conceptual design of the FFM seaport must take into consideration.

A solution to the material convergence problem is to work well together. There are multiple ways of working together: coordination, cooperation and collaboration. Coordination is the least intensive and collaboration the most intensive. However, achieving a successful way of working together is difficult and the cluster approach does not reach the desired level. From a social learning perspective, working together in a cluster is shown as a boundary process. The experience and competence of the actors are in tension. Participating actors are learning from each other how they perceive the disaster and what they think of the course of actions. A successful boundary process needs coordination, transparency and negotiability.



Three things necessary to break boundary
- Coordination
- Transparency
- Negotiability

Communication part of research investigate of the use of a new technology, a FFM seaport, will help with this.

Figure 4.1: Overview of the social learning approach for this research

5

Defining important factors

The next step in this research is to define the important factors which the conceptual design of the FFM seaport must take into consideration. Chapter 4 describes that material convergence is one of the main problems in disaster logistics and that the FFM seaport can be used in two ways to improve this. First by working together and second by adding extra handling capacity.

A casual loop diagram is used to identify the factors related to working together. A causal loop diagram gives an overview about the different important factors and their relationships. This chapter first presents this causal loop diagram. After that, this chapter explains the important factors which must be taken into account when determine how the extra handling capacity can be created. The creation of this extra handling capacity relates to the logistical conceptual design of the FFM seaport.

5.1. Causal loop diagram - Communication factors

The causal loop diagram places the material convergence problem, working together and the social learning perspective into the total context of the humanitarian relief effort. It shows the important processes and factors which plays a role. The goal of the causal loop diagram is to find a critical node or bottleneck issue. When this critical node is improved, this improves important other factors and start other processes in order to reach a certain main goal. In this research the main goal is to improve the material convergence problem. Material convergence is thus the central factor in the causal loop diagram. The created causal loop diagram can be seen in Figure 5.1.

The causal loop diagram determines three groups which influences the material convergence. This are: (1) physical elements like limited space and the amount of goods, (2) the characteristics of humanitarian supply chains like the amount of donors and the heterogeneous flow of goods and (3) the culture of NGOs like the unwillingness to share information and the unwillingness to work together. The factors described in these three groups are hard to improve by working together. The causal diagram also includes some suggested solutions from literature. Literature suggest the following things in order to solve the material convergence problem: inspect incoming cargo (Holguín-Veras et al., 2014), certification standards in training and documents (Tatham and Spens, 2016) and data monitoring and sharing systems (Tatham et al., 2017). Finally the causal loop diagram also contains some factors based on the social learning theory described in Chapter 4.2.6 such as: a boundary process, competence in tension with experience, negotiation, coordinated action and transparency.

The causal loop diagram shows that the factor with the most incoming and outgoing arrows is the sensemaking factor. This means that this factor is involved in the most processes which plays a role around material convergence and working together. Two of the three proposed solutions in literature influences the principle of creating a common view. Next to that, creating a common view of the situation influences physical elements like the amount of goods and factors in the culture of NGOs such as the unwillingness to share information. The causal loop diagram also shows that sensemaking is hard

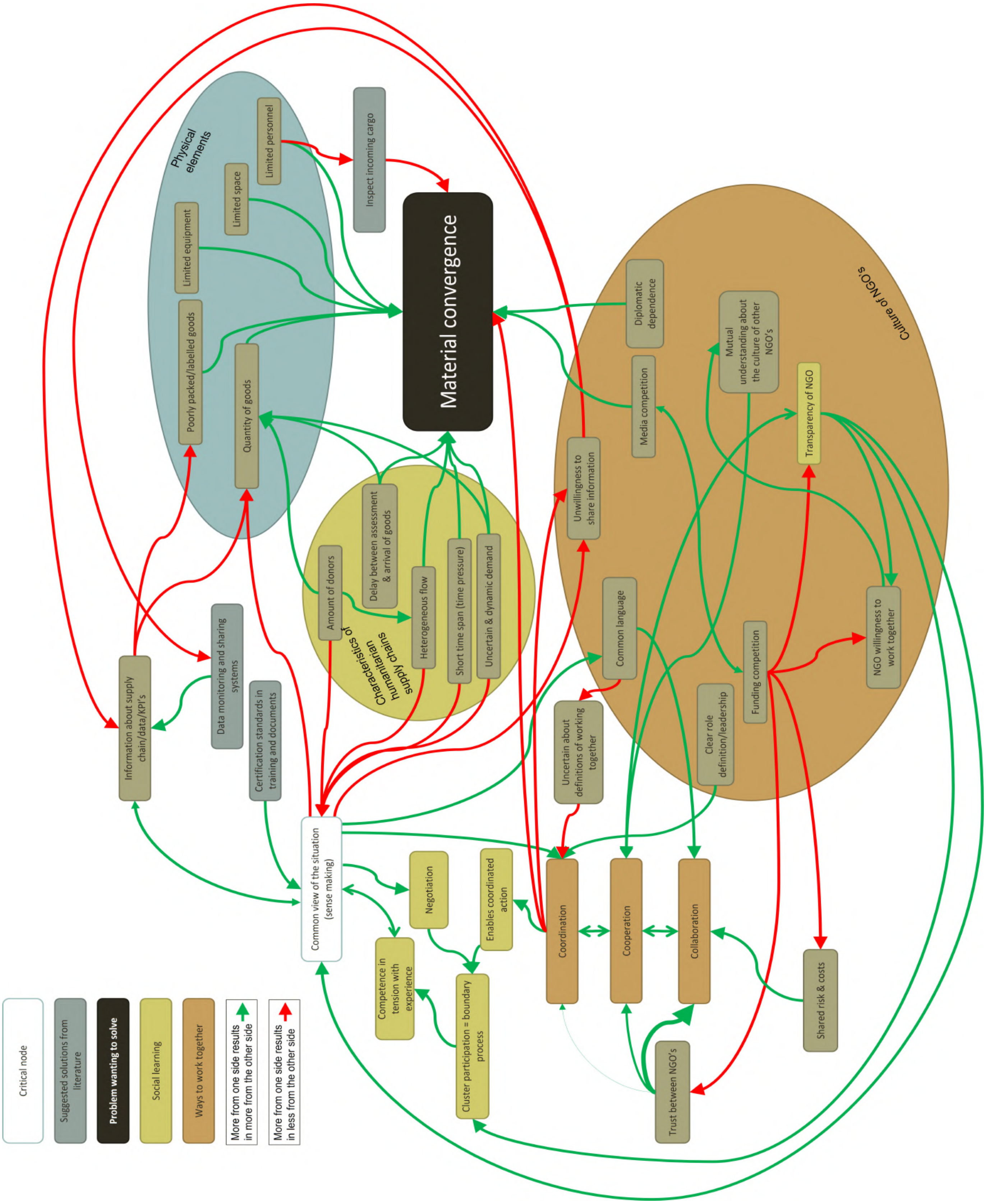


Figure 5.1: Causal loop diagram, factors which influences the material convergence

during crisis, because of among other things the characteristics of humanitarian supply chain factors.

The causal loop diagram shows that creating a common view of the situation fosters working together. Chapter 4.2 describes that working together helps to reduce the material convergence problem. In the causal loop diagram an arrow from coordination to material convergence illustrates this solution. However, it is important that sensemaking works as a recurring factor in order to foster working together. Figure 5.2 illustrates this process.

The figure shows that it all starts with NGOs working together in a successful boundary process. A successful boundary process takes negotiation, transparency and coordinated action into account (Wenger, 2000). When they work together, social learning theory tells that competence will be in tension with experience (Wenger, 2000). Together they create a common view of the situation. Creation of a common view of the situation improves the negotiation aspect of social learning. Creating a common view leads to a two-way connection between practises to make sure that multiple voices are heard. Creating a common view of the situation enhances the way of working together and at some moment this leads to coordination. This coordination leads to transparency and enables coordination action. Together with the already enhances negotiation aspect, this intensifies the boundary process. This creates a more thoroughly common view of the situation which leads to cooperation. This process repeat itself until a stable and effective collaboration is reached. At some moment a joint enterprise, mutual engagement and shared repertoire arises and thus a new community of practise is started (Wenger, 2000).

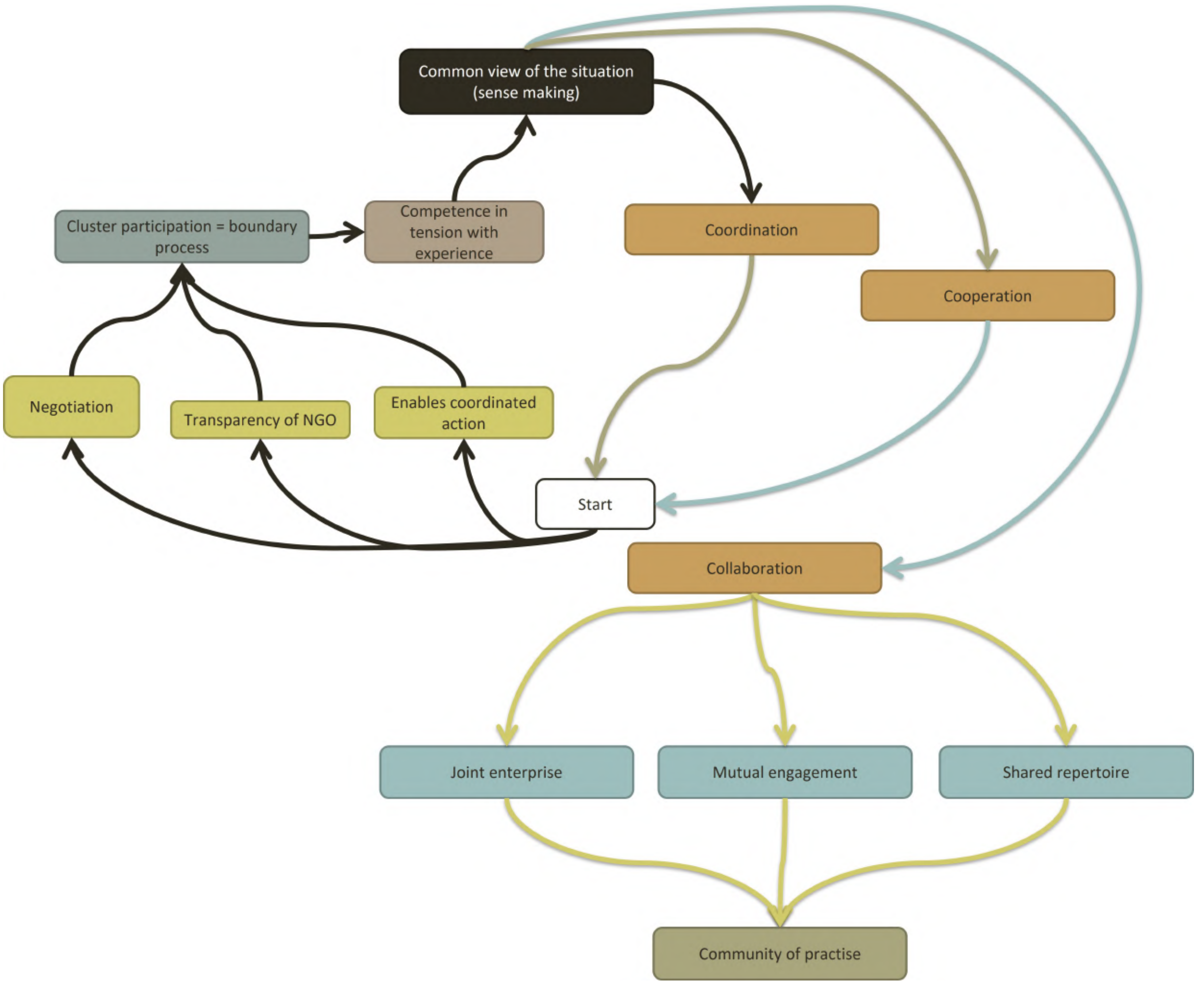


Figure 5.2: Sensemaking in relation to social learning and working together

The above means that creating a common view of the situation, improves working together which again improves the sensemaking, which again improves working together and so on. This is a never ending cycle and thus sensemaking and working together will continually be improved again and again. Since working together helps to reduce the material convergence (Holguín-Veras et al., 2014; Jahre and Jensen, 2010; Jensen and Hertz, 2016; Nagurney et al., 2016; Wankmüller and Reiner, 2020), this means that creating a common view of the situation will reduce the material convergence problem.

However there are more indirect ways in which an improved sensemaking leads to a reduced material convergence. Figure 5.3 shows the first one. This improvement is also related to working together. An improved common view of the situation improves the way in which people interacts and creates a common language. This fosters collaboration (Wankmüller and Reiner, 2020). Next to that, this also reduces the uncertainty about definitions of working together which again improves coordination (Jensen and Hertz, 2016; Wankmüller and Reiner, 2020). This improvement of working together reduces material convergence. Since improvements of working together also improves sensemaking again this again is a recurring loop. Sensemaking improves usage of a common language, which reduces the uncertainty about definition which improves working together which improves sensemaking and so on.

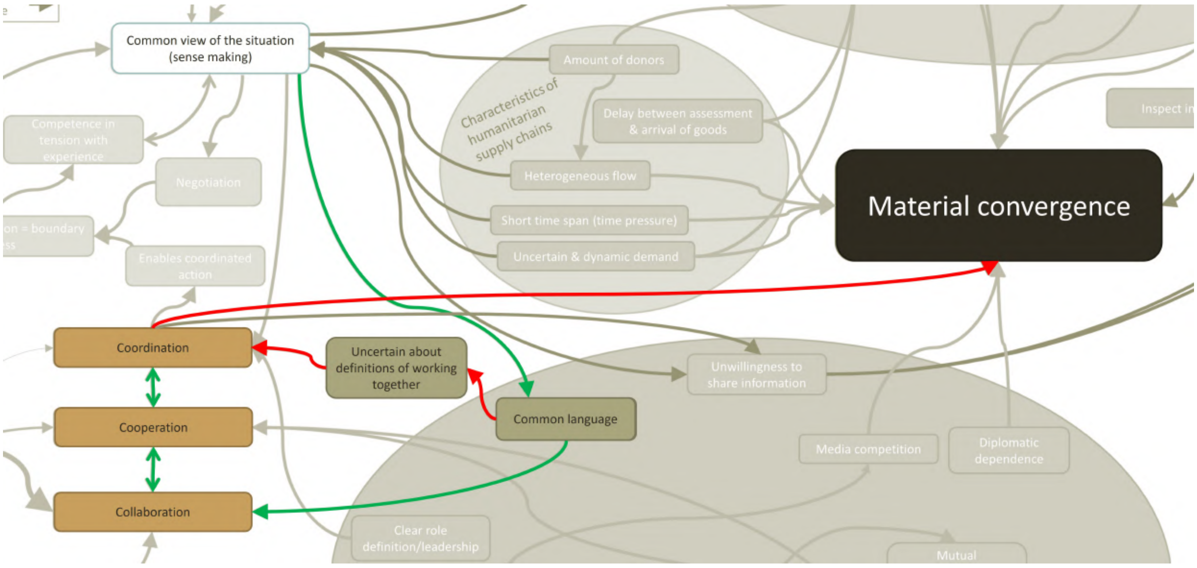


Figure 5.3: Improving sensemaking leads to reducing material convergence problem by creating a common language

A direct way of reducing the material convergence problem is due to the fact that sensemaking leads to a reduction of the quantity of goods. Actors have a better overview of the situation and there is less discrepancy between the assessments of different actors. Off course a reduction of the amount of goods will reduce the material convergence problem. Figure 5.4 shows this improvement.

A last way in which sensemaking reduces the material convergence problem is by reducing the unwillingness to share information. During the process of creating a common view of the situation, actors see that sharing information is important. When the unwillingness to share information is reduced, more data monitoring and sharing systems are used. This is one of the solutions for the material convergence problem as proposed in literature by Tatham et al. (2017). This leads to more data gathering about the supply chain and this reduces the quantity of goods and the amount of goods which are poorly packed or poorly labelled. This will reduce the material convergence. Figure 5.5 shows this process. This is also a continuously recurring cycle since more information sharing and more information gathering leads to more sensemaking and a better common view of the situation. This leads again to less unwillingness to share information and so on.

Figure 5.5 also shows that more working together leads to a reduction in the unwillingness to share information. Actors will get to know each other better, making them more willing to share information.

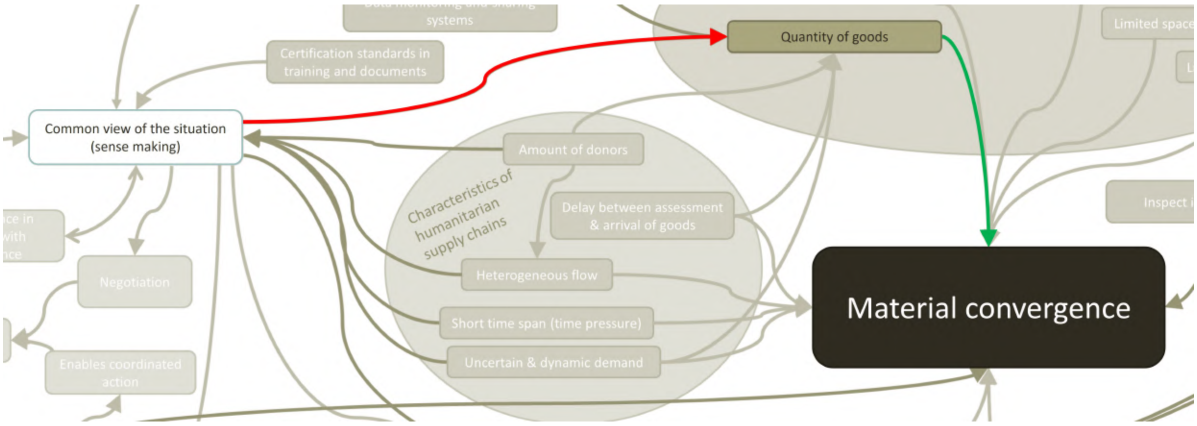


Figure 5.4: Improving sensemaking leads to reducing material convergence problem by reducing the quantity of goods

This is also a recurring cycle. This reduction in unwillingness to share information improves the sensemaking process, which again improves working together as which reduces the unwillingness to share information again.

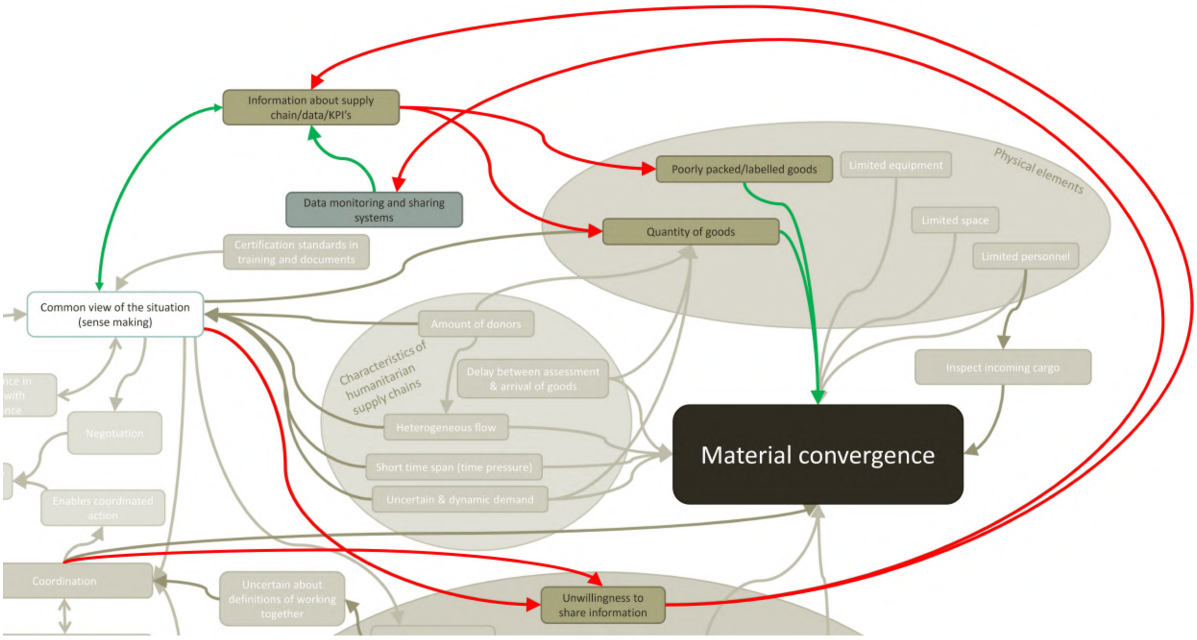


Figure 5.5: Improving sensemaking leads to reducing material convergence problem by sharing information

With all these recurring cycles it is inviting to say that it is easy to improve the material convergence by focusing on the sensemaking process. However there are also barriers which hinders the sensemaking process. Figure 5.6 shows these barriers. The characteristics of the humanitarian supply chain all negatively impacts the sensemaking process. These characteristics also directly increases the material convergence problem. Since it are characteristics of the humanitarian supply chain these characteristics are very difficult to influence.

When actors are aware of these barriers and keep on intensifying the way of working together they create a better common view of the situation. This in the end results in a reduced material convergence problem. The above means that sensemaking is the critical node in the communication part of this research. This research investigates how the design of the FFM seaport can incorporate factors which foster this sensemaking process. This results in working together in a better and more intensive way

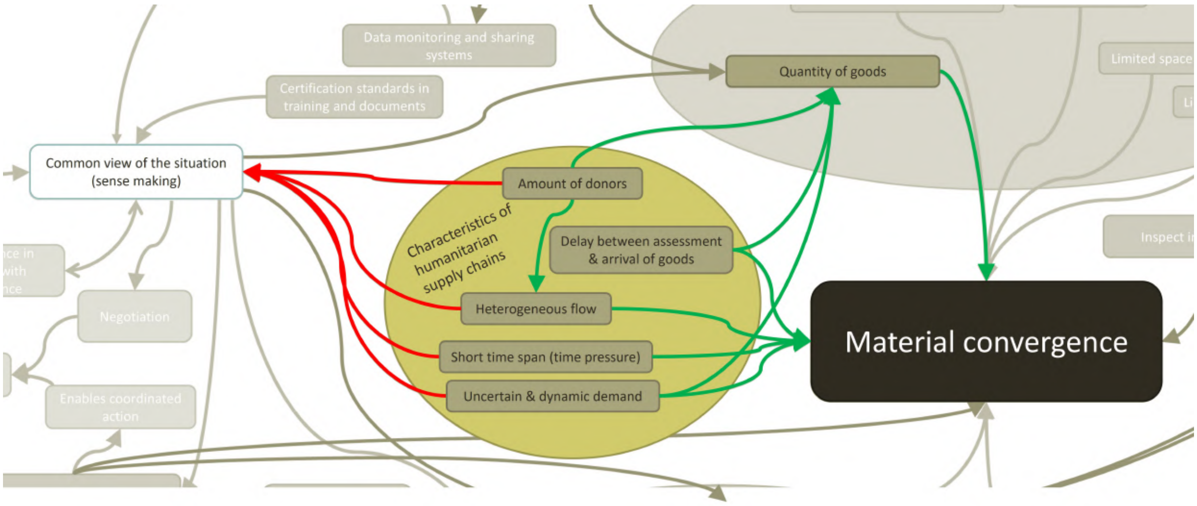


Figure 5.6: Barriers which reducing sensemaking and improving the material convergence problem

during a humanitarian relief effort. Which results in dealing effectively with the material convergence problem. Since working together is important, it is not only sensemaking, but also collective sensemaking what is important.

Chapter 4.2.1 explains that coordination, cooperation or collaboration are different ways of working together. Figure 5.2 shows that sensemaking and working together will lead ultimately to collaboration. The most intensive way of working together. This means that this research uses collaborative sensemaking as the exact description of factors which must be taken into account from a communicative perspective when designing the FFM seaport.

This research concludes that collaborative sensemaking during disasters is the critical node. Improving this critical node leads to improving all the different important factors of the material convergence problem. One of the major improvements is that collaborative sensemaking improves the way of working together. When actors work together during a disaster relief effort these actors are participating in a boundary process. Their competence is in tension with experience. A common view of the situation is created to deal with this tension. This improves the way of working together. The improved way of working together, benefits the boundary process and thus improves the sensemaking process which again improves the way of working.

5.2. Factors related to the logistical conceptual design

The communication factors which must be incorporated in the design of the FFM seaport are known. Next it is important to define the factors which determine the logistical conceptual design. The usage of a FFM seaport reduces the material convergence problem. The FFM seaport deals with the inflow of huge quantities of relief goods by transfer them from ships to shore. The logistical goal of this research is to design the logistical conceptual design of the seaport by determining the storage place and necessary handling capacity of the stored modules of the seaport.

Chapter 2.2 explains that there are three important key performance indicators within humanitarian logistics: speed, appropriateness and costs. Speed plays a role because the affected people must get help as soon as possible. Appropriateness tells that the affected people get the right supplies at the right time. These two key performance indicators are especially important in the first couple of days after a disaster. At that moment costs are less important. Later on in the disaster relief effort, actors try to find a more balanced ratio between those key performance indicators.

Speed is important in a disaster relief effort. Every disaster relief effort has to deal with time pressure. Time pressure arise because during a short time span cargo must be ordered, sent to the disaster area and handled. The causal loop diagram of the previous section shows that there is always a delay between the assessment and ordering of goods. The first weeks after a disaster, an airplane is chosen in order to sent goods to the affected area. This means that the seaport is not directly needed. The FFM seaport is needed at the moment that huge quantities of relief goods are sent with ships to the affected area. The FFM seaport must reach the affected area within that amount of time. To fulfill this requirement it is necessary that the FFM seaport is stored at a storage location which is close enough to reach that point within that time. Within this research this is translated to a maximum service distance. This is the maximum distance from a certain demand point that the FFM seaport must be stored in order to arrive on time at that demand point.

The causal loop diagram and Chapter 2.2 describes that high uncertainty is a characteristic of humanitarian logistics. Every humanitarian relief operation has to deal with uncertainty (Walton et al., 2011a). Uncertainty in a disaster relief effort relates to the timeline, geographic location, type of commodity and quantity of commodity (Liberatore et al., 2013). Liberatore et al. (2013) states that the uncertainty about the geographic location causes the other uncertainties. Uncertainty about the geographic location is the most important on a strategic level. Beforehand you never know if a certain location will be affected by disasters or not. Given this, the logistical conceptual design of the FFM seaport must deal with the uncertainty about the exact striking distance.

This research combines the uncertainty about the exact striking distance and the maximum service distance. It is never known beforehand which exact points will be hit by a disaster or not. This research let the uncertainty have an influence on the maximum service distance. It is allowed that the FFM seaport needs more time to travel to points which have a low risk of being affected then for points which have a high risk.

The appropriateness characteristics tells that the FFM seaport always must provide enough handling capacity to deal with all incoming cargo. Even if there are multiple disasters happening at the same time. Liberatore et al. (2013) highlights this point by stating that underestimating the amount of necessary goods results in substantial delays in the distribution. Next to that, due to appropriateness, it is important that the FFM seaport can assist in every disaster relief effort which is in need of such a seaport.

The above means that with respect to the three key performance indicators, speed and appropriateness are always met a certain predetermined standard. However, something must be optimized in order to define the optimal logistical conceptual design (storage location and amount of handling capacity stored) for a specific input configuration. Cost is the residual key performance indicator. This means that the cost to open storage facilities and store and transport a certain amount of handling capacity must be minimized, as long as the appropriateness and speed key performance indicators are met.

Most other models however predetermines a certain maximum amount of costs which can be spent. The objective of that models is to maximize the amount of help which can be offered with this amount of money. This is accepted as a limited and inappropriate objective. (Anaya-Arenas et al., 2014; Caunhye et al., 2012) state that, even while there is a need for efficiency, other factors like social cost or rapidity should be the main guideline.

To summarise, there are three important key performance indicators and one important characteristics of humanitarian logistics which are important for the design of the FFM seaport. This are:

- Speed. The seaport must arrive at the right place at the right time. It is not necessary for the seaport to be quicker then the expected incoming cargo ships. At the moment these ships arrive, the seaport must be installed at the disaster location ready for operation.
- Appropriateness. The humanitarian organisations must rely on the seaport in case of a disaster relief effort. The right type and amount of goods, must arrive at the right place before it is too late.

In terms of the FFM seaport this means that the exact demanded seaport handling capacity will be available at the right time.

- Costs. The seaport will be stored at a facility. Some storage locations will have a higher costs then other storage locations. The more handling capacity must be stored at a facility, the higher the costs of purchase and cost of purchase. Next to that, transportation and usage of the seaport also costs money.
- Uncertainty. Uncertainty in a disaster relief effort is related to the timing, geographic location, type of commodity and quantity of commodity. The uncertainty about the geographic location causes the other uncertainties and is in this research seen as the most important one.

The three key performance indicators: speed, appropriateness and costs, and the uncertainty characteristics in combination with the strategical goal of the FFM seaport leads to requirements for the model. Meeting these requirements results in a logistical conceptual design which contribute as best as possible to the material convergence problem. The requirements are:

- Minimize the cost of storage facilities to open. This is related to the cost key performance indicator.
- Minimize the cost of the handling capacities stored at all facilities. This is related to the cost key performance indicator.
- Minimize the cost of sending and operating handling capacity from a facility to a demand point. This is related to the cost key performance indicator.
- Determine location of storage facilities. This is necessary in order to define the conceptual design of the FFM seaport.
- Determine amount of capacity stored at every facility. This is necessary in order to define the conceptual design of the FFM seaport.
- Determine the amount of handling capacity sent from a certain facility point to a certain demand point in a specific situation. This is necessary in order to define the conceptual design of the FFM seaport.
- Keep enough capacity stored to supply every demand point. This is related to the appropriateness key performance indicator. When handling capacity is necessary, this handling capacity must be available.
- Contains a maximum service distance. This is the maximum distance between a storage facility and a demand point (island with more then 265,000 inhabitants) for which a storage facility can service that specific demand point. This is related to the speed key performance indicator.
- Every demand points has at least one storage facility within their maximum service distance. This is related to the appropriateness key performance indicator.
- Every demand point has their own individual maximum service distance. This is related to the uncertainty characteristic. Not every demand point does need the FFM seaport at the same time after the disaster hit.
- Uncertainty influences this maximum service distance. This is related to the uncertainty characteristic.
- Deal with the uncertainty about the exact striking area. This is related to the uncertainty characteristic. Beforehand it is not known where the exact disaster will happen.
- Deal with the fact that multiple disasters can happen simultaneously. This is related to the uncertainty characteristic. Multiple different disasters can happen simultaneously.
- Allow that demand points can be supplied by multiple storage facilities to deal with a disaster. As long as all the facilities together have enough capacity stored to help all demand points, it is allowed that multiple storage facilities can help in a disaster relief effort. It even helps in keeping the total stored capacity low and thus can help in minimizing the total costs.

The above lists presents the factors which, according to this research, the conceptual logistical design of the FFM seaport must take into consideration. Next to that, the previous section describes the communication factors which the conceptual design of the FFM seaport must take into consideration. This is collaborative sensemaking. The logistical and communication factors together gives the answer on the first research question about identifying the important factors which the conceptual design of the FFM seaport must take into consideration. By answering this question the introduction, background and context part of this research is concluded. This part explores the logistics as well as the communication part of this research. The following part of this research describes the literature, methods and results of the logistical part of this study.

The FFM seaport helps reduce the material convergence problem by creating more handling capacity to transfer goods from ship to shore. In order to maximize help it is important that the FFM seaport takes the costs, speed, appropriateness and uncertainty into account. The costs aspect shows that the costs have to be minimized while determining the conceptual design. It is allowed for a demand point to be helped by multiple facilities to keep the costs low. With regards to speed of transport there is a maximum service distance. This is the maximum distance between a storage facility and a demand point for which a storage facility can service that specific demand point. Appropriateness shows that (1) enough handling capacity must be stored to help every demand point and (2) every demand point needs to have a storage facility within their maximum service distance. With regards to uncertainty, the FFM seaport has to deal with (1) the uncertainty about the exact striking area and (2) with the fact that multiple disasters can happen simultaneously.

II

Literature, methods and results logistics research

6

Mathematical optimization models in current humanitarian logistics literature

The logistical goal of this research is to define an applicable conceptual design for a FFM seaport to be of help during a disaster relief effort. The logistical conceptual design consist of the optimal location to store such a FFM seaport and the amount of handling capacity stored at those locations. In order to find this applicable design a mathematical optimization model is the way to go. This chapter identifies how these type of mathematical optimization model are used in humanitarian research until now.

This chapter first identifies the, for this research, interesting types of humanitarian mathematical optimization models. After that, this chapter gives an overview of models which fall under this type. Finally, this chapter presents the insights of how the important factors find in Chapter 5.2 are modelled in current literature.

6.1. Define area of interest

Before discussing the interesting humanitarian mathematical optimization models developed by current research it is important to know a little bit more about mathematical optimization and which exact type of mathematical optimization models are of interest. This section identifies this interesting types.

6.1.1. Mathematical optimization

The first step is to take a closer look to mathematical optimization. A mathematical optimization involves optimization. There is a wish to maximize or minimize something (Williams, 2013). The quantity to be optimized is described in the objective function (Williams, 2013). In order to maximize or minimise some quantity, decisions are made. Solving the mathematical optimization model gives the optimal values of these so called decision variables. This represent a decision which result in the best possible value of the objective function (Hart et al., 2017). Next to that, a mathematical optimization model consist of constraints. Constraints restricts the possible values that decision variables can take (Williams, 2013). Constraints and objective functions are mathematical formula consisting of decision variables and parameters. Parameters represents the real-world situation which have to be modeled. This is for example the costs to build a storage location (Hart et al., 2017). Appendix F describes mathematical optimization in more detail.

Chapter 5.2 describes the factors which the conceptual logistical design of the FFM seaport must take into consideration. It is now possible to divide these factors into the important pieces which together forms a mathematical optimization model. This results in the following objectives:

- Minimize the cost of storage facilities to open.
- Minimize the cost of the capacities stored at all facilities.

- Minimize the cost of sending handling capacity from a facility to a demand point.

The decision variables are:

- Determine location of storage facilities.
- Determine amount of capacity stored at every facility.
- Determine amount of handling capacity sent from a certain facility point to a certain demand point.

The constraints are:

- Keep enough capacity stored to supply every demand point.
- Contains a maximum service distance in which stored capacity can reach a demand point.
- Every demand points has at least one storage facility within their maximum service distance.
- Every demand point has their own individual maximum service distance.
- Uncertainty has influence on this maximum service distance.
- Deal with the uncertainty about the exact striking area.
- Deal with the fact that multiple disasters can happen simultaneously.
- Allow that demand points can be supplied by multiple storage facilities to deal with a disaster.

The goal of this literature search is to find models which incorporates multiple of these objectives, decision variables and constraints. It is important to find the exact field of interest in which the models must be searched. Appendix G consist of an overview of mathematical optimization in humanitarian logistics. Different model categories exists: mass evacuation models, facility location models, resource allocation models, relief distribution models, casualty transportation models, search and rescue models, removal and recycling of debris models and infrastructure restoration models.

The type of decisions which must be made are described by the decision variables. These decision variables explain that this research must determine the location of storage facilities and the amount of handling capacity stored at those locations. The first part relates to a facility location problem and the second to a resource allocation problem. This means that a facility location-allocation model is the model of interest within this study. The next subsection discuss these models in more detail.

6.1.2. Facility location optimization models in humanitarian logistics

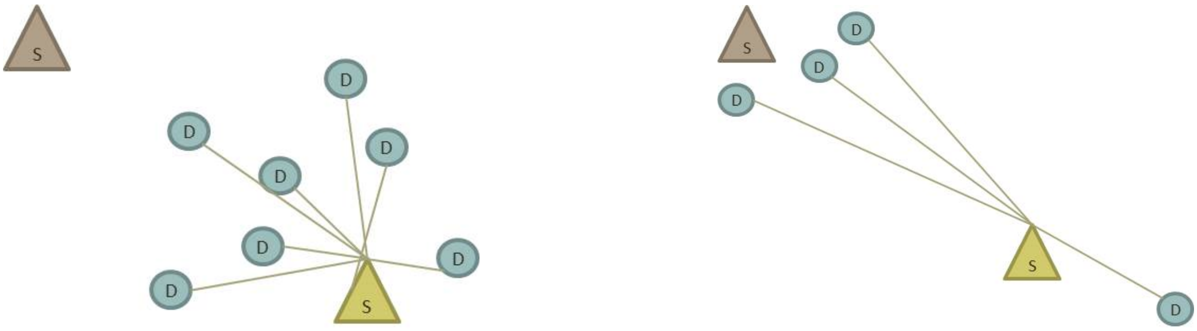
There are many different facility location optimization models for emergency humanitarian logistics (Boonmee et al., 2017; Hezam and Nayeem, 2021; Li et al., 2011). Normally this kind of models deals with two decisions: (1) which sites must be selected as depots for facilities and (2) how many goods must be placed at these depots in order to serve the demand points (Li et al., 2011). Facility location optimization models helps in strategic planning and design during pre-disaster operations (Boonmee et al., 2017).

There are three different kind of facility location optimization models. Figure 6.1 shows these three type of models. The three types are: p-median models, p-center models and covering models (Boonmee et al., 2017; Hezam and Nayeem, 2021; Li et al., 2011):

- P-median model: These models place a predetermined maximum amount of facilities. The model decide on which facilities to open with the goal to minimize the sum of all transport times between the demand points and facilities.

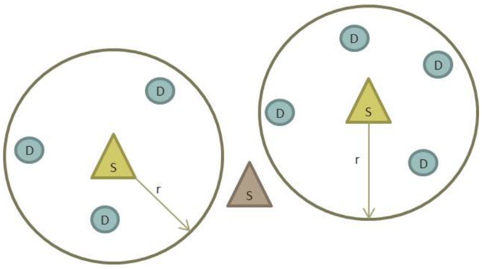
- P-center model: These models minimize the maximum distance between a set of demand points and the closest open facilities. Again these models place a predetermined maximum amount of facilities. These models are used for planning the location of hospitals, fire stations, shelters and other facilities.

- Covering model: The objective of covering models is to cover all demand points within a predetermined maximum distance. Normally, these models are used to determine the location of hospitals, fire stations and shelter sites. There are two main categories of covering models:
  - Set Covering model: The objective of these models is to minimize the total costs of opening facilities, while covering all demand points.
  - Maximal Covering model: These models place a predetermined maximum amount of facilities. The goal of these models is to maximize the total number of demand points which can be covered within the distance limits.

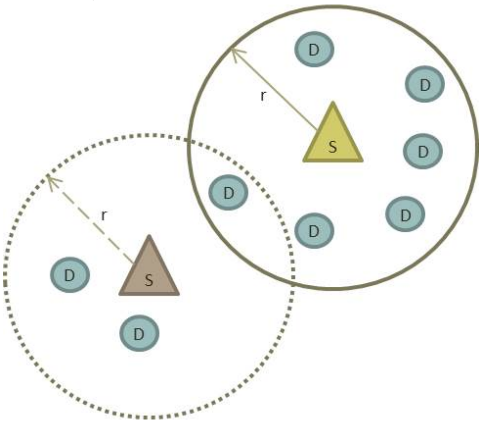


(a) P-median model. This example selects one supply point in order to minimize the distances between that one supply point and all demand points.

(b) P-center model. This example selects one supply point in order to minimize the maximum distance between that one supply point and all demand points.



(c) Set covering model. The circle around the supply points shows the maximum distance in which a supply point can serve a demand point. This example selects two supply points in order to serve all demand points with the minimum amount of supply points.



(d) Maximal Covering model. This example selects one supply point in order to maximize the amount of demand which can be served by only opening one supply point. The circle around the supply points shows the maximum distance in which a supply point can serve a demand point. The full circle is from the chosen supply point and the dotted circle of the supply point which is not chosen.

Figure 6.1: The four different types of location optimization models. Green triangles represents the selected supply points, brown triangles the non selected supply point options and blue dots represents the demand points.

To identify the interesting models in current literature it is important to determine the type of facility location optimization model which is most relevant to be used within this research. The objective in this research is to minimize the amount of cost. Next to that one of the constraints is that a demand point has a maximum service distance. These objective and constraint corresponds with a set covering model. The next sub section describes set covering models in more detail.

6.1.3. Set covering models - location allocation

The set covering model was probably the first emergency location optimization model (Li et al., 2011). The objective is to minimize the total number of facilities while satisfying all the demand points. The demand points have a given maximum distance for which a facility can serve that corresponding demand point (Boonmee et al., 2017; Hezam and Nayeem, 2021). The formulation of the set covering problem is as follow (Toregas et al., 1971):

Indexes and Set:

I	Set of demand points indexed by $i \in I$
J	Set of facilities indexed by $j \in J$
N	Set of facility sites located within the distance limit and that are able to service demand point $i (N_i = \{j \mid d_{ij} \leq S_i\})$

Decision Variables:

x_j	one if a facility is located at candidate node j and 0 otherwise

Input Parameters:

c_j	Fixed cost of facility j
S_i	The distance threshold for a demand node i to be considered as being covered

Min

$$\sum_{j} c_j x_j \tag{6.1}$$

subject to

$$\sum_{j \in N_i} x_j \geq one \qquad \forall i \tag{6.2}$$

$$x_j \in \{0,1\} \qquad \forall j \tag{6.3}$$

The objective function 6.1 minimizes the total costs of opening facilities. Constraint 6.2 ensures that every demand point is at least covered by one facility. Constraint 6.3 defines the binary variable of this model.

The next section takes a closer look at the current developed set covering models which are of interest for the mathematical optimization model needed in this research.

The mathematical optimization model in this research needs to determine the location of storage facilities and the amount of handling capacities. These kind of models are called facility location-allocation models. There are different kinds of facility location optimization models. The objective in this research is to minimize the amount of cost while one of the constraints is that a demand point has a maximum service distance. This objective and constraint combination corresponds with a set covering model. Set covering models minimize the total cost of opening facilities, while covering all demand points.

6.2. Interesting literature

This section describes the current set covering models with an application in disaster relief efforts. Several research within the location set covering is already performed. Not only in the context of humanitarian logistics but also in the context of first responders to incidents (such as police, fire departments and ambulances). It is important to note that work within the first responders context differs from work in the humanitarian logistics context. Locating and sizing stocks of supplies is necessary in humanitarian relief work and less in the first responders context. Next to that, there is more uncertainty about the disaster's location and the amount of supply which is necessary at that point (Rawls and Turnquist, 2010).

Next to set covering models also some models from other facility locations optimization types are interesting. The model needed in this research has the objective to determine the location of the facilities to open while minimize the costs of storage facilities to open. Of course, this is the typical objective and decision variable for set covering models. However, the model in this research also must determine the amount of handling capacity stored and sent. Not typically things which are determined by set covering models. This makes it interesting to also look at some important models from the other facility location optimization types. The next subsections give an overview of the found literature.

6.2.1. Non set covering models

Duran et al. (2011) made a P-median model which has the goal to preposition emergency items to react to natural disasters all over the world. Since this is a P-median problem they determined upfront the amount of warehouses which can be opened. They solved the model a couple of times with different number of warehouses to be opened. They divided the world in a couple of regions and treated a region as one demand point. Then they looked at historical data of 240 different time frames consisting of two weeks and formed scenarios. They determined for each scenario the amount of goods which are necessary per demand point. In this model they incorporated the fact that disasters can happen at the same time all over the world and assumed that within two weeks a warehouse can be replenished if necessary. Within the scenarios they looked at how much persons are affected. On basis of the type of disaster they identified the probability that certain goods are necessary. Based on the probability they also determined the amount of goods necessary. The created facility location optimization model minimize the total distance between all demand points and all facility points over all scenario. They gave every scenario a probability that this will happen again in the future, making it a stochastic model (Boonmee et al., 2017).

Balcik and Beamon (2008) also created a model to preposition goods for humanitarian relief. They made a maximal cover model. They used it to calculate the position and amount of goods which must be positioned at facilities all over the world to respond to earthquakes. The amount of warehouses was restricted by a maximum amount of costs and the goal of the model was to maximize the amount of covered demand, given this maximum amount of costs. Also this research used scenarios to model the uncertainties. Every scenario represents one disaster and the location and impact of this specific disaster was estimated based on historical data and the amount of persons which live close to the disaster site. Also every scenario was given a probability that it will happen again in the future based on this historical data. An assumption was made that multiple disasters will not happen simultaneously. Finally they determined different cover levels by stating that the closer a demand point to a facility, the better the cover level.

Sheu et al. (2005) used another method in order to deal with the uncertainty: fuzzy clustering and fuzzy linear programming. This was not used for facility location, but for allocation of goods in warehouses. The fuzzy clustering was used in order to cluster different demand groups together. They used a formula based on distance and the amount of times a particular area is affected. Next to that, fuzzy linear programming was used in the allocation of goods by stating that the amount of goods necessary at the demand point are following a triangle function. First there are no goods necessary, then after time is progressing more and more goods are necessary till a certain maximum amount is reached. After that time the amount of necessary goods stays at that maximum level.

Murali et al. (2012) created a maximal covering model to determine the points in a city where medicine should be handed to the population in case of emergencies. They also made use of different coverage levels by stating that the closer the facility is to the demand point, the better the cover level. Every demand point has the same amount and types of coverage levels. For every demand point only a certain maximum fraction of the total needed demand can be served by facilities located in a certain coverage level. They predetermined the number of facilities and they assumed that the location of the affected area is known before hand. They assumed that the amount of needed demand is uncertain. They dealt with this uncertainty by using a chance-constrained model. This model assumes that the probability distribution is known and it requires that the uncertain constraints be satisfied with high probability.

Finally, Rawls and Turnquist (2010) created a combination of a set covering and p-median problem. The objective of the model is to place facilities in such a way that the total cost of opening a new facility and traveling between the demand points and facilities is minimized. The model determines the location and amount of supplies to be prepositioned, under uncertainty about if, or where, a natural disaster will occur. They assigned an specified amount of money towards opening a facility somewhere. They also incorporated the possibility to unmet demand, but this cost money. The same with holding supplies at a facility after a disaster relief effort. They also worked with scenarios and the probability of occurrence of that particular scenario. Within the model they worked with two stages. The first stage chooses the locations of facilities and allocation of supply to that facilities under the objective to minimize costs. The second stage determines the route selection, the amount of unmet demand and the amount of unused relief goods under the objective to minimize the cost of the route, unmet demand and unused relief goods. The model is computational complex, because the two stages are dependant of each other. The model uses a heuristic algorithm referred to as the Lagrangian L-shaped method to solve the problem.

6.2.2. Set covering models - first responders

Toregas et al. (1971) developed the standard set covering model which is explained in subsection 6.1.3. The aim of that model is to minimize the total number of facilities needed to cover all demands. This was the first set covering model developed.

Aly and White (1978) created a model in order to locate the optimal stand by location for first responders. They created a set covering model and stating that the emergency calls are generated in a region instead of a discrete point. They supposed that the exact demand point is a random variable occurring uniformly within this region. This model requires that covering of all possible demand points must be satisfied with high probability.

Daskin and Stern (1981) created a multiple objective set covering model for placing ambulances. It minimizes the amount of ambulances needed to cover the demand points. This amount of ambulances is placed in such a way to maximize the amount of demand points which are covered by multiple ambulances. This to deal with the problem when vehicles are not available for service because they are engaged in earlier calls.

Revelle and Hogan (1989) proposed a probabilistic version of the set covering model, in order to deal with the problem that vehicles are not available for service because they are engaged in earlier calls. They estimate the server busy fraction, the fraction of time which the ambulances spends servicing calls. Given this estimated busy fraction they required all the demand points to be covered with a specific reliability level.

Ball and Lin (1993) also required that all demand points are covered within a specific reliability level. They however do not first estimate the busy fraction but directly model the source of uncertainty: the service calls originating from every demand point.

Ball and Lin (1993); Revelle and Hogan (1989) both assumed that the probability of an ambulance being busy is the same across the entire system. Marianov and Revelle (1994) has created a model that lead to results that are likely more realistic. They allowed for a neighborhood-dependent, or region-specific probability of an ambulance being busy.

Finally Shiah and Chen (2007) divided a city in areas. It used a classic set covering formulation to places ambulances on position in such a way that they can reach within a predetermined time every area. Second, it looked at the amount of people one ambulance can service and at the population distribution within this areas. If the population is more then the amount of people one ambulance could service, the program split up the area in two areas. This process repeated itself until a satisfied solution was found.

6.2.3. Deterministic set covering models - humanitarian relief

Dekle et al. (2005) used a deterministic set covering model to minimize the amount of disaster recovery centers in Florida. They used the classic set covering model but used a pick the farthest algorithm in order to bundle demand points.

Rath and Gutjahr (2014) created a multi-objective optimization model. The model have three objectives: (1) minimize the facility opening cost based on a classic set covering model, (2) maximize the covered demand and (3) minimizing transportation costs. The model decides about which facilities must be opened, how many quantity must be shipped to the depot and selected the arc to use on a tour of a vehicle. To deal with the multi objective aspect of the model the adaptive epsilon-constraint algorithm (AECA) was used. This algorithm solved a sequence of single objective optimization problems. One objective function of the multi-objective problem have to be chosen as objective function for the single-objective problem. All other objective functions are constrained by appropriate bounds determined by the algorithm.

Hu et al. (2014) also proposed a bi objective model in order to determine the location of and route to earthquake evacuation sites. The objective is to minimise the total evacuation distance, given the capacities of evacuation sites and the evacuation facility opening costs. This later objective was formulated from the classic set covering problem. They also incorporated a constraint which state that the residents of blocks on a certain route towards an evacuation site must always follow that certain route in order to avoid chaos among evacuees. Since it is a bi objective model they designed a non-dominated sorting genetic algorithm in order to solve the model.

Hale and Moberg (2005) introduced a set covering model. This model consists of not only a maximum distance in which demand points can be served by facilities but also a minimal distance in order to not place facilities inside potential disaster areas.

6.2.4. Stochastic set covering models - humanitarian relief field

The models in the previous subsection are all deterministic models. Off course there are also some stochastic or robust variants. Jabbarzadeh et al. (2014) made a robust optimization model that can assist in blood facility location and allocation decisions. The objective of the model is to minimize the total cost (combination of blood location facilities, transportation and blood holding), while ensuring a certain robustness to major disasters. The uncertain and dynamic nature of blood demand is explicitly addressed in the model by ensuring that the blood demands are met in the optimal way under each disaster scenario. The model consist of two stages. The first stage uses a set covering model to determine the location of the facilities. The second stage determines the allocation, blood collection and inventory level.

Chang et al. (2007) created a two stage stochastic model for flood emergency logistics. The first stage uses a set covering model in order to determine the rescue bases that needs to be set up after a disaster. The objective is to minimize the cost of setting up rescue bases. The second stage determines the quantity of rescue equipment in the bases and the transportation plans. This second stage is based upon the first stage and contains uncertainty about the amount of demand. This uncertainty is incorporated by using different scenarios. The stage minimizes the sum of the amount of rescue equipment cost and transportation times in every scenario.

Oksuz and Satoglu (2020) created a somewhat similar two stage stochastic model. The model was used to determine the amount and places of temporary medical centers. They used scenarios in order to deal with the uncertainty about the amount of casualties and road condition. In the first stage, regardless of the scenarios, the number and places of different temporary medical centers are determined with a set covering model. In the second stage the objective function minimizes the expected total transportation cost over all scenarios.

An et al. (2015) created a model which integrates the facility location design, en-route traffic congestion, in-facility queuing delay and probabilistic facility disruption. The facility location part of the model is described with a combination of a classical set covering model and a P-center model. It minimizes the amount of facilities while also minimizing the travel cost. Next to this, the model minimize the unsatisfied emergency service demand and in-facility queuing cost. In-facility congestion is addressed by queuing theory. Scenarios are used in order to model the uncertainty of facilities which can be disrupted. This facilities can not be opened in that specific scenario. In the end this results in a non linear, multi objective model which is solved with a Lagrangian Relaxation algorithm to find a near-optimum solution.

Table 6.1 gives an overview of the characteristics of all interesting literature. It includes information about the amount of and the details of the objectives and the stages of the model. Next to that it discusses, when applicable, other characteristics like how the model is solved and if and how scenarios are used in the model.

This is the end of this section which describes all found models. The next section contains an overview of this literature and corresponding interesting insights.

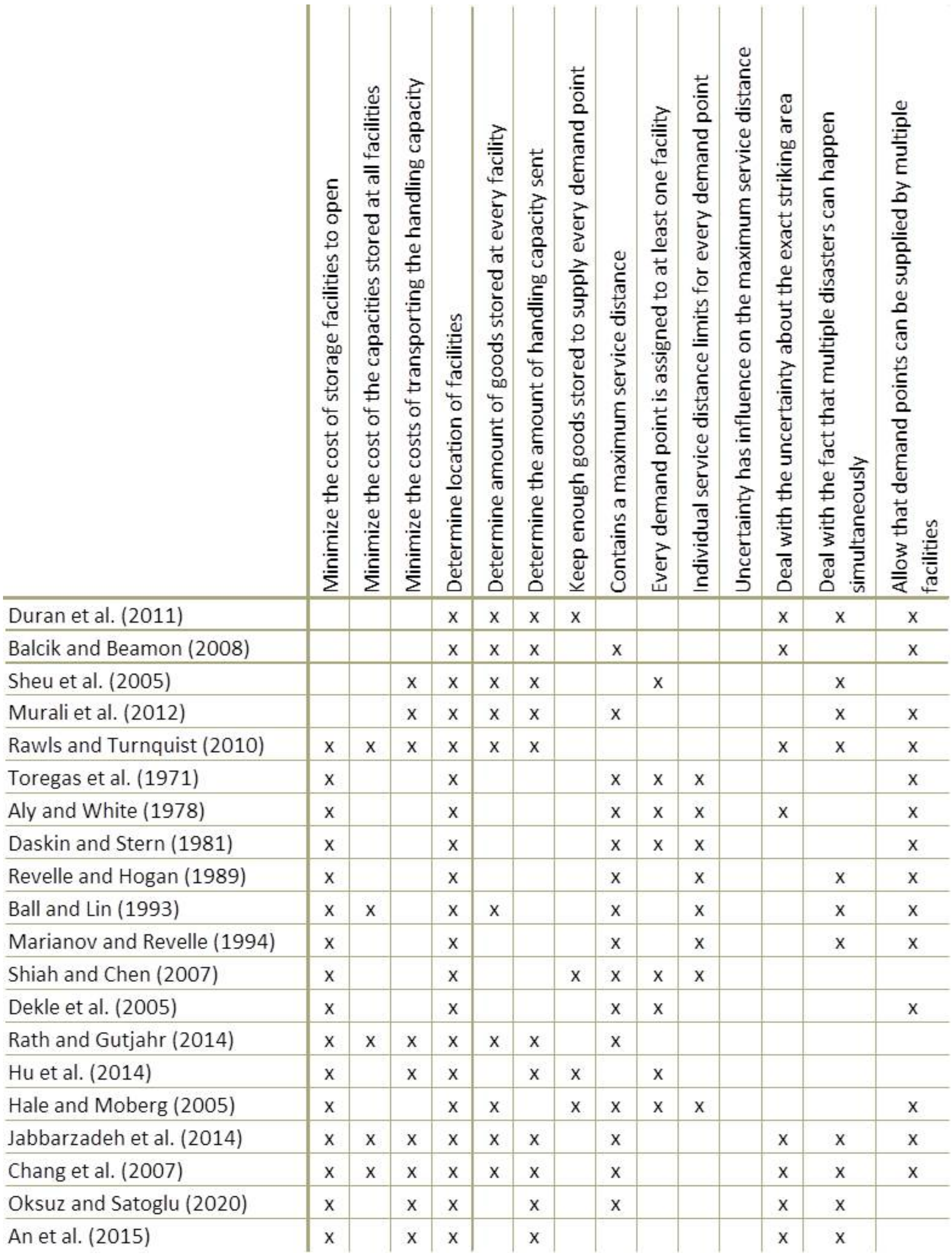
Table 6.1: Overview of the current literature

Literature	Characteristics
Duran et al. (2011)	Single objective and single stage. P-median model. Minimize the average response time over all the demand instances over all scenarios, given a maximum amount of facilities. A scenario consist of multiple different demand points wanting service. The experimental plan is to solve the mathematical model a number of times with different maximum amount of facilities and compare those results.
Balcik and Beamon (2008)	Single objective and single stage. Maximal cover model. Maximizes the demand over all scenario's which can covered by the distribution centres and places the amount of demand stored at a location. A scenario consist of one disasters and only one demand point.
Sheu et al. (2005)	Multi objective and multi stage. The first stage assigns one relief distribution center to each demand point under the objective of minimal travel time. The second stage determines the routing order on objective of minimal traveling costs.
Murali et al. (2012)	Multi objective and multi stage. Demand of the demand points not known beforehand. Chance-constrained model is used to deal with the uncertainty. The first stage determines which locations to be opened under the objective to maximize the amount of supplies transported between facilities and demand points. The second stage allocates demand points to the open facilities under the objective to maximize coverage and the third stage relocates open facilities to minimize the travel time between the facilities and demand points.
Rawls and Turnquist (2010)	Multi objective and multi stage. The first stage choosing the locations of facilities and allocation of supply to that facilities under the objective to minimize costs. The second stage determines the route selection, the amount of unmet demand and the amount of unused relief goods under the objective to minimize the cost of the route, unmet demand and unused relief goods. Multiple scenario's are calculated over the second stage and the sum of all these scenario including the probability of occurring of these scenario's is minimized. Since the two stages are dependant of each other the model is computational complex and a heuristic algorithm referred to as the Lagrangian L-shaped method is developed to solve the problem.
Toregas et al. (1971)	Single objective and single stage. Standard set covering model
Aly and White (1978)	Single objective and single stage. Standard set covering model, however facilities can only cover demand points which have a high probability of being located within the cover distance.
Daskin and Stern (1981)	Multi objective and single stage. The model minimizes the amount of ambulances needed and places the ambulances to maximize the amount of demand points which are covered by multiple ambulances. Every facility location can host maximum one ambulance.
Revelle and Hogan (1989)	Single objective and single stage. Standard set covering model. Estimated server busy fraction, the fraction of time which the ambulances spends servicing calls. Given this estimated busy fraction they required all the demand points to be covered with a specific reliability level. The probability that an ambulance is busy is not varying over the problem.
Ball and Lin (1993)	Single objective and single stage. Objective is to minimize costs of opening facilities and placing of ambulances on that facilities, while still be able to service the demand points with a specific reliability level based on the probability a facility fails to deliver demand.
Marianov and Revelle (1994)	Single objective and single stage. Standard set covering model. Estimated server busy fraction, the fraction of time which the ambulances spends servicing calls. Given this estimated busy fraction they required all the demand points to be covered with a specific reliability level. The probability that an ambulance is busy is varying over the problem.
Shiah and Chen (2007)	Single objective and single stage. Demand points are created by looking at the amount of people one ambulance can service and at the population distribution within an area.
Dekle et al. (2005)	Single objective and single stage. Standard set covering model is used. Pick the farthest algorithm is used to bundle demand and possible facility points.
Rath and Gutjahr (2014)	Multi objective and single stage. The model minimize the total facility opening costs, minimize the transportation and inventory costs and maximizing the demand coverage. Note that the first two are monetary objective functions and the last one isn't. They use the adaptive epsilon-constraint algorithm as the basic approach for dealing with the multi-objective aspect of the problem.
Hu et al. (2014)	Multi objective and single stage. The model minimises the total evacuation distance and minimizes the total facility opening costs. Uses a non-dominated sorting genetic algorithm to solve the problem of multi objective.
Hale and Moberg (2005)	Single objective and single stage. Standard set covering problem, however not only a maximum service distance, but also a minimum service distance. Also a facility can only help if it has enough supply to fully cover that demand point.
Jabbarzadeh et al. (2014)	Multi objective and multi stage. The first stage locates facilities with the objective of minimizes the opening costs. The second stage determines the moving of temporary facilities, operational costs, transportation cost and holding inventory costs also under the objective to minimize costs. These stages are separated since the first stage is determined before a specific disaster scenario happens and the second stage is calculated over different scenario's. Next to that both stages also has the objective to minimizes the under-fulfilment. Since both stages are dependant of each other and both objectives are in competition with each other a robust model is formulated.
Chang et al. (2007)	Multi objective and multi stage. The first stage locates the facilities and determines the allocation of goods under the objective to minimize the costs. The second stage determines the transport and inventory level decisions under the objective of minimizing the total cost of equipment, expected future transportation cost, supply-shortage cost and the demand shortage penalty. Since both stages are dependent of each other a sample average approximation is used to solve the problem.
Oksuz and Satoglu (2020)	Multi objective and multi stage. First stage is a classical set covering model which minimizes the number of hospitals to be opened such that the capacity is bigger then the total expected demand, regardless of the scenarios. The second stage places all victims over the hospitals with the objective to minimize the transportation cost. Note that this objectives are in competition with each other. It is assumed that the first objective is more important and thus the second stage is solved after the first stage. Chance-constraints are added to minimize the total unmet demand.
An et al. (2015)	Multi objective and multi stage. The first stage assigns the traffic while minimizing the en-route travel cost over all scenarios. The second stage determines the facility location while minimizing the total cost of: facility set-up over 1 scenario and unsatisfied emergency service demand and in facility queuing over all scenario's. To deal with, among other things, the competitive objectives, a customized Lagrangian Relaxation algorithm to find near-optimum solutions is used.

6.3. Insights for needed model

Chapter 6.1 describes the different objectives, decision variables and constraints which the model in this research must met. It is interesting to indicate if this found literature contains one of the necessary objectives, decision variables and constraints for this research. Table 6.2 presents this overview. Appendix H presents an elaborate overview of this table. It contains details about why models do or do not incorporate certain objectives, decision variables and constraints.

Table 6.2: Overview of the requirements for the model in this research and the current literature



	Minimize the cost of storage facilities to open	Minimize the cost of the capacities stored at all facilities	Minimize the costs of transporting the handling capacity	Determine location of facilities	Determine amount of goods stored at every facility	Determine the amount of handling capacity sent	Keep enough goods stored to supply every demand point	Contains a maximum service distance	Every demand point is assigned to at least one facility	Individual service distance limits for every demand point	Uncertainty has influence on the maximum service distance	Deal with the uncertainty about the exact striking area	Deal with the fact that multiple disasters can happen simultaneously	Allow that demand points can be supplied by multiple facilities
Duran et al. (2011)				x	x	x	x					x	x	x
Balcik and Beamon (2008)				x	x	x		x				x		x
Sheu et al. (2005)			x	x	x	x			x				x	
Murali et al. (2012)			x	x	x	x		x					x	x
Rawls and Turnquist (2010)	x	x	x	x	x	x						x	x	x
Toregas et al. (1971)	x			x				x	x	x				x
Aly and White (1978)	x			x				x	x	x		x		x
Daskin and Stern (1981)	x			x				x	x	x				x
Revelle and Hogan (1989)	x			x				x		x			x	x
Ball and Lin (1993)	x	x		x	x			x		x			x	x
Marianov and Revelle (1994)	x			x				x		x			x	x
Shiah and Chen (2007)	x			x			x	x	x	x				
Dekle et al. (2005)	x			x				x	x					x
Rath and Gutjahr (2014)	x	x	x	x	x	x		x						
Hu et al. (2014)	x		x	x		x	x		x					
Hale and Moberg (2005)	x			x	x		x	x	x	x				x
Jabbarzadeh et al. (2014)	x	x	x	x	x	x		x				x	x	x
Chang et al. (2007)	x	x	x	x	x	x		x				x	x	x
Oksuz and Satoglu (2020)	x		x	x		x		x				x	x	
An et al. (2015)	x		x	x		x						x	x	

Table 6.2 shows some interesting insights. These insights are: (1) there is no model which let uncertainty influence the maximum service distance, (2) keep enough goods stored to supply every demand point, (3) modelling uncertainty, (4) combine objectives and decision variables, (5) equipment already in use, (6) served by multiple facilities and (7) constraints related to a standard set covering model. The remainder of this section will describe these insights.

6.3.1. No model which let uncertainty influence the maximum service distance

There is no model in literature right now which covers the for this research necessary objectives, decision variables and constraints. This because there is no model which incorporate the uncertainty in the maximum service distance of a demand point. In set covering models this maximum service distance is a limited factor. A facility can only serve demand points which are within their reach. Most of the current existing research assumes that this covering distance is just a predetermined deterministic distance. There is at this moment not a model where uncertainty influences the maximum service distance.

A new model is created in order to make sure that the model contains all necessary objectives, decision variables and constraints. This new model is described in Chapter 7. This subsection describes the model of Aly and White (1978) in more detail. This model serves as an inspiration to meet the constraint of letting uncertainty influence the maximum service distance. Aly and White (1978) created a model where uncertainty plays a role in combination with the maximum service distance. A certain demand point can be served by a facility if the probability that the distance between the demand point and the facility is lower then the individual covering distance for a certain demand point.

The model of Aly and White (1978) uses the following equation:

$$a_{ij} = \begin{cases} 1, \text{if } Pr(t_{ij} \leq t_i) \geq \gamma_i \\ 0, \text{if } Pr(t_{ij} \leq t_i) < \gamma_i \end{cases} \tag{6.4}$$

This equation state that demand point i is covered by facility j if a certain probability (the probability that the distance between that demand point i and facility j is inside the individual maximum service distance for demand point i) is above a certainty threshold γ_i.

The model of Aly and White (1978) defined a certain probability threshold for every demand point. This means that uncertainty does not extend or reduce the maximum service distance. The model of Aly and White (1978) does not accept that the distance between a facility and a demand point can be made longer when there is a low probability a disaster will occur at a demand point. Chapter 5.2 describes that making this extension or reduction leads to optimal dealing with the key performance indicators: appropriateness, cost and speed. The model used in this research must thus be altered in order to deal with the constraint which state that uncertainty has influence on the maximum distance. This adjustment is described in more detail in Chapter 7.

6.3.2. Keep enough goods stored

It is good to notice that even if there was a model which let the uncertainty influences the maximum service distance, it is still not possible to combine two models into one in order to met the necessary constraints, objectives and decision variables. There are only four models which keep enough goods stored to supply every demand point. Appendix H shows that three of them contains additional conditions. Shiah and Chen (2007) state that a demand point can only be totally helped and served by one facility. Hu et al. (2014) state that every demand point needs only one supply unit. Hale and Moberg (2005) state that that a demand point can only be served by a facility which has enough capacity to totally help that demand point and only one demand point need help at a time. The model of Duran et al. (2011) does not impose these extra conditions but their objective functions are totally different then the necessary objective functions for this research.

6.3.3. Modelling uncertainty

Another insight is the way in which the uncertainty about the exact striking area is modeled. Appendix H shows that there are two ways of modeling this uncertainty. The first way is already discussed as this is the way which is used by Aly and White (1978). The other way is the usage of scenarios. This is done by An et al. (2015); Balcik and Beamon (2008); Chang et al. (2007); Duran et al. (2011); Jabbarzadeh et al. (2014); Oksuz and Satoglu (2020); Rawls and Turnquist (2010). Every scenario represents a static situation in which one or several demand points are in need of supplies. One scenario represents one disaster happening. They give a probability on the chance that this particular scenario will happen. Scenarios with a higher probability contribute more to the objective function and thus are more important to optimize then scenarios with a lower occurring probability. Demand points which have a low disaster occurring probability are less important to serve in these models. Disadvantage of this method is that a decision variable which can take different values in every different scenarios is necessary. This because some scenarios are more important to optimize then other scenarios and this results in the fact that minimizing or maximizing the values of these decision variables is in some scenarios more important then in other scenarios.

The model in this research needs to find the optimal location and amount of handling capacity stored at those location in response to multiple disasters. However, the amount of capacity stored at the storage facilities and the amount and location of the storage facilities keeps the same in response to a disaster. For example, it is not that in order to help for one disaster only a location in Oslo is opened and in response to another disaster only a location in Barcelona. The model must find the optimal location over all possible disasters scenarios. The goal is to minimize the total amount of cost over all these scenarios. It is not that a scenario is more important then others, because for every scenario these costs must be made.

The above means that only the part of transporting the handling capacity can vary over every scenario. In every disaster the amount of capacity sent from a facility to a demand point varies. However, it gives problems when summing only the part of the objective function which minimizes the costs of transporting over all scenarios. This because the cost of transportation depends on the locations of opening facilities. Choosing where to open facilities influences the travel time, and costs, between facilities and possible demand points. On top of that if the costs of transporting handling capacity is multiplied for certain scenarios by a certain possibility factor, the ratio of the costs between opening facilities and transporting handling capacity is changed. This results in an inappropriate way of taking the dependence of both costs into account. The current literature has the same problem.

The current literature deals with this problem differently. Balcik and Beamon (2008); Duran et al. (2011) have different objective functions then the necessary objective function for the model in this research. Duran et al. (2011) minimize the average response time over all scenarios and Balcik and Beamon (2008) maximize the coverage over all scenarios. These two models, summed the total objective function over all scenarios. An et al. (2015); Chang et al. (2007); Jabbarzadeh et al. (2014); Oksuz and Satoglu (2020); Rawls and Turnquist (2010) all deals with the problem by creating a multi stage approach. Note that creating this two stage approach is not solely done to avoid this problem, there are more reasons. However, it works to deal with the problem effectively.

Rawls and Turnquist (2010) for example, first determine the locations of facilities and allocation of supply to that facilities under the objective to minimize costs. In this stage the decision variables are just determined once. The second stage determines the route selection, the amount of unmet demand and the amount of unused relief goods under the objective to minimize the cost of the route, unmet demand and unused relief goods. Multiple scenarios are calculated over the second stage and the sum of all these scenario including the probability of occurring of these scenarios is minimized. However, these two stages are dependant of each other, the decisions made in the first stage (the position of location facilities), influences the decisions made in the second stage (route selection). This makes the model computational complex and a heuristic algorithm referred to as the Lagrangian L-shaped method is developed to solve the problem. This method calculates the expected value of the second-stage and incorporates this in calculating the first stage while minimizing everything.

Jabbarzadeh et al. (2014), Chang et al. (2007) and Oksuz and Satoglu (2020), all use a similar approach as discussed above. The first stage in those four models locates facilities with the objective of minimizes the opening costs. The other objectives relevant for that specific model such as the operational costs, transportation cost, supply-shortage cost and inventory costs are minimized in the second stage. All three models first determine the first stage before a specific disaster scenario happens. The second stage is calculated over different scenarios. To deal with the dependency of the two stages the three models all uses a different strategy. Jabbarzadeh et al. (2014) formulated a robust model, Chang et al. (2007) used a sample average approximation to solve the problem and Oksuz and Satoglu (2020) assumed that the first objective, placing the facilities, is more important and thus the second stage is solved after the first stage.

An et al. (2015) used a similar approach as Rawls and Turnquist (2010), but they used a different order of stages. The first stage assigns the traffic while minimizing the en route travel cost over all scenarios. The second stage determines the facility location while minimizing the total cost of: facility set-up over one scenario and unsatisfied emergency service demand and in facility queuing over all scenarios. To deal with the dependency of the stages, a customized Lagrangian Relaxation algorithm to find near-optimum solutions was used.

The above concludes that using scenarios to model uncertainty about the exact striking area leads to multi stage and multi objective models. The problem is that these are complex to solve. Non exact solving methods are used to solve this type of models. Only the model of Oksuz and Satoglu (2020) does not have this complex solving strategy. However, this model first determines the location at every facility while minimizing only the cost of facilities to open. It afterwards optimizes the cost of storage and transporting the handling capacity while minimizing the other costs. This method can lead to a solution in which the total costs are in the end higher, then the total costs when the objectives would have been combined in one objective function.

6.3.4. Combine objectives and decision variables

There are some models which combine the three necessary objectives and decisions into a model. These are the models of Chang et al. (2007); Jabbarzadeh et al. (2014); Rath and Gutjahr (2014); Rawls and Turnquist (2010). However, non of these models combine all these objectives and decision variables in a single stage, single objective model.

Chang et al. (2007); Jabbarzadeh et al. (2014); Rawls and Turnquist (2010) all use scenarios as described above. This means that they created multi objective and multi stage models and using a complex solving method to solve the model. However, when looking at the literature, they describe the models with one objective function. They use a cost minimization function to couple the minimization of the opening costs of facilities and the other objectives. For example the costs to open facilities and the cost to place a certain amount of goods at those facilities is just added together and minimized. A disadvantage of this approach is that the estimation of amount of costs must be accurate. When not, it is possible that the outcome of the model is not the true optimal solution.

Rath and Gutjahr (2014) do not work with scenarios. They however, create a multi objective model with one objective to minimize the cost and another objective to maximize covered demand. The minimization of costs objective contains the same objectives and decision variables as necessary for this research.

6.3.5. Equipment already in use

Another insight is the way in which models take the possibility that the equipment which is stored at an facility is already in use in response to another emergency into account. Most of the time, when scenarios are used, these scenarios can consist of multiple disasters happening at the same time. Another possibility is that there is a scenario which consists of a huge disaster where multiple locations in an area can suffer from the same disaster. Most models take the fact that supply can only assist in one disaster at a time into account. Balcik and Beamon (2008) is the only model which uses scenarios where only one disaster is happening at a time. They assumed that the maximum amount of supply stored at a facility location is not smaller then the maximum demand assigned to that facility location in response to a specific scenario.

Another method is proposed by Ball and Lin (1993); Marianov and Revelle (1994); Revelle and Hogan (1989). They don't incorporate scenarios but still deal with multiple disasters happening at the same time. They looked at the server busy fraction: the probability that a facility is already used by serving a emergency. Problem with this method is that a facility can only serve one demand point at a time. When a facility is busy it can not serve other demand points. Within first responders literature this method does not propose any problems. However, within humanitarian logistics facilities can assist in multiple disasters at the same time.

There is another way of dealing with multiple disasters happen simultaneously while let facilities assist multiple disasters at a time. Murali et al. (2012); Sheu et al. (2005) only optimized one set of inputs whereby multiple disasters are present in that one set.

6.3.6. Served by multiple facilities

There are only a couple of models which do not allow that demand points can be supplied by multiple facilities. These are the models of An et al. (2015); Hu et al. (2014); Oksuz and Satoglu (2020); Shiah and Chen (2007). These models place shelter facilities. Since people can only visit one shelter this makes sense. Every demand point, a person in need, does only need one facility, one place to shelter.

Also the models of Rath and Gutjahr (2014); Sheu et al. (2005) restrict a demand point to only be served by one facility. In this case because they are focusing more on route selection. All the other examined models allow that demand points can be served by multiple facilities.

6.3.7. Constraints related to a standard set covering model

A final insight is that some constraints are related to a standard set covering model. This are: a maximum service distance, every demand point is assigned to at least one facility within this maximum service distance and every demand point can have his own individual maximum service distance. The classical set covering models of Aly and White (1978); Daskin and Stern (1981); Toregas et al. (1971), all contain these three constraints. Other models contain some of these constraints and sometimes even all standard set covering constraints. This shows that these constraints are very easy to just add or remove from the model. This makes it is easy to incorporate these constraints in the model for this research.

The overview, together with this insights presents an answer on the second research question. This question asks how the factors which determine the storage place and necessary handling capacity of a FFM seaport be used in optimization models until now. The next step with respect to the logistical part of this research is to create a model which is able to define this storage place and handling capacity. During the creation of the model for this research these insights are used together with the current literature. Chapter 7 describes the model in more detail.

In current literature there is no model which lets uncertainty influence the maximum service distance. There is only a model which states that a facility is able to serve a demand point if the probability that the distance between those points is lower then a set distance. Next to that, there is also no model which keeps enough goods stored to supply every demand point without stating other conditions. With respect to modeling uncertainty, most models use scenarios. A scenario represent a disaster happening with the probability that this disaster can happen again. This results in multi objective and multi stage models. A scenario can also represent multiple disasters happening simultaneously.

There are at this moment some models which combine the objectives and decision variables necessary for this research. Next to that, a lot of models allow a demand points to be served by multiple facilities. The standard set of covering models incorporate constraints which include (1) a maximum service distance, (2) assign every demand point to at least one facility within this maximum service distance and (3) let every demand point have his own individual maximum service distance.

7

Created mathematical optimization model

The logistics research goal of this thesis is to create the logistical conceptual design for the FFM seaport. This logistical conceptual design consist of the locations of storage for the FFM seaport and the amount of handling capacity which is stored at those locations. A mathematical optimisation model is created in order to find those locations and amount of handling capacity stored. Note that this optimization model is the point of interest in research question three. Research question three asks what is the best optimization model to define the logistical conceptual design of the FFM seaport.

Chapter 6 describes the current literature on facility location and goods allocation within the humanitarian logistics and emergency management. Section 6.3 describes that there is no model in literature right now which can be used to define the logistical design. A new model is thus created. This model is described in this chapter. First this chapter mentions the objectives, decision variables and constraints. Second this chapter describes a preprocessing step which deals with the uncertainty. This is followed by a chapter which describes a preprocessing step which deal with the constraint that multiple disaster can happen simultaneously. Fourth this chapter describes the last preprocessing step. This step deals with the individual maximum service distance of every demand point. Finally this chapter describes the mathematical optimization model in more detail.

7.1. Objectives, decision variables and constraints

Section 5.2 describes the factors which the conceptual logistical design of the FFM seaport must take into consideration. Section 6.1 translates these factors to objective, decision variables and constraints. A mathematical optimization model is created which contain exactly these objectives, decision variables and constraints. To remind, this section describes the objectives, decision variables and constraints again.

The objectives are:

- Minimize the cost of storage facilities to open.
- Minimize the cost of the capacities stored at all facilities.
- Minimize the cost of sending handling capacity from a facility to a demand point.

The decision variables are:

- Determine location of storage facilities.
- Determine amount of capacity stored at every facility.

- Determine amount of handling capacity sent from a certain facility point to a certain demand point.

The constraints are:

- Keep enough capacity stored to supply every demand point.
- Contains a maximum service distance in which stored capacity can reach a demand point.
- Every demand points has at least one storage facility within their maximum service distance.
- Every demand point has their own individual maximum service distance.
- Uncertainty has influence on this maximum service distance.
- Deal with the uncertainty about the exact striking area.
- Deal with the fact that multiple disasters can happen simultaneously.
- Allow that demand points can be supplied by multiple storage facilities to deal with a disaster.

Next to the objectives, decision variables and constraints there are also two assumptions. These assumptions are made in order to create the mathematical optimization model. The assumptions are:

- When a disaster hit an island with a facility location at that island, that facility location can not assist in disaster relief efforts in the same time frame.
- With respect to the costs it is assumed that all costs are fixed costs. It is expected that, for example, the costs to store one TEU of handling capacity is the same when nothing is stored at that location as when already ten or more TEU is stored at that location.

The mathematical optimization model contains all objectives and decision variables. However not all constraints are incorporated directly in the mathematical optimization model. Some constraints are met by using three preprocessing steps. This steps deal with preprocessing the inputs for the mathematical optimization model. The remainder of this chapter will discuss how this research met the objectives, decision variables and constraints.

7.2. Preprocessing one - uncertainty

Two constraints are related with uncertainty. This are: (1) uncertainty has an influence on the maximum service distance and (2) deal with the uncertainty about the exact striking area. Section 6.3.1 describes that there is no model right now which let uncertainty have an influence on the maximum service distance. Within this research the first preprocessing step covers these two constraints. Figure 7.1 gives an overview of this first preprocessing step.

This preprocessing step starts with the set of demand points. Chapter 3 describes that the demand points in this research are all the islands with more then 265,000 inhabitants. This preprocessing step determines for every demand point the consequences if a disaster happen and the probability that a disaster will happen. These two factors, together with the transport speed of the FFM seaport, determine the maximum distance for every individual demand point to be considered as covered. When the occurring probability and/or the disaster impact is low, the maximum covering distance for that individual demand point is higher then if the probability and/or impact is high. The output of this first step are all demand points and the maximum distance for every individual demand point to be considered as covered.

This means that this step met the constraint of uncertainty having an influence on the maximum service distance. Note that this constraint is met in the preprocessing step and not within the mathematical optimization model itself. This means that uncertainty does not play a role in the mathematical optimization model. That model is deterministic.

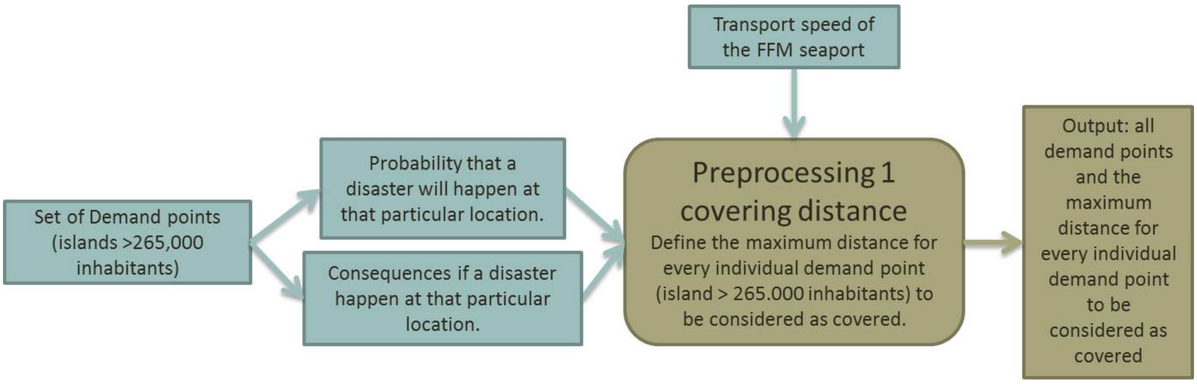


Figure 7.1: Overview of the first preprocessing step. This step determines the demand points and the maximum distance for every demand point to be considered as covered.

The inspiration of incorporating uncertainty in a specific maximum service distance, comes from Sheu et al. (2005). They however uses such a factor to model uncertainty in the amount of demand and not to deal with the uncertainty about the place of a disaster. Within current literature there is no model which let uncertainty influence the maximum service distance.

This step also deal with the uncertainty about the exact striking area. It thus also met this constraint. It accepts a larger maximum service distance if the disaster occurring probability is low. Section 6.3.3 discuss that there are two ways in which current models incorporate uncertainty about the exact striking area. The first one is by using scenarios. However, section 6.3.3 describes that using scenarios leads to a complex solving strategy. This research doesn't use scenarios in order to avoid the complex solving strategy. This model uses a variant of the other way in which uncertainty about the exact striking are is taken into account.

This other way was the method of Aly and White (1978). They state that a demand point can only be covered by a facility if a certain probability is above a certainty threshold. This is the probability that the distance between that demand point and facility is lower then the individual maximum service distance. This model uses a variant of this last method, by determining a maximum covering distance which is based on, among other things, the probability that a disaster will happen at that point.

This preprocessing step ensures that uncertainty has an influence on the maximum service distance and that the uncertainty about the exact striking area is taken into account. This approach does not make use of scenarios. Because of that, it is possible to combine the objectives and decision variables into on objective in a single stage and single objective model. Section 6.3.4 describe that the combining of the objectives and decision variables in a single stage and single objective model is in current humanitarian relief research not performed. This preprocessing step makes sure that it is possible to create such a single stage and single objective model. This preprocessing step is thus, as far as researched, novel for this field and results in a less complex model.

Before it is possible to use the created mathematical optimization model, several prepossessing steps needs to be performed. The first preprocessing step determines the maximum distance for every individual demand point in order to be considered as covered. This is based on both the probability that a disaster will happen and the consequences of a disaster happening at that particular location. In case of a low occurring probability and/or the disaster impact, the maximum distance of coverage is larger for that specific demand point than if the probability and/or impact is high.

7.3. Preprocessing 2- multiple disasters can happen simultaneously

This preprocessing step deals with the constraint that the model must deal with the fact that multiple disasters can happen simultaneously. Section 6.3.5 describe that most of the current existing models use scenarios to take the possibility that the equipment which is stored at a facility is already used in response to another emergency. Within that current models, one scenario consist of multiple disasters happening at the same time or one scenario consist of a huge disaster where multiple locations in an area can suffer from the same disaster.

This model makes use of a similar method. It makes use of different demand situations. The difference between a demand situation and a scenario is the fact that scenarios takes also the probability that a given scenario will happen into account. A disaster situation doesn't take this into account. A situation consist of all different demand points which need help within the same time frame. A specific demand situation have to be fulfilled with the help of every open facility. By defining multiple situations, the model makes sure that the conceptual design of the FFM seaport can assist in every demand situation.

This means that it is important to beforehand determine every demand situation which can happen. This is performed in the second preprocessing step. The demand situations are determined based on the results of the disaster relief efforts analysis which can be found in Chapter 3. Every demand situation is independent of the others. This means that these demand situations are not happening in each other time frame. This time frame is the amount of time that the FFM seaport is used during a disaster relief effort and the time to transport back to the corresponding storage facility. The situations consist of all different demand points which needs help within this time frame. Multiple different disaster situations are determined since there are different time frames in which multiple different demand points want help.

In order to define the different demand situation it is also important to know the lifetime of the FFM seaport. This lifetime determines which different and how many different demand situations must be taken care of within the lifetime of the seaport. Next to that, also the amount of times that different disaster situations did happen within that lifetime is important to take into account. In the end, the objective function of the mathematical optimization model calculates the total costs which is corresponding to realising the conceptual design. The amount of times that handling capacity is sent to a certain demand point have to be taken into account in this costs.

Defining demand situations is not novel and already performed by other researchers. For example, Duran et al. (2011) also define demand situations based on historical data from the International Disaster Database. This database contains the worldwide disasters happened in the past ten years. They define disaster scenarios and thus their disaster situations are coupled to a probability that this situation will happen. Chapter 8.2.3 describes how the demand situations for his research are determined.

Figure 7.2 contains an overview of this preprocessing step. The results of the disaster relief effort analysis contains the information about which demand points are affected simultaneously in one time frame. Next to that the lifetime of the FFM seaport is determined. Together this will give all demand situations and the amount of times this demand situations happen within the lifetime of the FFM seaport.

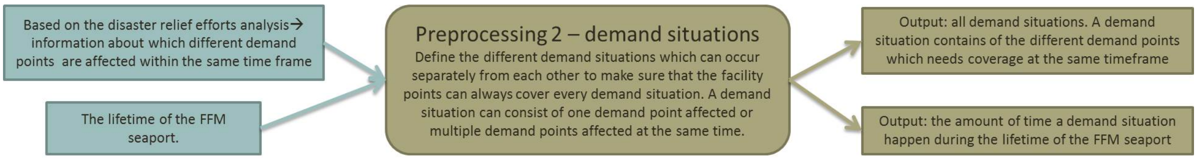


Figure 7.2: Overview of the second preprocessing step. This step determines the demand situations and the amount of times this demand situations happen within the lifetime of the FFM seaport.

The second preprocessing step determines the different demand situations. A demand situation consist of all demand points which need help within the same time frame.

7.4. Preprocessing 3- Individual maximum service distance

This preprocessing step deals with two constraints. First, that every demand point have his own individual maximum service distance. Second, this step deals with the constraint which state that a maximum service distance have to be implemented in the model. This preprocessing step uses the outputs of the previous two preprocessing steps and the set of all possible facility locations. The output of the first preprocessing step are every demand point and the maximum distance for every demand point to be considered as covered. This preprocessing step combines this set of demand points with the set of all possible facility locations. This determines the distances between every demand point and every possible facility location. This distances are compared with the maximum distance for every demand point to be considered as covered. This results in all facility locations which are inside the maximum service distance of a demand point and thus in all facility locations which can be of help for a specific demand point.

The output of the second preprocessing step are the demand situations. These situations are also combined with the set of possible facility locations. This research assumes that a possible facility location on a island can not be used in a disaster relief operation, when a disaster affects that island.

This preprocessing step is inspired by the research of Aly and White (1978). Their model also contains a preprocessing step. This step consist of equation 6.4 discussed in section 6.3.1. Their equation couples the uncertainty with the maximum service distance. This preprocessing step uses an adjusted version of their equation in order to meet the constraints for this research. This results in the following equation:

$$a_{ijs} = \begin{cases} 1, & \text{if } d_{ij} \leq Sd_j \quad and \quad FA_{is} = 0 \\ 0, & \text{if } d_{ij} > Sd_j \quad or \quad FA_{is} = 1 \end{cases} \tag{7.1}$$

This equation state that a certain demand point j is covered by a facility i if the distance between those two d_{ij} is lower or equal then the predetermined maximum service distance of that individual demand point Sd_j. On top of that facility point i have to be not affected by the disaster $FA_{is} = 0$ happening in a certain situation s. When a facility point is affected by a disaster in that situation, the “facility affected” parameter FA_{is} is set to 1.

Figure 7.3 gives an overview of this preprocessing step. The resulting a_{ijs} is an input parameter for the mathematical optimization model. This mathematical optimization model uses this input parameter the same as Aly and White (1978) used their parameter in their model. In the end, the usage of this parameter in the mathematical optimization model results in meeting the constraint of letting every demand point have his own individual maximum service distance and of incorporating a maximum service distance. The next section explains the mathematical optimization model created in this research.

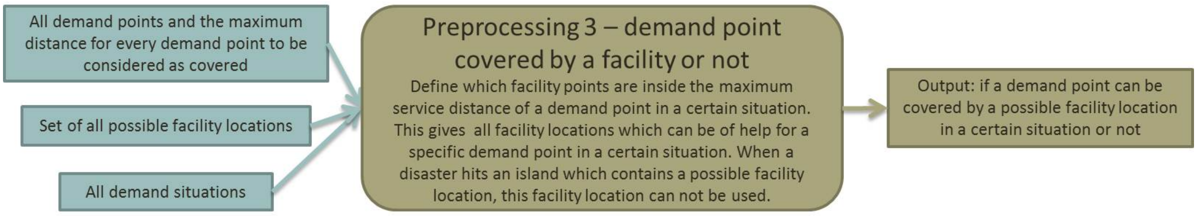


Figure 7.3: Overview of the third preprocessing step. This step determines if a demand point is covered by a certain possible facility location or not.

The third preprocessing step determines whether a demand point can be covered by a potential facility location or not. This is based on the distance between a demand point and a facility location, the demand points maximum distance to be considered as covered and the demand situations. In case a disaster affects an island which contain a potential facility location, that facility location can not be used.

7.5. Mathematical optimization model

The outputs of the three preprocessing steps are inputs for the mathematical optimization model. This mathematical optimization model determines the locations where the seaport have to be stored, the amount of throughput capacity that have to be stored at these locations and the amount of handling capacity sent from a certain facility point to a certain demand point. This while the model minimizes the total costs of usage of the FFM seaport. Note that this corresponds with the necessary objectives and the decision variables. The next subsection discusses these objectives and decision variables in more detail. To solve the model some inputs are necessary. Figure 7.4 gives an overview of the inputs and outputs of the mathematical optimization model.

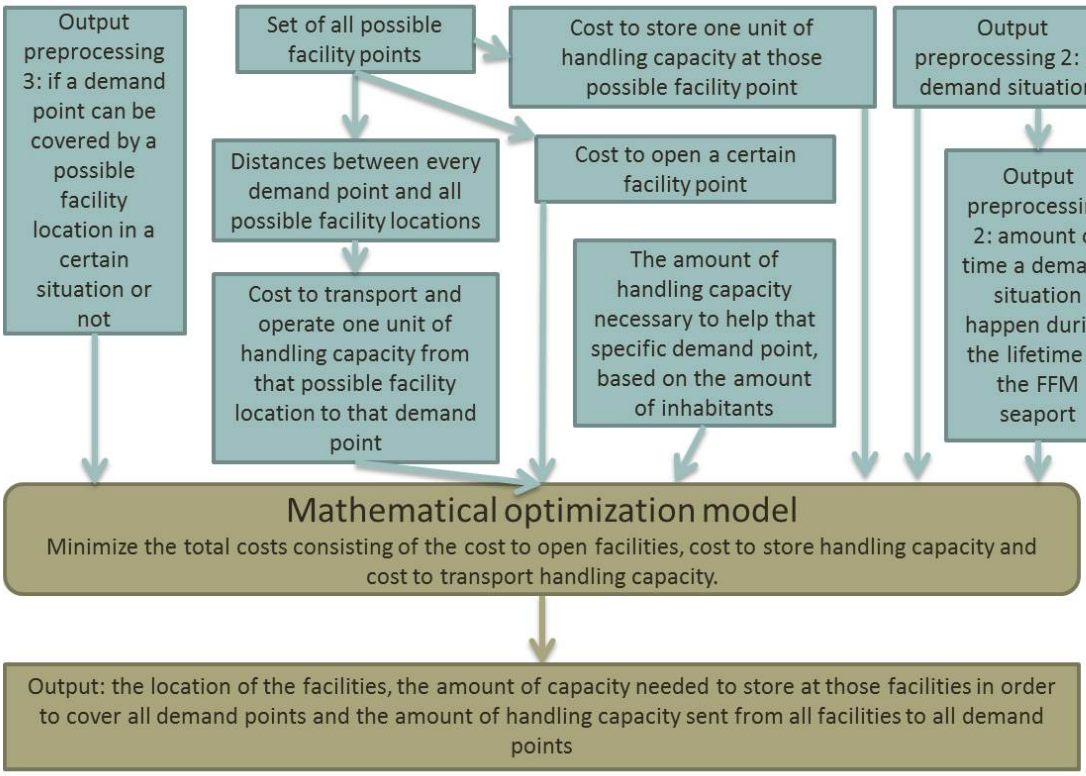


Figure 7.4: Overview of the inputs and outputs of the mathematical optimization model

Again, the set of all possible facility points is necessary. This set determines the distances between every demand point and all possible facility locations. These distances between facilities and demand points determine the cost to transport one unit of handling capacity from that possible facility location to that demand point. This costs is an input for the mathematical optimization model. The set of all possible facility points determines the cost to store one unit of handling capacity at those possible facility points and the cost to open a certain facility point. These are both inputs for the mathematical optimization model. The final input for the mathematical optimization model is the amount of handling capacity necessary to help that specific demand point. This is based on the amount of inhabitants on that demand point (island).

The above sums up all inputs for the mathematical optimization model. These inputs are set into the model. The model has the objective to minimize the costs of opening facilities, store handling capacity and transport handling capacity. This objective is achieved by determining which facilities are opened, the amount of handling capacity stored at those facilities and the amount of handling capacity sent from a certain facility to a certain location. The model ensures that certain conditions are satisfied. This are the remaining constraints which are not met by the preprocessing steps. Subsection 7.5.2 discusses these constraints in more detail.

The output of this mathematical optimization model will give the location of the facilities, the amount of capacity needed to store at those facilities in order to cover all demand points and the amount of handling capacity sent from all facilities to all demand points for every situation. This while keeping the costs to create and operate the FFM seaport as low as possible. In the end this output gives the cost wise optimal logistical conceptual design of a FFM seaport given that specific input configuration. The remainder of this section explains the objectives, decision variables, constraints and mathematical formulation of this model.

7.5.1. Objectives and decision variables

The mathematical optimization model has three objectives: minimize the cost of storage facilities to open, minimize the cost of the handling capacity stored and minimize the cost of transporting this handling capacity. Corresponding to these objectives, several decision variables are determined. The value of these decision variables determines the conceptual design. These decision variables are: the location of the storage facilities, the amount of handling capacity stored at every storage facility and the amount of handling capacity transported from all storage facilities to all demand points for every demand situation.

Section 6.3.4 describes that there are certain current models which also combine these objectives and decision variables in one model. These are the models of Chang et al. (2007); Jabbarzadeh et al. (2014); Rath and Gutjahr (2014); Rawls and Turnquist (2010). The mathematical optimization model in this research uses a certain part of their objective functions. Only a part, because their models contain more objectives and decision variables then necessary for this research. There is no model in humanitarian logistics literature which has exactly and only the same objective and decision variables as necessary in this research. All four models are multi objective. Three of the four models are multi stage. The only one which is not multi stage is the model of Rath and Gutjahr (2014). This because they do not include scenarios and the probability that a certain scenario happens. Only one demand situation is calculated by this model. The three other models does include scenarios and probability. As discussed, this results in a multi stage approach.

This research doesn't work with demand scenarios but with situations. This means that it is possible to combine the objectives into a single stage. The objective function of this single stage is almost the same as the first objective function of Rath and Gutjahr (2014). They combine these objectives into one monetary objective function. This is also done in this research. The difference is that in this research the transport costs is summed over all different demand situations, while also multiplying every situation with the amount of happening of that situation. In the research of Rath and Gutjahr (2014) only one demand situations is calculated. Next to that, Rath and Gutjahr (2014) also incorporate another, non monetary, objective function of maximizing the covered demand. This makes their model multi objective. Within this research that objective function is not necessary and thus in this research the model is single objective.

Note that this objective function also almost corresponds with the first part of the objective functions of Chang et al. (2007); Jabbarzadeh et al. (2014); Rawls and Turnquist (2010). The only difference is that the probability that a disaster scenario occurs is not taken into account, but that factor is replaced with the amount of times that a certain disaster situation happens. Their models sums over all demand scenarios and the model in this research sums over all demand situation. Their work forms an inspiration in order to define the single objective and single stage objective function for this research.

The objective and decision variables necessary in this research are inspired by the current models in humanitarian logistics literature. However, those models are multi stage and multi objective. Working with demand situations in this research instead of demand scenarios used in current literature, results in a single objective and single stage logistics model. The objective is to minimize the costs of opening storage facilities and having handling capacity stored and transported. The decision variables are: (1) is a storage location opened or not, and (2) the amount of handling capacity stored and transported.

The necessary objective function and decision variables are combined into one objective function. The next step is to look at the constraints. The next subsection describes the creation of this constraints.

7.5.2. constraints

The preprocessing steps deal with five of the eight mentioned constraints in section 7.1. This are: (a) let uncertainty have an influence on the maximum service distance, (b) deal with the uncertainty about the exact striking distance, (c) deal with the fact that multiple disasters can happen simultaneously, (d) there is an individual service distance limits for every demand point and (e) contains a maximum service distance. Three other constraints still have to be met: (1) keep enough goods stored to supply every demand point, (2) allow that demand points can be supplied by multiple facilities and (3) every demand point is assigned to at least one facility. These three constraints are met within the mathematical optimization model.

The first constraint which have to be incorporated in the mathematical optimization model is is to keep enough goods stored to supply every demand point. Section 6.3.2 describes that there are four models which keep enough goods stored to supply every demand point. Three of those models impose extra additional conditions. Only the model of Duran et al. (2011) does not impose extra conditions. The constraint in this research is thus directly copied from their model.

Next to that, the model of Duran et al. (2011) also includes a constraint which state that only open facilities can hold capacity. This constraint was not mentioned in section 7.1 since it is a straightforward constraint which obviously always have to be met. It makes no sense to store goods at facilities which are non existing. This condition must be met in order to comply with a real world situation. However, this is also a constraint which must be met in this model. This constraint out of the model of Duran et al. (2011) is also copied for this research.

The second constraint which must be met by the mathematical optimization model is to allow that demand points can be supplied by multiple facilities. Section 6.3.6 describes that there are a lot of models which incorporate this constraint. For example the model of Duran et al. (2011) also contain this constraint. The constraint of their model is directly copied in this model.

The third constraint which must be met by the mathematical optimization model is that every demand point is assigned to at least one facility. Section 6.3.7 describes that this is a typical set covering model constraint. The model in this research uses the method of Aly and White (1978) to deal with the other two typical set covering model constraints. This are: containing a maximum service distance and an individual service distance limit for every demand point. This constraints are met in the third preprocessing step. However, section 7.4 explains that the output of this preprocessing step needs to correctly incorporated within the mathematical optimization model. To do so, this research uses a constraint which is also inspired on the constraint of the model of Aly and White (1978).

To incorporate this, the only constraint of the model of Aly and White (1978) is a little bit changed. Their equation state that every demand point is at least covered by one facility which is in their maximum coverage distance. In the model for this research this constraint must still be met, but in this research also the amount of transported goods is taken into account. This transported goods can only come from facilities which are in the maximum service distance of that demand point. The constraint from their model is changed to the constraint stating that transported goods can only come from facilities which are in the maximum service distance. Since the first constraint which must be met was that the demand must always be fulfilled, it means that also always a demand point is assigned to at least one facility. The formulation of this constraint used in this research is novel within the humanitarian logistics field. Although off course, the constraint is heavily inspired by Aly and White (1978).

Five of the eight necessary constraints for the model of this research are met in the preprocessing steps. Three constraints still have to be met. The formulation of two of those constraints are copied from current humanitarian logistics model. The third one is novel and not used in previous humanitarian logistics literature, but heavily inspired on the work of Aly and White (1978).

7.5.3. Mathematical formulation

The previous two subsections sums up all objectives, decision variables and constraints which are necessary for this mathematical optimization model. In the end, the model in this research is a combination of parts of the models from Aly and White (1978); Duran et al. (2011); Rath and Gutjahr (2014); Rawls and Turnquist (2010). The objective function is the same as parts of the objective function of Rath and Gutjahr (2014); Rawls and Turnquist (2010). It differs from Rath and Gutjahr (2014) by summing the transportation costs over all demand situations and it differs from Rawls and Turnquist (2010) since the probability that a demand situation occurs is not taken into account. It differs from both objective functions by using situations and also incorporating the amount of times that situation will happen into the objective function. The standard set covering constraints are copied from Aly and White (1978) whereby the equation which state that a demand point is covered or not is adjusted (equation 7.1). Also the constraint stating that every demand point is assigned to at least one facility, is adjusted to meet the constraint necessary for this research. The other necessary constraints for this research are met by copying constraints from the model of Duran et al. (2011). This all results in the following optimization model:

Indexes and Set:

I	Set of facilities indexed by $i \in I$
J	Set of demand points indexed by $j \in J$
S	Set of demand situations need to be responded to by the storage facilities indexed by $s \in S$

Input Parameters:

a_{ijs}	one if demand point j can be covered by facility i in situation s and 0 otherwise. See equation 7.1
R_{js}	The requested capacity of demand point j in demand situation s
M	A very big number
H_s	The amount of times a disaster situation happens
C_i^1	Cost to open facility i
C_i^2	Cost to place one unit of handling capacity in facility i
C_{ij}^3	Cost to transport and operate one unit of handling capacity from facility i to demand point j

Decision Variables:

y_i	one if a facility is located at candidate node i and 0 otherwise
x_{ijs}	The amount of capacity sent from facility i to demand point j in demand situation s
q_i	The amount of capacity stored in facility i

Objective function:

$$\text{Min} \sum_i y_i C_i^1 + \sum_i q_i C_i^2 + \sum_s H_s \left[\sum_i \sum_j x_{ijs} C_{ij}^3 \right] \tag{7.2}$$

Constraints:

$$\sum_i x_{ijs} A_{ijs} \geq R_{js} \qquad \forall j, \forall s \tag{7.3}$$

$$\sum_j x_{ijs} \leq q_i \qquad \forall i, \forall s \tag{7.4}$$

$$x_{ijs} \leq y_i * M \qquad \forall i, \forall j, \forall s \tag{7.5}$$

$$y_i \in \{0,1\} \qquad \forall i \tag{7.6}$$

$$x_{ijs}, q_i \geq 0 \qquad \forall i, \forall j, \forall s \tag{7.7}$$

The objective function 7.2 minimizes the total costs of opening facilities, storing the handling capacity at those open facilities and the transport of handling capacity from those facilities to the demand points. Constraint 7.3 states that the sent capacity from all facilities to a demand point is greater then or equal to the demand at that point for that given demand situation and that handling capacity will only be transported from facilities which are in the maximum covering distance of a demand point. Constraint 7.4 ensures that for each demand situation the total amount of handling capacity transported from a facility to all demand point which will be served by that facility is always less than or equal to the amount of handling capacity stored at that facility. Constraint 7.5 ensures that handling capacity will only be transported from facilities which are open. Constraint 7.6 defines the binary location variable. Finally, constraint 7.7 represents the fact that the sent capacity from a facility to a demand point and the amount of handling capacity stored at a facility can not be negative.

The mathematical optimization model met the desired objective functions and decision variables. As discussed three constraints have to be met by the mathematical optimization model. The constraint of keep enough goods to store every demand point (equations 7.3 and 7.4) is included. The constraint which allows that demand points are supplied by multiple facilities is met by constraint 7.3. This constraint states that a demand point can be fulfilled by the sum of send handling capacity from all facilities.

The constraint which state that every demand point is assigned to at least one facility is indirectly met by constraints 7.3 and 7.5. Constraint 7.3 states that every demand point gets service and constraint 7.5 states that this service can only come from open facilities. Since every demand point must be fully covered and this coverage can only come from open facilities, this means that also every demand point is assigned to at least one facility.

The constraints which are met in preprocessing steps one and three are: let uncertainty have an influence on the maximum service distance, deal with the uncertainty about the exact striking distance, there is an individual service distance limits for every demand point and contains a maximum service distance. This constraints are coupled in the mathematical optimization model by using the input parameter a_{ij}. This parameter is determined by using equation 7.3 and by incorporating this parameter in the mathematical optimization model these necessary constraints are met. Preprocessing step two met the constraint of dealing with multiple disasters which can happen simultaneously. This preprocessing step results in disaster situations. The set of demand situations, S, are used in constraints 7.3, 7.4, 7.5 and 7.7 in order to couple this preprocessing step with the mathematical optimization model.

The above means that the mathematical optimization models reaches every necessary objective, determines every decision variable and met all constraint. Measure up to these objectives, decision variables and constraints leads to the conceptual design of the FFM seaport. Solving this mathematical optimization model determines the location of the facilities, the amount of handling capacity stored at those facilities and the amount of handling capacity transported. This mathematical optimization model is the answer to research question three. This questions asks about the best optimization model to determine the factors which determine the logistical conceptual design of the FFM seaport. To create this conceptual design the optimization model is used. The next chapter presents the experimental plan which contain details about the way in which the optimization model is used in order to define this design.

8

Experimental plan

The fourth research question asks about an applicable logistical conceptual design of a FFM seaport in order to be of help during disaster relief efforts. Solving the mathematical optimization model determines this logistical conceptual design. However the outcome of the mathematical optimization model differs when different inputs are given. In order to find an applicable design to be of help, the mathematical optimization model is run several times with several different input configurations. This chapter explains the different runs, inputs and input configurations.

Figure 8.1 shows the different inputs for the mathematical optimization model. The blue inputs do not change over several different runs. These are: the cost to store one unit of handling capacity at a possible facility point, cost to open a certain facility point and the cost to transport and operate one unit of handling capacity from a possible facility location to a demand point. The figure shows that these costs depends on the set of all possible facility locations. The cost to transport and operate one unit of handling capacity depends on the distance between every demand point and all possible facility locations.

Figure 8.1 contains also some green inputs. These inputs have different values over the different runs. An input configuration is a certain configuration of these inputs. These inputs are: if a demand point can be covered by a possible facility location in a certain situation or not, the demand situations, the amount of times a demand situation happen during the lifetime of the FFM seaport and the amount of handling capacity necessary to help a specific demand point.

Figure 8.1 also contains the outputs of the mathematical optimization model. These outputs are different for every different input configuration. Chapter 9 describes the outputs and the different results of the mathematical optimization model when these different input configurations are used.

The remainder of this chapter discusses the different inputs and input configurations. First this chapter discusses the inputs which don't differ over the different input configurations. Second it discusses the inputs which differ over the different inputs configurations. Finally, this chapter gives an overview of the different input configurations. Note that this chapter briefly describes these different inputs. Appendix I describes the different inputs more elaborate.

The mathematical optimization model is solved multiple times with different input configurations. Every input configuration gives a conceptual design which is the best option cost based to deal with that specific input configuration.

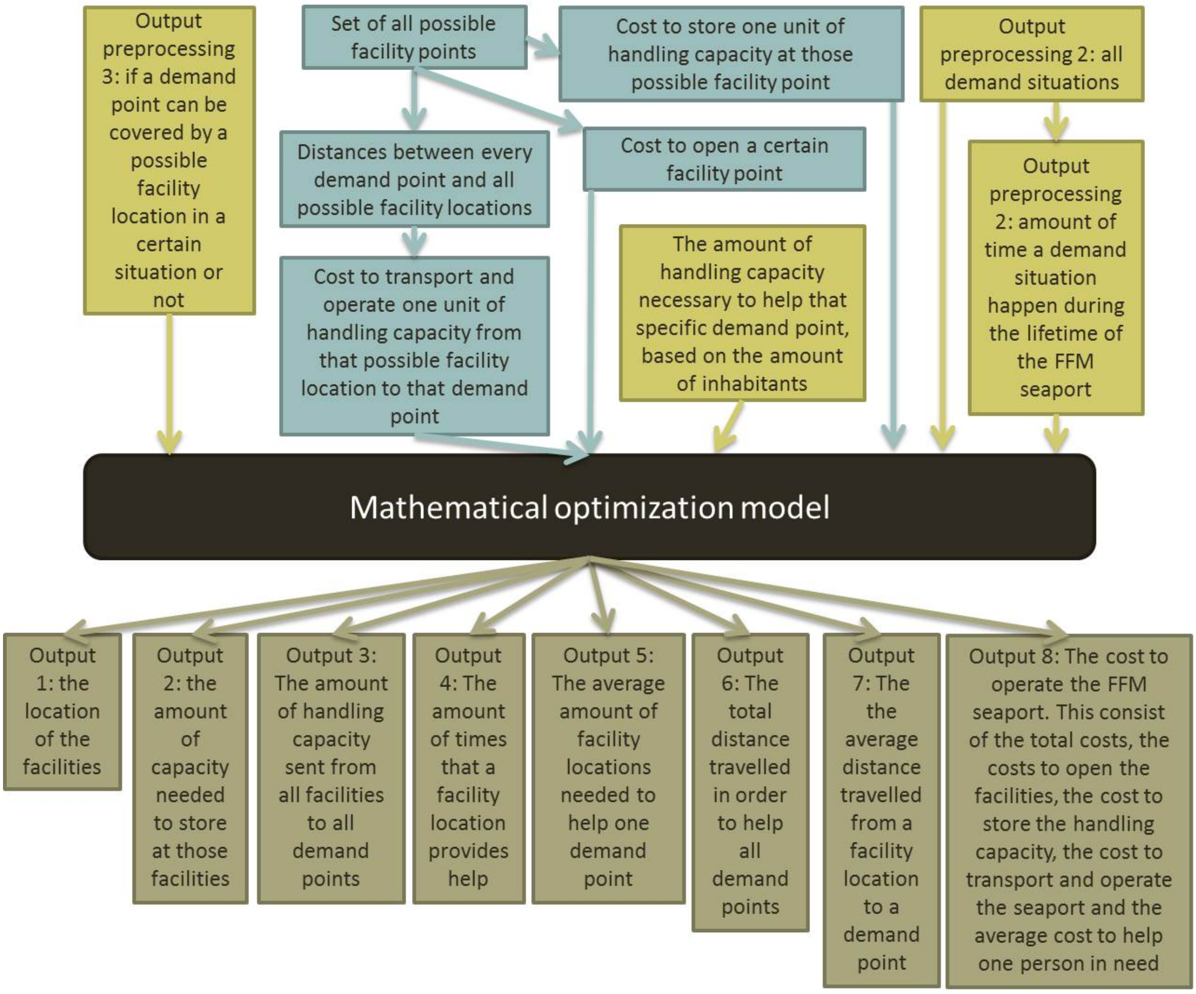


Figure 8.1: The inputs and outputs of the mathematical optimization model. The model is run several times to define the applicable conceptual design. Every run consist of a different input configuration. The blue inputs don't change over this different runs. The green inputs do change.

8.1. Inputs which stay constant

The three costs inputs stay constant over every different run. These costs are based on the set of all facility location and the distance between every demand point and facility point. This section describes all these five inputs.

8.1.1. Facility locations

The set of all possible facility locations is based upon five different sets. The first set are the locations of the United Nations Humanitarian Response Depots (UNHRD). The second set is the facility location set of the research from Duran et al. (2011). They performed research towards the best facilities to preposition emergency items for CARE International. The third set are Amazon fulfillment centres. The fourth set are locations from the Logistic Emergency Team participants. As discussed in Chapter 2.4 the Logistic Cluster has a strategic partnership with four of the largest global logistics and transportation companies. The last set is the facility location set of Stienen et al. (2021). They located possible facility locations by identifying cities which has a major seaport and airport close to each other.

These data sets together contain 256 possible facility locations. Some sets contains the same locations. Removing of duplicates leaves 157 available facility locations. However, there are a couple of locations which are very close to each other. To reduce the workload, locations are selected which are further away from each other. This results in the final set of 62 possible facility locations. Figure 8.2 shows these 62 locations.

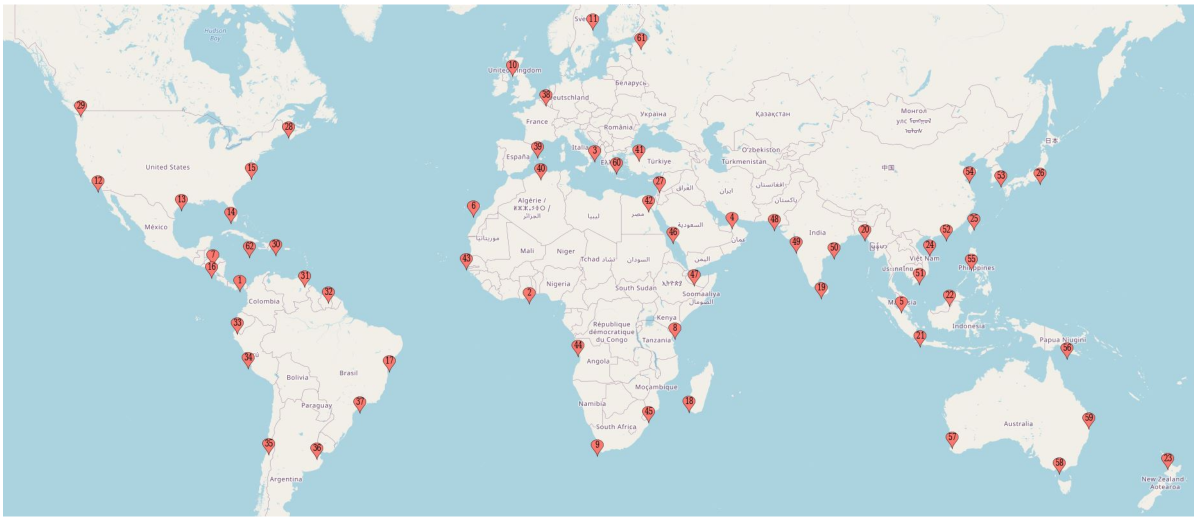


Figure 8.2: The final possible facility locations

8.1.2. Distances between demand points and facility locations

The previous step determines all facility points. The set of demand points is also known. Chapter 3 describes that this last set contains of all the islands with more then 265,000 inhabitants. Section 8.2.1 describes this last set in more detail. With these two sets it is possible to determine the distance between every demand point and every possible facility location. This is the distance which the FFM seaport modules must travel when it will be used to serve a certain demand point. When determining this route, this research assumes that the FFM seaport modules can travel with a constant maximum speed. Next to that, it assumes that the FFM seaport modules can travel with their maximum speed via the Panama, Suez or Kiel canal.

All facility locations are cities with a seaport. These cities are lying next to a sea or ocean. To determine the exact distance between these cities and the demand points, it is important to know the location of installation for the FFM seaport. This research assumes that the FFM seaport is installed as close as possible to the most populous city on the island affected by a disaster.

With the above it is possible to determine the route to travel from all possible facility locations to all demand points. On average the route between a facility and demand point is 11,214km. The longest route is 23,810km. This is the route from the demand point of Sakhalin (Russia) to the possible facility location of St. Petersburg (Russia). The shortest route is 0km. This because there are some facility locations which are located on an island. This are: Las Palmas de Gran Canaria (Spain), Manila (Philippines), Port Moresby (Papua New Guinea), Colombo (Sri Lanka), Jakarta (Indonesia), Auckland (New Zealand), Taipei (Taiwan), Tokio (Japan) and Kingston (Jamaica).

8.1.3. Cost to transport and operate one unit of handling capacity

The previous subsection describes the distances. Since these are known, it is possible to determine the cost to transport one TEU of handling capacity over that distance. Appendix I describes that it is assumed that it costs \$0.67 to transport one TEU/h of handling capacity one km. This means that on average it costs 11,214km*\$0.67=\$7513 to transport one TEU/h of handling capacity from a demand point to a facility location. The longest route between a facility point and a demand point is 23,810km. It costs \$15953 to transport one TEU/h of handling capacity between that demand point and facility location.

Appendix I describes that it costs \$19 per TEU per hour to operate a FFM seaport. Every demand point as his own amount of time of which a seaport will be of help. This because the travel time to some demand points is allowed to be bigger then for other demand points. This \$19 per TEU is for every demand point multiplied by the amount of hours the seaport is of help for that demand point. This results in the operational costs of using the seaport for that demand point. This operational costs is added up by twice the transport costs. This transport costs is added up twice since the FFM seaport have to be delivered, but also come back after the disaster relief operation. This means that for every possible route an unique operation costs is given. This consist of the transport costs which is different for every possible route and a operation costs which is different for every demand point.

8.1.4. Cost to store one unit of handling capacity at a possible facility point

Within the costs to store one unit of handling capacity several components are taken into account. These are: the investments costs of the modules for the seaport and the necessary seaport equipment, the costs of the semi-submersible heavy lift vessels and the costs to realise storage facilities. The investment costs of the modules, seaport equipment and of the semi-submersible heavy lift vessels are the same for every facility point. The costs to realise storage facility is different for every possible facility location.

Appendix I shows the calculation to determine the investments cost of the modules and necessary seaport equipment for the FFM seaport. It shows that the investment costs of a FFM seaport with one TEU/h handling capacity is \$2,028,664.

Appendix I also explains that it is assumed that semi-submersible heavy lift vessels transports the FFM seaport from the facility locations to the demand points and back. The cost to store one unit of handling capacity also take the construction costs of the semi-submersible heavy lift vessel into account. Appendix I calculates that the construction costs of a semi-submersible heavy lift vessel, which can transport one TEU/h of handling capacity, is \$998,900.

The last part is the costs of realizing storage facilities. This research assumes that the FFM modules and the seaport equipment are stored on land and not on water. When the FFM seaport needs to be deployed, the modules and equipment is transported from this storage facility to the semi-submersible heavy lift vessel. This semi-submersible heavy lift vessel is also stored in the seaport in order to quickly hit the open seas when necessary. The costs of realizing a storage facility consist of the price to buy the land and the construction costs. These two costs are different for every location and are expressed in the costs per square metre of storage facility. To calculate the costs it is necessary to known how many square metre of storage facility is necessary to store one TEU/h. Appendix I calculates that one TEU/hour handling capacity relates to a storage area of $135m^2$ inside the storage facility.

The above gives the cost to realize a facility at a certain location. This by adding up the cost to buy land at that location and the construction costs at that location. However, the costs are not only dependent on these two factors but it also depends on the facility location provider. Section 8.1.1 describes that there are mutiple sets of facility locations. The facilities of UNHRD, DP World, Maersk, Agility, UPS, Amazon can be used or no facility provider can be available. Depending on the exact facility provider certain costs are reduced. For the UNHRD it is assumed that no land costs are necessary and the construction costs are half the normal costs. For the DP World it is assumed that no land costs are necessary and cost to build a warehouse are normal. For Maersk and Agility is it assumed that the land costs are normal and the construction cost are half then normal. For UPS is it assumed that the land prices and construction costs are half less then normal. For Amazon it is assumed that the land prices are normal and costs to build a facility are 25% less the normal. When no facility provider has a warehouse or facilities yet at that location, the full costs are taken into account.

In the end this means that the costs to store one TEU/h is over all facilities on average \$3,145,953. The most expensive facility location is Gourock (UK). Over there it costs \$3,372,100 to store one TEU/h. The cheapest facility location is Accra (Ghana). Over there it costs \$3,060,639 to store one TEU/h.

8.1.5. Cost to open a certain facility point

This research assumes that the costs to open a certain facility are the operational costs. Half of this operational costs are the labour costs (Savills, 2021). This research assumes that no matter how much capacity is stored, the amount of workers necessary is always the same.

Appendix I describes that for every country of a possible facility location the national monthly minimum wage is determined and multiplied by 40. This later is the amount of workers a storage location need. This labour costs is multiplied by two and this gives the total operational costs and thus the cost to open a facility in that country. This means that on average the cost to open a facility is $24,715,071. The cheapest storage facility to open is Berbera (Somalia) with $58,368. The most expensive storage facility to open are Fremantle, Melbourne and Brisbane in Australia with $81,941,376.

There are several inputs which do not change between different input configurations. These are: the set of the 62 possible facility locations, the distances between a demand point and a facility location, the cost to transport and operate one unit of handling capacity, the cost to store one unit of handling capacity and the cost to open a specific facility point.

8.2. Inputs with different input configurations

There are four inputs which differ over the different runs of the mathematical optimization model. Due to this varying inputs, the results of the model also varies. Comparing these results helps to define an applicable logistical conceptual design of the FFM seaport. These varying inputs are: if a demand point can be covered by a possible facility location in a certain situation or not, the amount of handling capacity necessary to help a specific demand point, the demand situations and the amount of times a demand situation happen during the lifetime of the FFM seaport. The remainder of this section describes these varying inputs.

8.2.1. Demand point be covered by a facility location or not

The set of demand points consist of islands with 265,000 or more inhabitants. It is checked for these islands if there is a road connection with the mainland of the landmasses of Afro-Eurasia, Americas and Mainland Australia. If yes, then this island can be reached by trucks over the road and FFM seaport is not a necessary anymore. This islands are removed from the set. Figure 8.3 shows the final set of demand points.

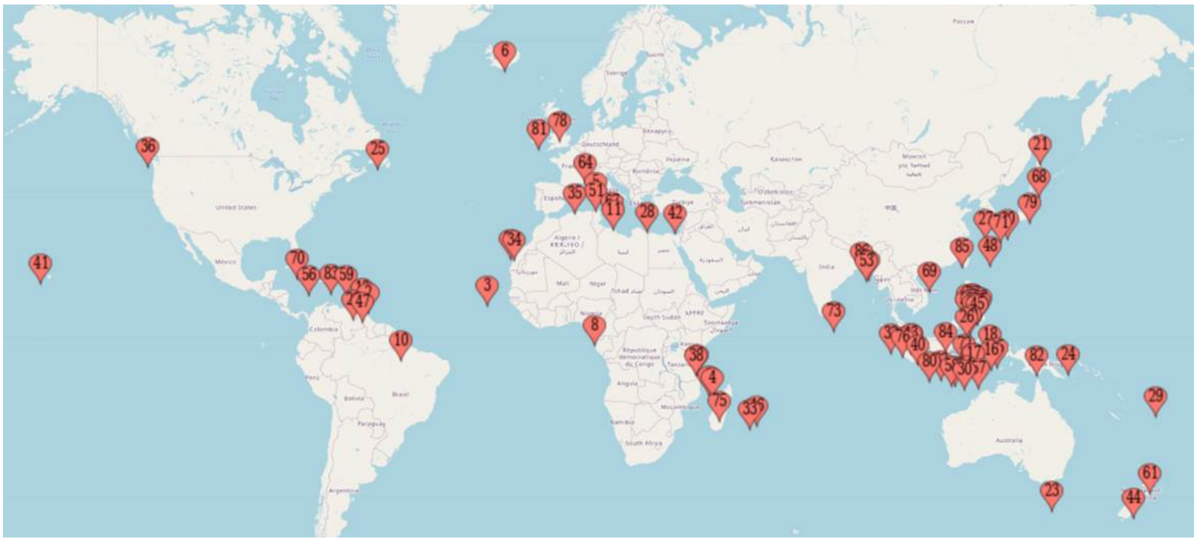


Figure 8.3: The set of all demand points. This are islands with 265,000 or more inhabitants and without road connection with the mainland.

From this resulting set the probability that a disaster will happen at that demand point and the consequences if a demand point is affected by a disaster are taken into consideration. The probability that a disaster will happen is based on the geographic vulnerability of the location of the island and the amount of previous big disasters. The consequences if a disaster affects a demand point are based on the likelihood of generally suffering damage, the amount and size of airports on the island and the amount and size of seaports on the island.

The probability that a disaster will happen and the consequences if a disaster happen are combined. This determines the maximum distance for a demand point to be considered as covered. Every facility point within this distance can help that demand point. This maximum covering distance is based on the amount of time passed after a disaster before the FFM seaport is necessary. Section 2.3.1 discusses that, at the earliest, 14 days after the disaster the FFM seaport is necessary. This research assumes that demand points which score bad on the probability and consequence factor indeed need the FFM seaport after 14 days. This research assumes that if the demand points scores excellent on these factor, the time for the FFM seaport to be operational for that demand point is two times as much.

Appendix I shows a formula which is used in order to determine a certain multiplication factor. This multiplication factor is a number between one and two and for every demand point this factor is multiplied with 14 days. This figure gives the maximum days after the seaport must be operational at that demand point. It is assumed that it take two days to install the FFM seaport. This assumption is based on the fact that the military also are theoretically able to create an operational seaport within two days. This is discussed in Appendix B.

Appendix I also shows that the FFM seaport is transported from the facility location to the demand point by a semi-submersible heavy lift vessel. These vessels have a maximum speed of 33 km/h. By subtracting two days from the maximum amount of days till the seaport must be operational and multiplying this number with 24 hours and 33 km/h the maximum distance reachable within the time frame is calculated. This maximum distance is the maximum coverage distance for that particular demand point. This demand point can only be served by facilities which are within this maximum coverage distance.

Over all demand points, on average, after 21.16 days the FFM seaport is necessary. This correspondents with a distance of 15,176km. The demand point which is in less need for help and thus accepting help after the most amount of time is Iceland. After 28 days the FFM seaport is necessary over there. This relates to a distance of 20,591km. The demand point which needs help the quickest is Hispaniola (Dominican Republic and Haiti). This demand point needs help after 15.17 days which corresponds with a distance of 10,427km.

Section 8.1.2 describes that the distances between the facility points and demand points are determined. The next step is combining these distances with the maximum distance for every demand point to be considered as covered. This results in the input which state if a demand point can be covered by a certain possible facility location or not.

Note that this input does not yet include something which differs in the different runs. Within this step there is also checked if a disaster hits an island which contains a possible facility location. If yes, then this facility location can not be used. The thing which differs over the different runs is which islands are hit by a disaster and thus also which facility locations can not be used due to this. When a facility location is hit by a disaster this facility location is taken out of the set about the facilities which can serve a certain demand point.

Every demand point has its own maximum service distance. This research checks for every demand point which facility locations are inside this maximum service distance. This determines which facilities can be of help for that point. This does not change over the different runs. However, it is also checked if an island hit by disaster contains a potential facility location. If yes, then this facility location can not be used. Over the different runs, the islands impacted can vary. Therefor the use of a facility locations can differ depending on the islands impacted in a run.

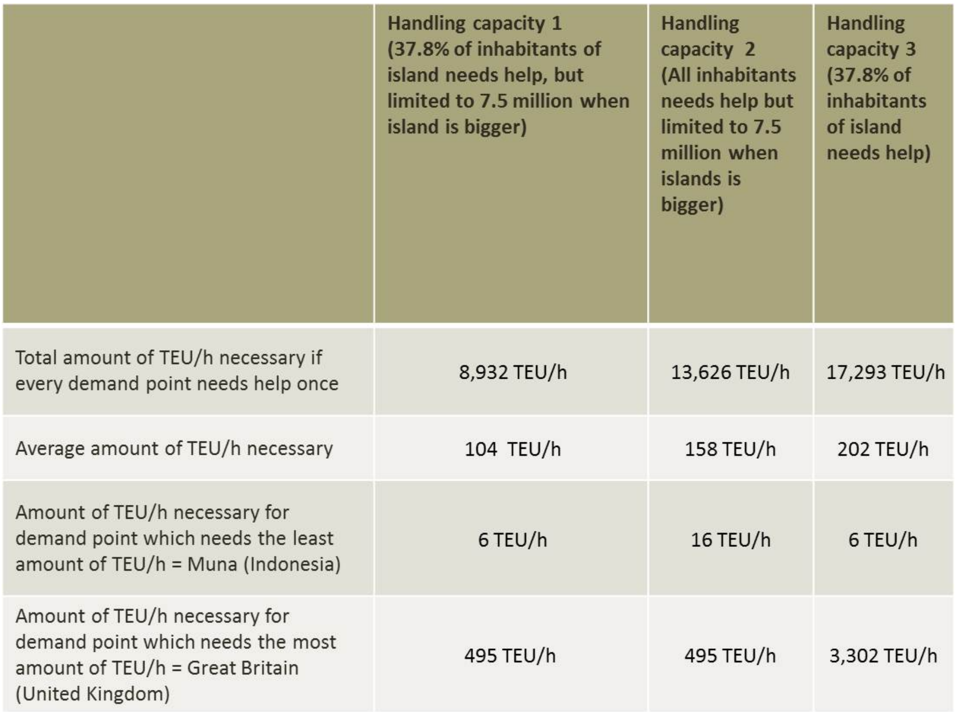
8.2.2. Amount of handling capacity

Chapter 3 contains the disaster relief effort analysis. This analysis concludes that in total 0.102 TEU per person is necessary on average to help them during a disaster relief effort. For every demand point this 0.102 TEU per person is transformed to a certain handling capacity of TEU/h/person necessary for the seaport. This is calculated by dividing the total amount of necessary TEU per person with the amount of time the FFM seaport is used at that specific demand point. It is assumed that the FFM seaport will operate 24 hours, seven days a week during the disaster relief period.

However, multiplying 0.102 TEU per person with the amount of inhabitants of an island lead to a very high number. Appendix I shows that for bigger islands this can results in a FFM seaport necessary as big as the current existing port of Antwerp. However, the disaster relief effort analysis shows that the biggest amount of affected people on an island is 7.5 million, during the wildfire in Indonesia. The disaster relief effort analysis also shows that the highest percentage of affected people on an island is 37.8% of the inhabitants of that island.

This leads to three different handling capacity inputs. The mathematical optimization model is solved for every different handling capacity input. In this research these handling capacity inputs are called handling capacity tactics. The first tactic is to maximize the amount of inhabitants which need help to 7.5 million, even although the island has more inhabitants. The second tactic is to reduce the amount of people which need help to 37.8% of the total population of an island. The third tactic is a combination of both. So to reduce the amount of people which need help to 37.8% of the total population of an island and for the bigger island to limit this to 7.5 million people. Table 8.1 gives some statics of these three different handling capacity tactics.

Table 8.1: Some statistics of the three different handling capacity tactics



	Handling capacity 1 (37.8% of inhabitants of island needs help, but limited to 7.5 million when island is bigger)	**Handling capacity 2 (All inhabitants needs help but limited to 7.5 million when islands is bigger)**	**Handling capacity 3 (37.8% of inhabitants of island needs help)**
Total amount of TEU/h necessary if every demand point needs help once	8,932 TEU/h	13,626 TEU/h	17,293 TEU/h
Average amount of TEU/h necessary	104 TEU/h	158 TEU/h	202 TEU/h
Amount of TEU/h necessary for demand point which needs the least amount of TEU/h = Muna (Indonesia)	6 TEU/h	16 TEU/h	6 TEU/h
Amount of TEU/h necessary for demand point which needs the most amount of TEU/h = Great Britain (United Kingdom)	495 TEU/h	495 TEU/h	3,302 TEU/h

The different input configurations vary with respect to the amount of handling capacity necessary per demand point. The first handling capacity tactic is to maximize the amount of inhabitants which need help to 7.5 million. The second tactic is to reduce the amount of people who need help to 37.8% of the total population of an island. The third tactic is a combination of both. So to reduce the amount of people who need help to 37.8% of the total population of an island and limit this to 7.5 million people.

8.2.3. Demand situations and amount of times a demand situation happen

The final two inputs for the mathematical optimization model are the different demand situations and the amount of times that specific demand situation happen. Every situation occurs separate from each other and consist of the demand points which needs service within the same time frame. Next to that, it is checked for every situation how many times this specific demand situation happen.

To analyse demand situations, it is important to know the total lifetime of the FFM seaport. It is important to know which demand situations happen and how many times this specific demand situations happen within the lifetime of the seaport. The mathematical optimization model minimizes the costs for creating and operating a FFM seaport over this lifetime. Appendix I describes that it is assumed that the FFM seaport has a lifetime of 38 years.

The next step is to compose the different disaster situations that will happen within that 38 years. This set of disaster situations together with the amount of times that specific disaster situation happen are inputs for the mathematical optimization model. However, it is hard to know which disaster situations will happen in the future. Therefore, the past is taken as an example. The disaster relief effort analysis of Chapter 3 contains all big disasters over the past 38 years. This forms the inspiration for the disaster situations used in this research.

However, making decisions based on past disasters forms a risk. The past does not give any guarantee for the future. Therefore, four different set of disaster situations with corresponding amount of times that a disaster situation happen are taken into consideration. These disaster situation sets are inputs which differ over the different runs. Next to that, these different demand situations also influences the possible facility locations. Section 8.2.1 explains that a possible facility location is not taken into consideration when a disaster situation affects an island which contain a possible facility location.

The first demand situation set is a direct copy from the past. From the disasters happening in the past 38 years there is checked if a disaster affects one of the islands from the set of demand points. When a disaster hits one of these demand points there is checked if there are more demand points affected within the time frame that a FFM seaport is transported and/or in usage in response to that first disaster. If so, these demand points are added to the demand situation. If not then the demand situation consist only of that one demand point which is affected. All disasters over the past 38 years are taken into consideration and put together in one demand situation set.

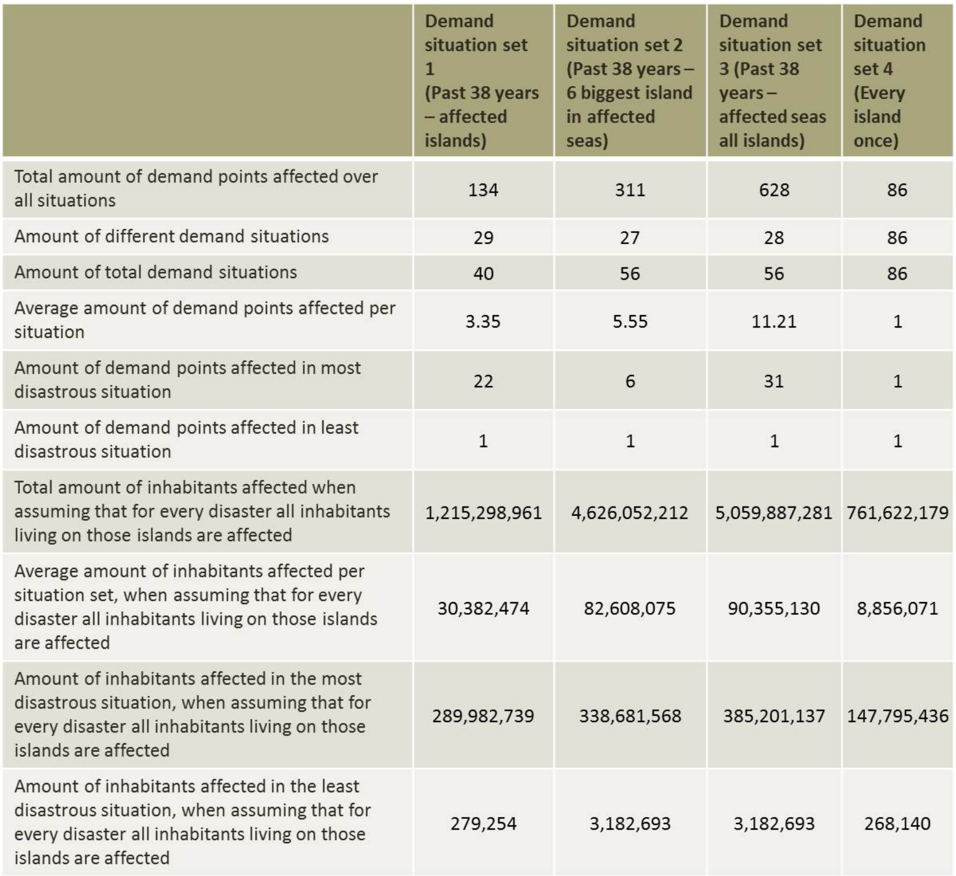
To create the second demand situation set there is checked for every demand situation from the first set in which seas the affected demand points are located. This second demand situation set takes these seas as a basis. The disaster relief effort analysis of Chapter 3 shows that in the past 38 years no more then six islands were affected on a large scale in the same time frame. The second demand situation set looks at the different affected seas in the demand situations from the first set and take the six most populous islands of those seas into account.

The third set is a worst case scenario. Again the affected seas from the first demand situation set are taken as a basis. However, in this case not the six most populous islands are taken into consideration but all islands with more then 265,000 inhabitants located in these seas.

All these three sets are based on the disasters which happened the past 38 years. Since history does not always give guarantees for the future also a fourth set is analysed. This set consist of all demand points which are affected once, independent from each other. This set is maybe not the most realistic one, but it give a good comparison with history.

This gives four different demand situation sets. Table 8.2 gives some statistics of these four different sets. This means that together with the three different handling capacity tactics this leads to 12 different input configurations and thus to 12 different runs. The next section gives an overview of these 12 runs.

Table 8.2: Some statistics of the four different demand situation sets



	Demand situation set 1 (Past 38 years – affected islands)	Demand situation set 2 (Past 38 years – 6 biggest island in affected seas)	Demand situation set 3 (Past 38 years – affected seas all islands)	Demand situation set 4 (Every island once)
Total amount of demand points affected over all situations	134	311	628	86
Amount of different demand situations	29	27	28	86
Amount of total demand situations	40	56	56	86
Average amount of demand points affected per situation	3.35	5.55	11.21	1
Amount of demand points affected in most disastrous situation	22	6	31	1
Amount of demand points affected in least disastrous situation	1	1	1	1
Total amount of inhabitants affected when assuming that for every disaster all inhabitants living on those islands are affected	1,215,298,961	4,626,052,212	5,059,887,281	761,622,179
Average amount of inhabitants affected per situation set, when assuming that for every disaster all inhabitants living on those islands are affected	30,382,474	82,608,075	90,355,130	8,856,071
Amount of inhabitants affected in the most disastrous situation, when assuming that for every disaster all inhabitants living on those islands are affected	289,982,739	338,681,568	385,201,137	147,795,436
Amount of inhabitants affected in the least disastrous situation, when assuming that for every disaster all inhabitants living on those islands are affected	279,254	3,182,693	3,182,693	268,140

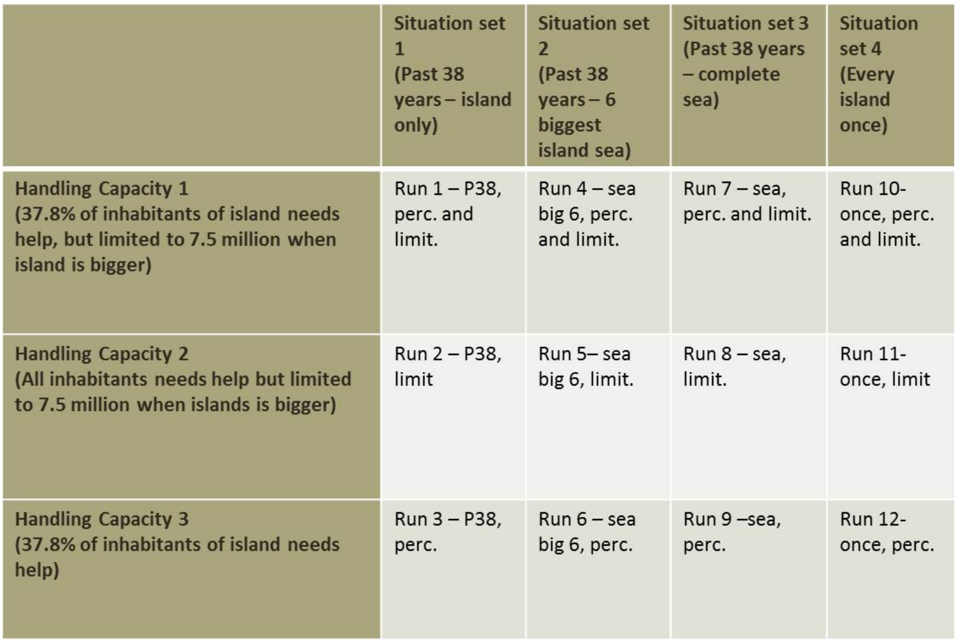
The different input configurations vary with respect to the demand situation set. These sets consist of all demand situations which are expected to happen in the coming 38 years, the lifetime of the FFM seaport.

A demand situation consist of the demand points that need help during the same time frame. Four different demand situation sets are analyzed: (1) all islands which were also affected the past 38 years, (2) the six biggest islands located in the seas that have been affected in the past 38 years, (3) all islands located in the seas that have been affected in the past 38 years and (4) every island in the world which was affected once, independently from each other.

8.3. Overview of the different input configurations

This experimental plan leads to 12 different input configurations. This results in 12 different runs of the mathematical optimization model. Every run is given a certain name. Table 8.3 gives an overview of these 12 runs and their name. Next to that, the statistics of the three different handling capacity tactics and the four different demand situation sets shows that the input configurations differ with respect to the amount of people the FFM seaport needs to help. It shows that with respect to the amount of handling capacity needed per demand point handling capacity one is the best scenario and handling capacity three is the worst case scenario. With respect to the demand situation sets, it shows that demand situation set one is the best scenario and demand situation set three is the worst case scenario. Note that demand situation set four is not taken into account when determining this worst and best case since this is a set for comparison purpose only and not based on a realistic scenario. Table 8.4 shows per run if they are the best, medium, or worst case scenario with respect to the demand situation set and the handling capacity tactic. The figure also mentions the total amount of persons in need for that input configuration.

Table 8.3: Overview of the combination of situation sets and handling capacity tactics which leads to a certain run. Also the name of the runs is given.

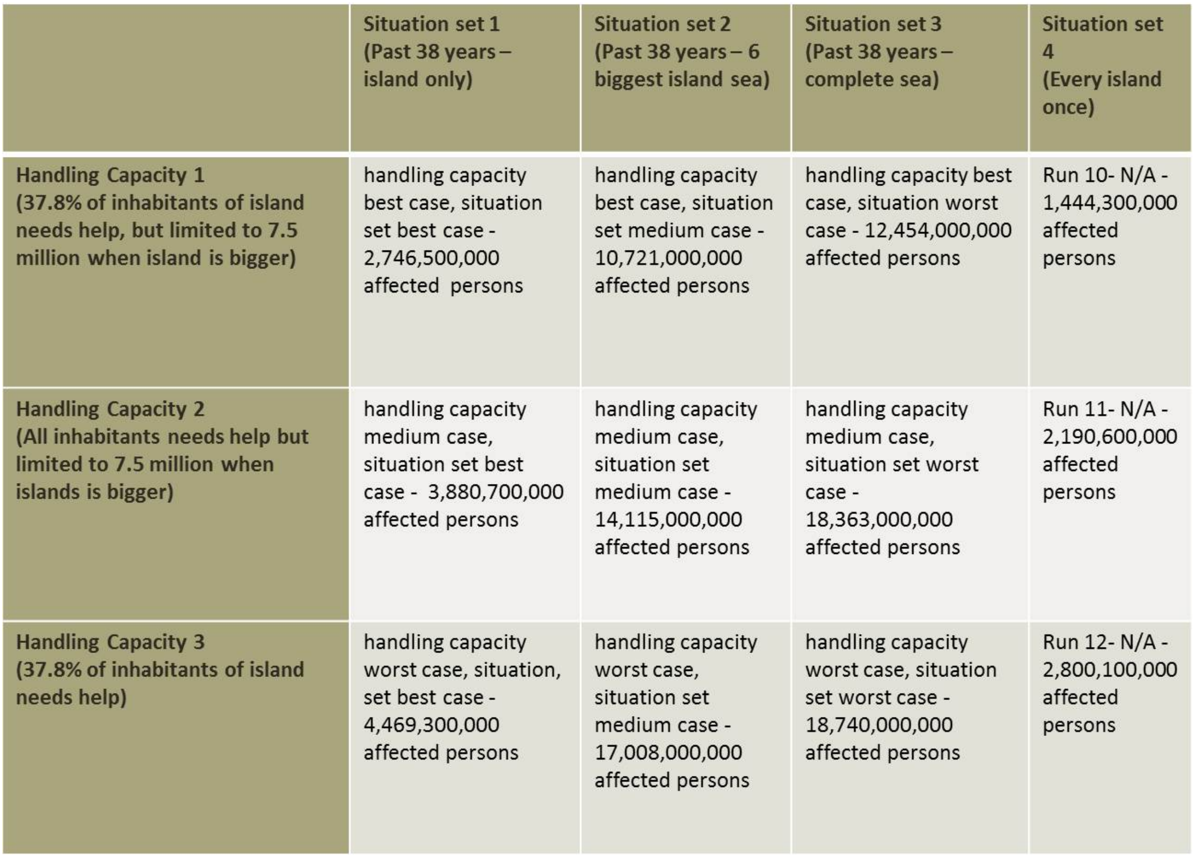


	Situation set 1 (Past 38 years – island only)	**Situation set 2 (Past 38 years – 6 biggest island sea)**	**Situation set 3 (Past 38 years – complete sea)**	**Situation set 4 (Every island once)**
Handling Capacity 1 (37.8% of inhabitants of island needs help, but limited to 7.5 million when island is bigger)	Run 1 – P38, perc. and limit.	Run 4 – sea big 6, perc. and limit.	Run 7 – sea, perc. and limit.	Run 10- once, perc. and limit.
Handling Capacity 2 (All inhabitants needs help but limited to 7.5 million when islands is bigger)	Run 2 – P38, limit	Run 5– sea big 6, limit.	Run 8 – sea, limit.	Run 11- once, limit
Handling Capacity 3 (37.8% of inhabitants of island needs help)	Run 3 – P38, perc.	Run 6 – sea big 6, perc.	Run 9 –sea, perc.	Run 12- once, perc.

Every input configuration is put in the mathematical optimization model. With the help of Yalmip, the mathematical optimization model is build in Matlab (Löfberg, 2004). The model is solved with the Gurobi solver (Gurobi Optimization, 2019) to obtain the results. The results of those 12 input configurations are compared. There are different outputs of the mathematical optimization model: (1) the location of the facilities, (2) the amount of capacity stored, (3) the amount of handling capacity sent from a facility to a demand point, (4) the amount of times a facility location provides help, (5) the average amount of facility locations needed to help one demand point, (6) the total distance travelled in order to help all demand points, (7) the average distance travelled from a facility location to a demand point, (8) the total costs of creating and operating a FFM seaport, (9) the cost to open the facilities, (10) the cost to store the handling capacity, (11) the costs to transport and operate the seaport and (12) the average cost to help one person in need. Chapter 9 compare these outputs over the different runs. In the end this comparison leads to the answer of research question four. This question asks about the logistical conceptual design of a FFM seaport. Note that this design is also the goal of the logistical part of this research.

Combining every handling capacity tactics and demand situation set stated in this chapter together leads to 12 different input configurations. These 12 different input configurations are used to solve the mathematical optimization model 12 different times.

Table 8.4: Overview of the different runs and if it is the best, medium or worst case setting with respect to the handling capacity tactics and the situation sets. Also the amount of total persons which are helped by the FFM seaport for those input configurations is given.



	Situation set 1 (Past 38 years – island only)	**Situation set 2 (Past 38 years – 6 biggest island sea)**	**Situation set 3 (Past 38 years – complete sea)**	**Situation set 4 (Every island once)**
Handling Capacity 1 (37.8% of inhabitants of island needs help, but limited to 7.5 million when island is bigger)	handling capacity best case, situation set best case - 2,746,500,000 affected persons	handling capacity best case, situation set medium case - 10,721,000,000 affected persons	handling capacity best case, situation worst case - 12,454,000,000 affected persons	Run 10- N/A - 1,444,300,000 affected persons
Handling Capacity 2 (All inhabitants needs help but limited to 7.5 million when islands is bigger)	handling capacity medium case, situation set best case - 3,880,700,000 affected persons	handling capacity medium case, situation set medium case - 14,115,000,000 affected persons	handling capacity medium case, situation set worst case - 18,363,000,000 affected persons	Run 11- N/A - 2,190,600,000 affected persons
Handling Capacity 3 (37.8% of inhabitants of island needs help)	handling capacity worst case, situation, set best case - 4,469,300,000 affected persons	handling capacity worst case, situation set medium case - 17,008,000,000 affected persons	handling capacity worst case, situation set worst case - 18,740,000,000 affected persons	Run 12- N/A - 2,800,100,000 affected persons

9

Results logistics experiment

Chapter 7 describes the mathematical optimization model. Chapter 8 describes the experimental plan about how this mathematical optimization model is used. In the end 12 different runs are performed. These 12 runs have all a different input configuration with respect to the handling capacity tactic and demand situation sets. This chapter describes the outputs of these 12 different runs. Comparing these results leads to the creation of the logistical conceptual design for the FFM seaport. This is the answer on the fourth research question and the logistical sub goal of this research.

All the inputs and outputs per run are ordered in a table. The author of this thesis published this table online (Bakker, 2022). The remainder of this chapter discusses the most important outputs. Three subgroups of results are composed in order to compare the different runs. First this chapter shows the results with respect to the facility locations. Second it presents results with respect to the travel distances. In the end it shows results with respect to costs.

9.1. Facility locations

The first result is the total handling capacity stored over all facility locations in a specific run. To gain insight in the size of such handling capacities, this amount of handling capacity in TEU/h is also shown as the capacity stored in km^2. Next to that, it is also interesting to see how many different facility locations are needed to help one demand point. Thus for every demand point in every demand situation there is count how many facility locations sent handling capacity to that demand point to help. From these numbers the average is determined in order to find the average amount of facility locations needed to help one demand point in that run. Table 9.1 shows these three outputs.

Note that the table consist of four blocks. Every block contains three runs and relates with a demand situation set. The first block of runs shows the demand situation set which contain the demand point which were affected in the past 38 years. The second block shows the demand situation set which contain the six biggest demand points in the seas which were affected in the past 38 years. The third block shows the demand situation set which contain all demand points in the seas which were affected in the past 38 years. The fourth block shows the demand situation set which contain all demand points which are affected once. The table also contains a color code. Every color relates to a handling capacity tactic. The blue color relates to the tactic which takes %37.8 of the inhabitants of a demand point and contains a limit to 7.5m affected inhabitants. The green color relates to the tactic which limits to 7.5m affected inhabitants. The grey color relates to the tactic which takes %37.8 of the inhabitants of a demand point. Note that both indicators are indicated from best case scenario to worst case scenario from left to right. These blocks and color code are also used for the other tables in this chapter.

One of the direct outcomes of the mathematical optimization model are the different facility locations that are opened in order to help the affected islands as best as possible within that run. Those facility locations are opened and a certain amount of handling capacity is stored at those facilities. Figure 9.1

Table 9.1: Of every different run, the amount of total capacity stored over all facility locations in TEU/h, the total capacity stored over all facility locations in km^2 and the average amount of facility locations needed to help one demand point.

	Run 1 – P38, perc. and limit.	Run 2 – P38, limit	Run 3 – P38, perc	Run 4 – sea big 6, perc. and limit.	Run 5– sea big 6, limit.	Run 6 – sea big 6, perc.	Run 7 – sea, perc. and limit.	Run 8 – sea, limit.	Run 9 –sea, perc.	Run 10- once, perc. and limit.	Run 11- once, limit	Run 12- once, perc.
Total capacity stored (TEU/h)	2,693 TEU/h	3,735 TEU/h	6,502 TEU/h	2,708 TEU/h	2,708 TEU/h	7,587 TEU/h	3,976 TEU/h	5,604 TEU/h	8,689 TEU/h	663 TEU/h	663 TEU/h	3,302 TEU/h
Total capacity stored (km^2)	0.69 km^2	0.96 km^2	1.67 km^2	0.70 km^2	0.70 km^2	1.95 km^2	1.02 km^2	1.44 km^2	2.23 km^2	0.17 km^2	0.17 km^2	0.85 km^2
Average amount of facility locations needed to help one demand point	1.93	1.95	2.03	2.61	3.75	2.30	2.88	3.25	3.75	1.27	1.67	1.02

show the different locations which are opened in different runs. The figure shows that in total eleven different locations are being considered over the different input configurations. Not every location is being opened in every run. Some locations, like Los Angeles and Ho Chi Minh City, are only being opened in two different runs. While, on the other hand, Kuala Lumpur is being opened in every run. Also Corinto and Maputo are opened in seven runs, which is relatively many. Note that this means that out the set of 62 possible facility locations, only 11 facilities are used in these 12 runs.

Figure 9.1: The 11 storage facilities which are opened in the different runs out of the 62 possible facility locations.

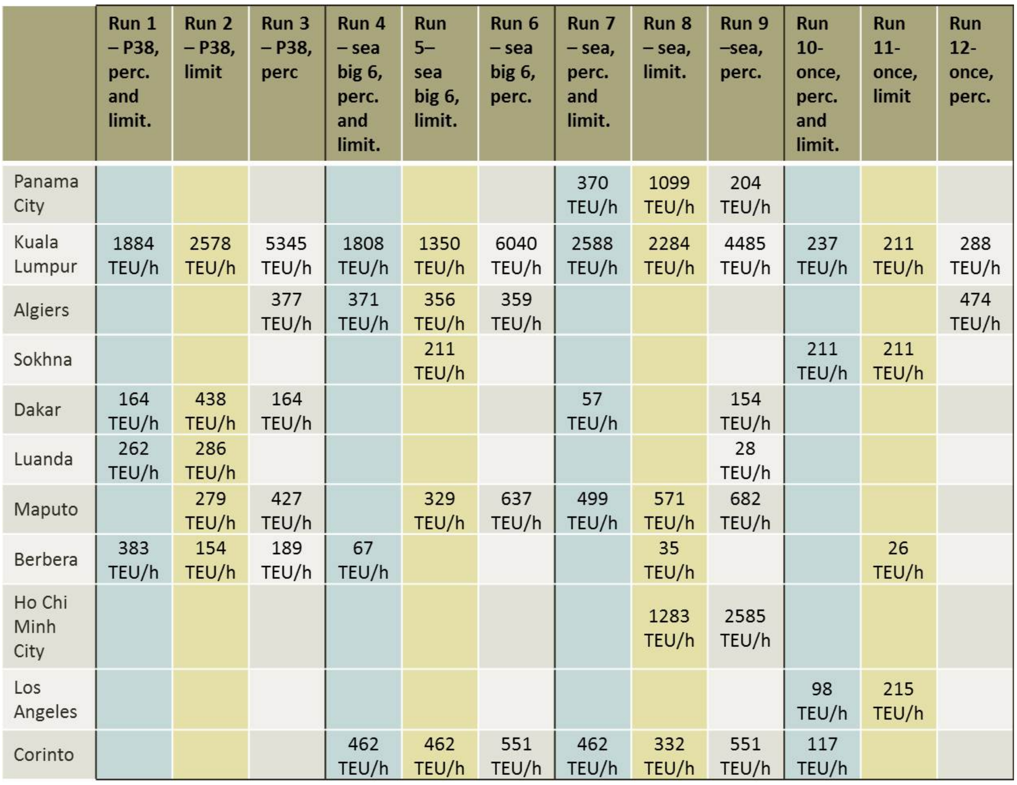
Section 8.1.4 describes that there are six different facility providers. This are: UNHRD, DP World, Maersk, Agility, UPS and Amazon. Most of the locations out the set of possible facility locations contain an already existing facility of one or multiple of those facility providers. There are only six locations in the set of 62 possible facility locations which don't contain an already existing facility by these providers. It is interesting to see if the 11 locations which are opened in the 12 runs also contain already an existing facility by one of those providers. Table 9.2 shows for every facility that is opened in the 12 runs which facility providers already have an existing facility at that location.

Table 9.2: For the 11 facility locations that are opened in the 12 runs there is showed which facility providers already have an existing facility at that location.

	UNHRD	DP World	Maersk	Agility	UPS	Amazon
Panama City	x		x			
Kuala Lumpur	x		x		x	
Algiers		x				
Sokhna		x	x		x	
Dakar		x	x			
Luanda		x				
Maputo		x		x		
Berbera		x				
Ho Chi Minh City		x	x			
Los Angeles			x		x	
Corinto			x			

Next to the location, also the amount of handling capacity stored at a facility location is an outcome of the mathematical optimization model. This is expressed in the amount of TEU per hour handling capacity stored. This amount varies over different runs. For example, in run six (sea big 6, perc.) there is 6040 TEU/h stored in Kuala Lumpur and in run one (P38, perc. and limit) this is 1884 TEU/h. This difference makes sense since the different amount of demand needed at a demand point differs over the different runs. Table 9.3 shows the total stored handling capacity at every facility location in every run.

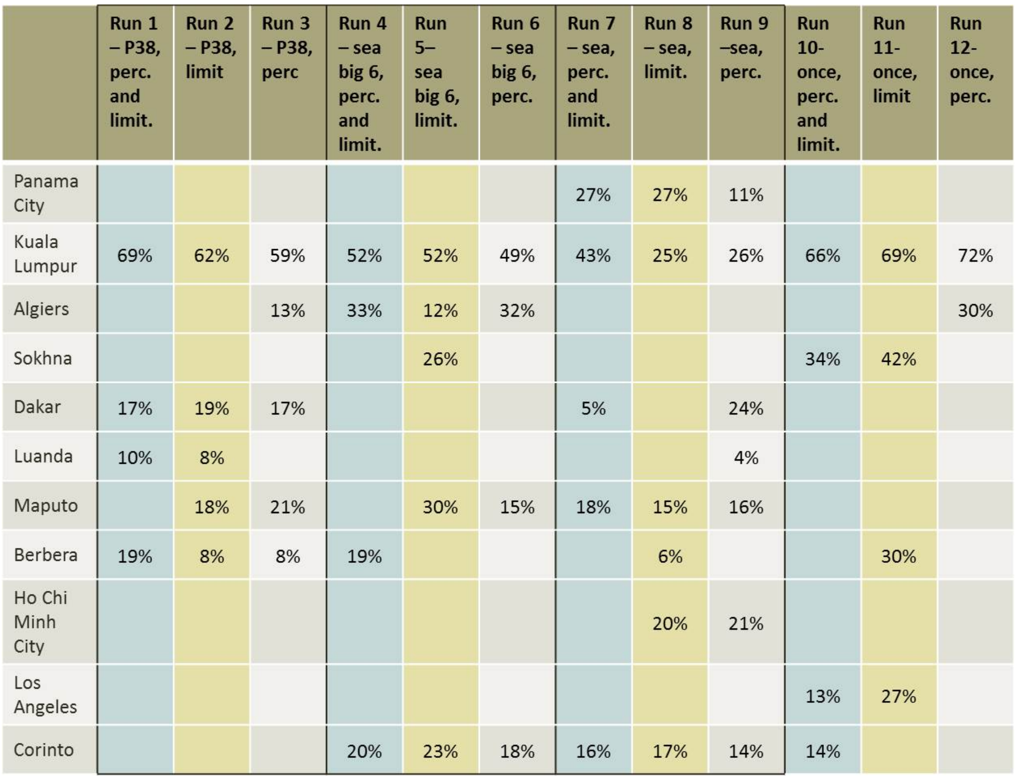
Table 9.3: The amount of handling capacity, in TEU/h, stored at the different facility locations in the different runs.



	Run 1 – P38, perc. and limit.	Run 2 – P38, limit	Run 3 – P38, perc	Run 4 – sea big 6, perc. and limit.	Run 5– sea big 6, limit.	Run 6 – sea big 6, perc.	Run 7 – sea, perc. and limit.	Run 8 – sea, limit.	Run 9 –sea, perc.	Run 10- once, perc. and limit.	Run 11- once, limit	Run 12- once, perc.
Panama City							370 TEU/h	1099 TEU/h	204 TEU/h			
Kuala Lumpur	1884 TEU/h	2578 TEU/h	5345 TEU/h	1808 TEU/h	1350 TEU/h	6040 TEU/h	2588 TEU/h	2284 TEU/h	4485 TEU/h	237 TEU/h	211 TEU/h	288 TEU/h
Algiers			377 TEU/h	371 TEU/h	356 TEU/h	359 TEU/h						474 TEU/h
Sokhna					211 TEU/h					211 TEU/h	211 TEU/h	
Dakar	164 TEU/h	438 TEU/h	164 TEU/h				57 TEU/h		154 TEU/h			
Luanda	262 TEU/h	286 TEU/h							28 TEU/h			
Maputo		279 TEU/h	427 TEU/h		329 TEU/h	637 TEU/h	499 TEU/h	571 TEU/h	682 TEU/h			
Berbera	383 TEU/h	154 TEU/h	189 TEU/h	67 TEU/h				35 TEU/h			26 TEU/h	
Ho Chi Minh City								1283 TEU/h	2585 TEU/h			
Los Angeles										98 TEU/h	215 TEU/h	
Corinto				462 TEU/h	462 TEU/h	551 TEU/h	462 TEU/h	332 TEU/h	551 TEU/h	117 TEU/h		

Next to the amount of handling capacity stored, it is also interesting to see how many times a facility location actually helped a demand point in need. For example, Berbera only holds a small amount of handling capacity and only helped 6% of the total demand points in need in run Run eight (sea, limit). While, for example in run one (P38, perc. and limit.), Kuala Lumpur transport their stored handling capacity to 69% of the total affected demand points. Table 9.4 shows the percentages of all different runs for every facility location. The figures represents the amount of times that the facility location provides help as a percentage of the total amount of times that demand points need help in that run.

Table 9.4: The amount of times that a facility location provides help in ever run. This is showed as the percentage of the total amount of times that demand points need help in that run



	Run 1 – P38, perc. and limit.	Run 2 – P38, limit	Run 3 – P38, perc	Run 4 – sea big 6, perc. and limit.	Run 5– sea big 6, limit.	Run 6 – sea big 6, perc.	Run 7 – sea, perc. and limit.	Run 8 – sea, limit.	Run 9 –sea, perc.	Run 10- once, perc. and limit.	Run 11- once, limit	Run 12- once, perc.
Panama City							27%	27%	11%			
Kuala Lumpur	69%	62%	59%	52%	52%	49%	43%	25%	26%	66%	69%	72%
Algiers			13%	33%	12%	32%						30%
Sokhna					26%					34%	42%	
Dakar	17%	19%	17%				5%		24%			
Luanda	10%	8%							4%			
Maputo		18%	21%		30%	15%	18%	15%	16%			
Berbera	19%	8%	8%	19%				6%			30%	
Ho Chi Minh City								20%	21%			
Los Angeles										13%	27%	
Corinto				20%	23%	18%	16%	17%	14%	14%		

9.2. Travel distances

Also, the amount of distance travelled in order to transport the stored handling capacity from the facility locations to the demand points is interesting. The total amount of distance travelled can be seen in Table 9.5. This is the total distance travelled by the semi-submersible heavy lift vessels to help all the demand points in every disaster situation in that run. It consist of the travel distance to reach a demand point and to get back to the facility location after help is not necessary anymore. The total distance travelled in a certain run is especially interesting in order to compare runs with the same disaster situation set but with different handling capacity tactics. Those runs have the same situations consisting of one or multiple demand points which need to receive help. The difference in total distance travelled between those runs says something about the travel efficiency of the open facilities. For example, the first three runs, which contain the same disaster situations as the past 38 years, shows that the second run (P38, limit) does need less travel distance in order to help every demand point then run one (P38, perc. and limit) and run three (P38, perc.). From a travel time and travel cost perspective this run performs the best when looking at those three runs.

All demand points have to be helped by facilities which are within the maximum service distance of that concerning demand point. However, it can be an extra asset if the facility location is closer by the demand point then necessary. This gives more time to prepare the humanitarian relief effort and the usage of the FFM seaport within that effort. The installation time can be extended or the seaport can be transferred slower and more economically friendly. The average distance travelled to reach a demand point is thus an interesting number. Table 9.5 shows this number.

Table 9.5: The table shows of every different run the total distance travelled by the semi-submersible heavy lift vessels in order to help all demand points. Also it shows the average distance travelled from a facility location to a demand point.

	Run 1 – P38, perc. and limit.	Run 2 – P38, limit	Run 3 – P38, perc	Run 4 – sea big 6, perc. and limit.	Run 5– sea big 6, limit.	Run 6 – sea big 6, perc.	Run 7 – sea, perc. and limit.	Run 8 – sea, limit.	Run 9 – sea, perc.	Run 10- once, perc. and limit.	Run 11- once, limit	Run 12- once, perc.
Total distance travelled	1,654,278 km	1,586,630 km	1,617,218 km	4,287,826 km	6,593,964 km	3,699,054 km	4,951,124 km	4,980,714 km	5,697,352 km	1,108,918 km	1,835,166 km	729,606 km
Average distance travelled to reach demand point	5371 km	5118 km	5118 km	5554 km	7459 km	5225 km	3572 km	3578 km	3918 km	5087 km	6372 km	4146 km

9.3. Costs

Finally, also the costs are an interesting result. The total cost is the outcome of the objective function and thus a direct result from the mathematical optimization model. Table 9.6 shows this total cost per run. The objective function shows that this costs consist of three parts: the cost to open facilities at certain locations, the cost to store the necessary handling capacity at those locations and the cost to transport and operate the FFM seaports. This last cost consist of (1) the cost to transport the necessary handling capacity from the storage facility to the demand point and back and (2) the cost to operate such a FFM seaport during the disaster relief effort. Since the objective function consist of those three parts, also these three costs can be determined separate from each other. Table 9.6 shows the corresponding values.

A final interesting figure is the average cost to help one person in need at a certain run. In every run the amount of people that are helped differs. This means that this cost helps to compare all the different runs. For every demand situation there is determined how many people in need will be helped by the FFM seaport. Dividing this number by the total cost leads to the average cost to help one person in need. Table 9.6 shows this number.

Table 9.6: This table shows for every run the total costs, the costs to open the facilities, the cost to store the handling capacity, the cost to transport and operate the seaport and the average cost to help one person in need.

	Run 1 – P38, perc. and limit.	Run 2 – P38, limit	Run 3 – P38, perc	Run 4 – sea big 6, perc. and limit.	Run 5– sea big 6, limit.	Run 6 – sea big 6, perc.	Run 7 – sea, perc. and limit.	Run 8 – sea, limit.	Run 9 –sea, perc.	Run 10- once, perc. and limit.	Run 11-once, limit	Run 12-once, perc.
Total costs	8,981,500,847 USD	12,457,365,136 USD	21,097,173,259 USD	10,934,325,120 USD	11,904,865,924 USD	27,341,219,804 USD	15,126,848,688 USD	21,473,154,018 USD	31,088,100,606 USD	2,474,325,193 USD	2,667,565,473 USD	10,832,381,668 USD
Cost to open facilities	15,314,304 USD	19,396,416 USD	25,525,056 USD	23,307,072 USD	31,048,128 USD	27,330,816 USD	35,837,952 USD	39,420,288 USD	44,932,416 USD	64,536,768 USD	59,305,536 USD	17,959,104 USD
Cost to store the handling capacities	8,299,833,642 USD	11,511,866,070 USD	20,025,853,128 USD	8,351,908,908 USD	8,359,575,828 USD	23,376,142,936 USD	12,255,212,720 USD	17,282,886,354 USD	26,807,880,136 USD	2,056,054,026 USD	2,064,658,557 USD	10,168,102,908 USD
Cost to transport and operate the seaport	666,352,901 USD	926,102,650 USD	1,045,795,075 USD	2,559,109,140 USD	3,514,241,968 USD	3,937,746,052 USD	2,835,798,016 USD	4,150,847,376 USD	4,235,288,054 USD	353,734,399 USD	543,601,380 USD	646,319,656 USD
Average cost to help one person in need	3.27 USD	3.21 USD	4.72 USD	1.02 USD	0.84 USD	1.61 USD	1.21 USD	1.17 USD	1.66 USD	1.71 USD	1.22 USD	3.87 USD

Comparing these results leads to defining an applicable conceptual logistical design of the FFM seaport. This conceptual design is the logistical goal of this research and corresponds with the answer on research question four. Chapter 10 describes the evaluation and comparison of the results in order to define this logistical conceptual design.

The results of the 12 different runs are shown next to each other in order to compare the different runs. Comparing those runs leads to defining an applicable conceptual logistical design of the FFM seaport which is of help for every input configuration. For every different run several things are compared: (1) the location of the facilities, (2) the amount of capacity stored, (3) the amount of handling capacity sent from a facility to a demand point, (4) the amount of times a facility location provides help, (5) the average amount of facility locations needed to help one demand point, (6) the total distance travelled in order to help all demand points, (7) the average distance travelled from a facility location to a demand point, (8) the total costs of creating and operating a FFM seaport, (9) the cost to open the facilities, (10) the cost to store the handling capacity, (11) the costs to transport and operate the seaport and (12) the average cost to help one person in need.

10

Evaluation of the results of the logistics experiment

The previous chapter presents the results of the logistical experiment. The next step is to evaluate these results and take a look at what the results mean. This chapter evaluates the results of the 12 different runs. Those 12 runs were performed by solving the mathematical optimization model 12 times with 12 times different input configurations. The goal of the evaluation is to define the conceptual logistical design of the FFM seaport. This conceptual design is the logistical goal of this research and corresponds with the answer on research question 6.

Comparing the different runs is not straightforward. It is not simply picking the results of the run which resulted in the best value of the objective function or the run which results in the least average cost to help one person in need. The different runs represents different settings and thus the final design is dependent on the setting which are chosen.

However, a couple of things stand out when comparing the results. The following sections describes these insights.

10.1. The lowest amount of facilities to serve all demand points

The first insight is the fact that every demand point can be reached using just two facilities. Run 12 (once, perc.) has the demand situation set which simulates a situation were ever islands in the world with more then 265,000 inhabitants is affected once independent from one another. The output of this run indicates that Kuala Lumpur and Algiers are opened. Kuala Lumpur, in particular, is opened in all runs. The results of run 12 indicate that with these two facility locations it is possible to reach every demand point in the world, while taking the maximum service distance of every demand point into account.

Opening only these two facility locations leads to a low total distance travelled. Two other runs with the same demand situation set but other handling capacity tactics (run 10 and run 11), have a higher total distance travelled to reach the same demand points. In run 12, almost every demand point uses just one facility for help. This is mostly the facility which is closest near the demand point. This makes the total distance travelled low. In run 10 and 11 the average amount of facilities locations needed to help one demand point is higher. This means on some occasions a demand point gets help from a facilities that isn't the nearest of the open facilities. This shows opening more facilities leads to an increased average amount of facility locations helping one demand point. The low total distance in run 12 makes sense as the results of run 10 and 11 indicates that more facilities are opened (both runs four facilities) then the two facilities in run 12.

Results show that when more facilities are opened, the average amount of facility locations needed to help one demand point increases. An increase in average amount of facility locations needed for help of one demand point, correlates to a higher the total distance travelled overall. Next to that, an increase in total distance travelled, corresponds also with a higher average distance to reach a demand point.

The above is not only true for demand situation set four (every island is affected once). It is also true for the demand situation set two (6 biggest islands in the affected seas of the past 38 years) and the demand situation set three (all islands in the affected seas of the past 38 years). More facility locations are transporting handling capacity to demand points, resulting in more total distance travelled. This because some extra handling capacity is coming from facilities further away.

However, the results shows that the balance is delicate. For example, demand situation set one (corresponding with the demand situations as they were the past 38 years) shows that in the run with the least amount of facilities opened, the total distance travelled is the highest. Looking closely, when comparing run one (P38, perc. and limit.) with runs with the same demand situation set (run two and run 3), the differences are minimal with respect to the total travel distance and the average distance travelled to reach a demand point.

Something else is noticeable, when comparing runs with a different demand situation set but the same handling capacity tactic. The average distance travelled to reach a demand point is the lowest in the situation which take all islands in the affected seas of the past 38 years into account, no matter handling capacity tactic. The average distance travelled to reach a demand point is the highest in the situation which take the six biggest islands in the affected seas of the past 38 years into account, no matter handling capacity tactic. So apparently the location of the six biggest islands in the affected sea is not advantageous in comparison with the location of all islands in the affected sea.

The above evaluates the results from a perspective of keeping the amount of facilities to open low, keeping the amount of total travel distance low and keeping the average distance to reach a demand point low. One can argue that opening two facilities in Kuala Lumpur and Algiers results in the design which scores the best on this perspective. An advantage to consider in having more facilities is more redundancy in case that a facility location is not able to provide service.

Comparing the outcomes of all different runs of the mathematical optimization model with different input configurations shows that the more facilities are opened, the higher the average amount of facility locations needed to help a demand point is. This resulted in a higher the total distance travelled and a higher the average distance to reach a demand point. The results also show that it is possible to reach every single demand point when opening just two facilities. One in Kuala Lumpur and the other in Algiers.

10.2. Cost to transport and operate the seaport

The question arises why the mathematical optimization model opens multiple location in several runs. The previous section concludes that the more facilities are opened to serve the same demand situation set, the higher the total distance travelled. It seems logical that the higher this total distance travelled, the higher the travel costs. Next to that, the more facilities are opened, the higher the cost to open facilities.

The costs shows however that it is not true that the higher the total distance travelled, the higher the travel costs. This because, also the amount of TEU/h transported have to be taken into account. The higher the amount of TEU/h, the higher the weight and volume that have to be transported. This results in a higher price when more TEU/h have to be transported. This results in the fact that it is not always true that the higher the total distance travelled, the higher the travel costs. It is more cost effective when a lot of the necessary handling capacity is transported from a nearby facility and a small amount from a location further away, then all handling capacity from a location further away.

Next to that, the cost aspect shows that the cost to open facilities is very low compared to the cost to store handling capacity and the cost to transport and operate the FFM seaport. This means that it is not always necessary true that the less facilities are open, the lower the costs.

The results show that it is not true that highest total distance travelled corresponds with highest costs. The volume of the transported handling capacity also needs to be taken into account. Next to that, it was shown that the contribution of opening facilities to the total cost is very low compared to the costs to store handling capacity and the costs to transport and operate the FFM seaport.

10.3. Average costs to help one person in need

The results also provide an insight with respect to the average costs to help one person. For every different demand situation set the results show that the handling capacity tactic which set a limit to maximum 7.5m people in need per demand point leads to the lowest value. The handling capacity tactic which assumes that 37.8% of the inhabitants are in need, scores the highest value of all demand situation sets. Next to that, the lowest values are scored for every handling capacity tactic where the runs corresponds with the demand situation set which contains the six biggest islands of the affected seas of the past 38 years. The highest value are scored in runs which corresponds with the demand situation set which contain the affected islands of the past 38 years.

The above is remarkable since this means that the medium case scenario scores the best with respect to the demand situation sets and the handling capacity tactic. This means that run five has the optimal input configuration and corresponding solution, when looking at the average cost to help one person in need.

The best performing run with respect to the average cost to help one person in need correspondents with the six biggest islands located in the seas which have been affected by a disaster in the past 38 years and with a limit of maximum 7.5m people helped for the bigger islands.

10.4. Stored amount of handling capacity

The costs to open are only a very small proportion of the total costs. One can argue that opening the 11 facilities which are at least opened in one of the runs is a good idea. Out of the set of 62 possible facility locations, these facilities are chosen at least as a solution for one input configuration. Taking these 11 facilities for the conceptual design results in the assurance that the conceptual design is able to deal with every disaster configuration. The question then remains of how much handling capacity must be stored at those locations. Especially because the largest contributor of the total cost is the cost to store and buy the handling capacity.

Looking at the total amount of handling capacity stored, stored capacity increases as the worst case scenario is approached. This makes sense since in the worst case scenario, with respect to the amount of handling capacity necessary at a demand point, more people are in need of help and thus the highest amount of throughput capacity is necessary. Remarkable is the fact that the same is not true with respect to the demand situation set.

The problem is the fact that the total capacity stored in the runs with the worst case handling capacity tactic (run 3, run six and run 9), is higher then the capacity per hour of the seaport of Shanghai. This is the busiest seaport of the world with a capacity of around 5,000 TEU/hour (World Shipping Council, 2021). It is considered a little excessive to store the equivalent of the biggest seaport in the world at a facility only to help when that seaport is necessary during a disaster. On the other hand, the handling capacity tactic wise more favorable runs shows that the total capacity stored in run 1, run four and run seven is equivalent to more or less the fifth largest seaport of the world (World Shipping Council, 2021).

With respect to the amount of handling capacity stored the results show a very large amount of capacity is stored. The exact number depends on the input configuration, but the amount of handling capacity stored is in every case more than the handling capacity of the current fifth largest seaport in the world.

10.5. Costs per year

The cost per year for the FFM seaport is important to consider for the financial impact on relief effort organizations. The worst case scenario, for both the demand situation set as well as for the handling capacity tactic, is represented by run 9. If the logistical conceptual design of this run is implicated and exactly this worst case scenario will happen, then the total costs of operations is 31bn euros over a span of 38 years. This relates to a cost of 818 million euros per year on average. For comparison, the annual revenue of the United Nations is $62bn (CEB, 2021) and the annual revenue of the World Food Program is $8.4bn (WFP, 2021). This indicates that the predestined owners could take the cost. However, it will be a big part of their budget, especially when taking into consideration that 60-80% of the income of humanitarian organization (or $10 billion to $15 billion per year) is at this moment spent on logistics (Tatham and Spens, 2016; Tatham et al., 2017). On the other hand, in relation with the total costs of disasters, which was $280bn in 2021 alone (Munich RE, 2022), the worst case scenario costs of the FFM seaport is very small.

Relating these cost per year back to cost per person gives a second indication for cost impact on relief effort organizations. The disaster relief effort analysis shows that on average $14 per person was spent to help one person for 76 days on food. In all runs, the highest average cost to help one person in need is $4.72 in run three (P38, perc). The lowest average cost to help one person is $0.84 in run five (sea big 6, limit). This shows that the costs per helped person with the FFM seaport is bearable.

As the above indicates, it is interesting to compare the costs of the FFM seaport with the current costs and financial resources of disaster relief effort organizations. Table 10.1 shows the costs of the FFM seaport for the different runs as a percentage of the current relevant costs and financial resources of disaster relief organizations.

Table 10.1: The costs for the different runs as a percentage of other relevant costs.

	Run 1 – P38, perc. and limit.	Run 2 – P38, limit	Run 3 – P38, perc	Run 4 – sea big 6, perc. and limit.	Run 5– sea big 6, limit.	Run 6 – sea big 6, perc.	Run 7 – sea, perc. and limit.	Run 8 – sea, limit.	Run 9 –sea, perc.	Run 10- once, perc. and limit.	Run 11- once, limit	Run 12- once, perc.
Total yearly cost as percentage of annual revenue of the United Nations	0.38%	0.53%	0.90%	0.46%	0.51%	1.16%	0.64%	0.91%	1.32%	0.11%	0.11%	0.46%
Total yearly cost as percentage of annual revenue of World Food Program	2.81%	3.90%	6.61%	3.43%	3.73%	8.57%	4.74%	6.73%	9.74%	0.78%	0.84%	3.39%
Total yearly cost as percentage of total costs of disaster	0.08%	0.12%	0.20%	0.10%	0.11%	0.26%	0.14%	0.20%	0.29%	0.02%	0.03%	0.10%
Average cost to help one person as a percentage of the food cost to help one person in need	23.4%	22.9%	33.7%	7.3%	6.0%	11.5%	8.6%	8.4%	11.9%	12.2%	8.7%	27.6%

When considering the yearly cost it shows that financial wise it is possible to realize the FFM seaport. The different actors which need to invest in such a seaport are financially able to do so.

10.6. Defining final logistical conceptual design based on these results

The question about the applicable conceptual design remains open. The cost wise best logistical conceptual design is dependent on the exact disasters that will happen in the future. This means that choosing the best design is about choosing which input configuration the decision maker favours. The input configuration that the decision maker deems likely to happen in the future.

The decision maker could consider for simplicity that in the coming 38 years the same disasters as the previous 38 years will likely happen. In this case he needs to consider the first three runs.

However, it is known that due the climate change the frequency and intensity of extreme weather events increases (Keen et al., 2003). If the decision maker want to be prepared for the worst scenario, the best facility location places and amount of handling capacity stored at those location correspondents with run nine (sea, perc.). This logistical conceptual design is able to deal with the medium and best case scenarios as well.

The difficulty is that size wise this run results of a very big number of stored handling capacity. From an economic perspective the worst case scenario seems feasible. However, taking the worst case scenario still leads to the largest number cost wise. Run nine (sea, perc.) also has seven different facility locations are opened. This is the most over all runs. This leads to a high number of average amount of facility locations which are needed to help one demand point. One can imagine that opening this amount of locations and coordinating transport from this much locations will not be an easy task. So a consideration remains if there is a better way of finding a better applicable design based on the results of all the runs.

Since it is possible to reach every demand point from Kuala Lumpur and Algiers it is argued that opening these two facilities is the most realistic plan. This is the lowest amount of facilities which have to be opened to serve all demand locations. In that case almost every demand point is helped by just one of the two facilities. As concluded, keeping the amount of facilities to open low results in keeping the amount of total travel distance low and this keeps the average distance to reach a demand point low. This favours the decision to only open Kuala Lumpur and Algiers.

With respect to the costs it is not the optimal solution for every possible future disaster scenario, but it is concluded that the economic side of the FFM seaport does not have to propose a problem.

The only question remains is the amount of capacity that has to be stored at those locations. As concluded, it is a little excessive to store the equivalent of the biggest seaport in the world at a facility only to help when that seaport is necessary during a disaster. This means that the runs which contain the worst case scenario with respect to the handling capacity tactic (run 3, six and 9) are a little too extravagant. These results shows that the medium case scenario with respect to the handling capacity tactic and demand situation sets leads to the lowest average cost to help one person. So it is assumed that this input configuration will happen in the future and then in total there is 2,708 TEU/h needed to help every person in need. Next to that, the results show that in run 12 Kuala Lumpur had to help in 72% of the time and Algiers in 30%. Taking these percentages and storing at those location that percentage of the total stored amount of capacity. This leads to opening Kuala Lumpur with a storage of 1,950 TEU/h and opening Algiers with a storage of 812 TEU/h.

Note that the above forms the answer on the fourth research question. It forms the applicable conceptual logistical design of the FFM seaport. This conceptual design corresponds also with the logistical goal of this research. The next part of this research describes the communication part of this research.

The outcome of this communication research presents some interesting insights which can be integrated in order to evaluate the results from a new perspective. Chapter 15 describes this integration.

The best logistical conceptual design from a financial view point is very dependent on the exact disasters that will happen in the future. This means choosing the best design is about choosing which input configuration the decision maker favours.

However, when looking at the most applicable design, it can be argued that the best way to go is to place facilities in Kuala Lumpur and Algiers. This can be beneficially combined with the total amount of handling capacity stored in the run which scored the most favourable with respect to the average costs to help one person. This results in a configuration with Kuala Lumpur opened and storing 1,950 TEU/h and opening Algiers with a storage capacity of 812 TEU/h.

III

Literature, methods and results communication research

11

Systematic literature analysis

The introduction, background and context part of this report indicates that collaborative sensemaking in disasters is the construct which must be improved. Improving this construct leads to reducing the material convergence problem. This results in an improved disaster relief effort.

It is important to analyse this construct further since construct are latent variables which cannot be directly observed or measured (Volchok, 2015). A construct is conceptualised using different concepts. Together these concepts forms the construct. A concept consist of several variables which can be measured in order to say something about that concept.

Is is important to analyse the construct of collaborative sensemaking in disasters further to find out which concepts and variables plays a role. Finding this concepts and variables answers research question five of this research. The concepts and variables together forming a theoretical framework which is created based on the findings of a systematic literature analysis. A systematic literature analysis is carried out because this results in a transparent review, aiming to create a broad overview on the construct, not steered by the researcher's bias (Bryman, 2012). This chapter discusses the search strategy and results of this systematic literature analysis

11.1. Search strategy

Appendix D describes that literature overviews of collaboration, sensemaking and disasters are analysed. These literature overviews gave some interesting factors which can be incorporated in the detailed design of the FFM seaport. This factors are thus not used within this research, but in the future they can be important. Appendix D shows these factors. Next to these factors, the investigated overviews also contains several keywords. Table 11.1 shows the keywords found in those literature overviews. The systematic literature analysis used these keywords to search for interesting literature.

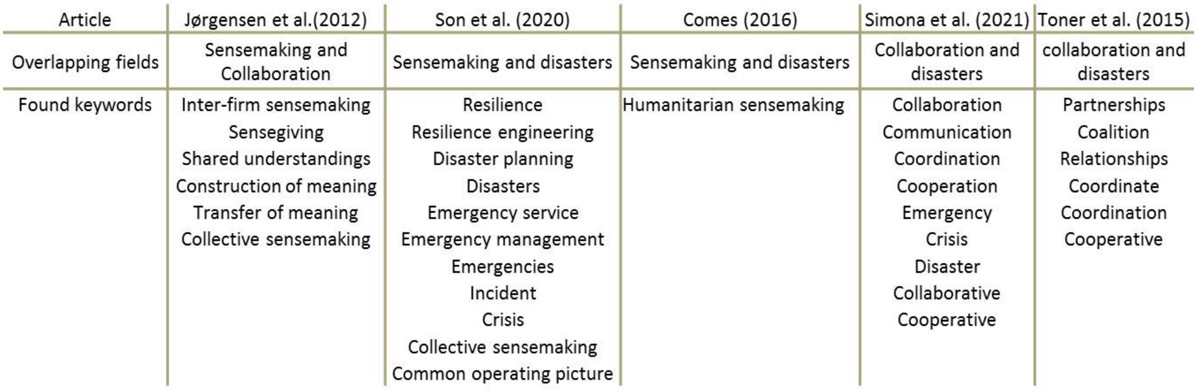
The following search query is used to search in the article title, abstract and keywords of papers:

”inter-firm sensemaking” OR ”inter firm sensemaking” OR ”inter-firm sense-making” OR ”inter firm sense-making” OR ”inter-firm sense making” OR ”inter firm sense making” OR ”sense giving” OR ”sense-giving” OR ”sensegiving” OR ”collabo* sensemaking” OR ”collabo* sense-making” OR ”collabo* sense making” OR ”collect* sensemaking” OR ”collect* sense-making” OR ”collect* sense making” OR ”cooper* sensemaking” OR ”cooper* sense-making” OR ”cooper* sense making” OR ”coordinat* sensemaking” OR ”coordinat* sense-making” OR ”coodinat* sense making” OR ”humanitarian sensemaking” OR ”humanitarian sense-making” OR ”humanitarian sense making” OR ”transfer of meaning”

AND

”disaster*” OR ”emergency” OR ”emergencies” OR ”resilience”

Table 11.1: Overview of the keywords found in Chapter D



Article	Jørgensen et al.(2012)	Son et al. (2020)	Comes (2016)	Simona et al. (2021)	Toner et al. (2015)
Overlapping fields	Sensemaking and Collaboration	Sensemaking and disasters	Sensemaking and disasters	Collaboration and disasters	collaboration and disasters
Found keywords	Inter-firm sensemaking Sensegiving Shared understandings Construction of meaning Transfer of meaning Collective sensemaking	Resilience Resilience engineering Disaster planning Disasters Emergency service Emergency management Emergencies Incident Crisis Collective sensemaking Common operating picture	Humanitarian sensemaking	Collaboration Communication Coordination Cooperation Emergency Crisis Disaster Collaborative Cooperative	Partnerships Coalition Relationships Coordinate Coordination Cooperative

The search query uses and combines several keywords. This research defines the concepts and variables which play a role during collaborative sensemaking in disaster. The query uses variations of the word collaboration, the word cooperation, the word coordination, the word inter-firm and the word collective to emphasize on the collaborative aspect. The query uses variations of the word sensemaking, sensegiving and transfer of meaning to emphasize on the sensemaking aspect. To emphasize that sensemaking is performed in a collaborative setting, the query combines keywords related with collaboration and keywords related with sensemaking together. However, since sensegiving, transfer of meaning and humanitarian sensemaking always induces some form of collaboration these words are not combined with the words related to the collaborative aspect. A final note about the search query is that it incorporates all variations of the word sensemaking: with a hyphen (sense-making), a space (sense making) and written together (sensemaking). The search query does the same with the word inter-firm and sensegiving.

This systematic literature review doesn't use keywords such as shared understanding, construction of meaning and common operating picture. In disaster literature, shared understanding and common operating picture have the goal to visualise or describes the situation and to share this information among the actors. It doesn't relate to actors creating an overview of the situation in a collaborative way. Construction of meaning is not taken into account because it doesn't relates to a collaborative process but to an individual one.

The search query searches for papers which combines one of the keywords mentioned above together with a disaster component. The query uses different keywords related to this disaster component. This are: disaster, emergency and resilience. Note that the query not uses the words crisis and incident. Incident and crisis are both less inclusive and can also relate to a personal incidents or crisis. Next to that, these words also relates to a negative change in the security, political, economic, environmental and societal situation of a country.

The next step in the systematic literature review was to check the papers which are found by the search query. The interesting papers had to be selected for full review. Figure 11.1 gives an overview of this selection process and shows how the papers necessary for full review were selected. The search for literature was carried out by using Scopus and Web of Science as databases. The two complement each other. Via Scopus 41 articles were found and 44 in Web of Science. All found articles were written in English. Chapter 1.2 describes that the humanitarian logistics field draw a lot of attention after the 2004 Asian tsunami. Since the design of the FFM seaport helps current and future disaster relief efforts, only contemporary research was taken into account. Literature published after 2004 was taken into account. These papers describe the current disaster relief effort context the best. Only literature which was cited minimal five times or was published in 2019 or later was selected. This in order to incorporate only articles which are valued in the field.

After removing duplicates out of the literature found in the two databases, 45 papers were selected to examine in more detail. By investigating the title, abstracts and keywords, 21 papers were selected to read completely. The other papers did not describe the collaborative sensemaking process during disasters. For example, some describe the sensemaking process of the public with help of social media during disasters. Others describe a personal or internal organization crisis which is not related to a disaster or emergency situation. Next to that, some papers describe a personal sensemaking process. Finally, some papers describe the sensemaking of the public, financial donors or politicians and not the collaborative sensemaking process of decision makers during disasters. Appendix E presents an overview of all read papers and the exact reason why a paper is included in the systematic literature review or not.

Figure 11.1: Overview of the selection process of found literature based on the keywords to include in the literature review

The articles were analysed by a combination of open coding and axial coding (Bryman, 2012). First open coding was used, to find interesting passages of the different literature. After that axial coding was used to cluster and connect all the different relevant interesting passages. This in order to find overlaying concepts and variables which foster the collaborative sensemaking in disasters. Together this concepts and variables forms the theoretical framework which forms the basis of the communication research. The next chapter explains this framework.

The construct of collaborative sensemaking in disasters is the construct of interest in this research. A construct consist of concepts which consist of variables. Measuring these variables gives a picture of the construct of collaborative sensemaking in disasters. In order to find the concepts and variables, a systematic literature analysis is performed. This resulted in 21 interesting papers to analyse more in-depth. These articles were analysed by a combination of open coding and axial coding. First open coding was used to find interesting passages of the different literature. After that axial coding was used to cluster and connect all the different relevant interesting passages. This eventually resulted in the concepts and variables of the construct of collaborative sensemaking in disasters.

11.2. Theoretical framework

The outcome of the systematic literature review shows that several different concepts play a role within collaborative sensemaking in disasters: shared information gathering, shared interpreting of information, collective actions, shared leadership, conversation quality, conversation participation and feelings. Next to that the literature explains something about the total sensemaking process and the relationship between those concepts. Together they form the conceptualisation of collaborative sensemaking in disasters. This conceptualisation forms the theoretical framework, the basis of the communication research.

Every concept forms a subsection of this section. Within this subsection the variables which are related to those concepts are explained. Variables are factors which can be measured in order to measure the performance of the construct. These variables are found in the selected literature of the systematic literature analysis. This chapter discusses the relation between the concepts and gives an overview of the theoretical framework after the different concepts are discussed.

11.2.1. Shared information gathering

The first concept which plays a role during collaborative sensemaking in disasters is the collectively gathering of information (Alharthi et al., 2018, 2021; Krafft et al., 2017; Moon et al., 2020). Information is gathered from different sources. It is important to note that people are biased. People only see a specific subset of disaster communication and information (Krafft et al., 2017). This calls for a diversifying of information resources (Son et al., 2020a). This makes communication between actors crucial and it emphasizes the collectiveness needed in information gathering (Krafft et al., 2017).

This means that the first variable is related to the gathering of information from different sources. Actors must be aware of were the information came from and who has which information. The first variable is thus variety of sources.

It is important to not only gather information, but also collecting, filtering, processing, authenticating, and interpreting information is necessary in order to extract the right information (Alharthi et al., 2018, 2021). Individual choices are made about which information needs to be used and seen as important. This important information is shared with others.

The rules which determine if information is important or not are set up collectively. These rules are not hard criteria. It is about developing collectively fundamental assumptions about a number of attributes such as the level of risk presented in a situation and the acceptable level of risk (Baran and Scott, 2010). The rules makes sure that there is a collectively understanding about the consequences of certain information for actions made in and extreme events happening during the disaster relief effort (Gilstrap et al., 2016). It also gives some sense about the needed information and the forecasted information needs (Son et al., 2020a). These rules are flexible and change over time when the sensemaking process evolves. This makes it important to keep on communicating with all involved actors. The information gathering process is seen as a collective action.

Gathering information is related with asking questions to other actors such as: “What is going on here?”, “What assumptions should we question?” or “How does this relate to what we have seen before?

(Baran and Scott, 2010). It is about considering and identifying the current available resources which can help dealing with the disaster (Gilstrap et al., 2016).

This means that the second variable of the concept is related to the choices which must be made. A choice is made if information is used and if information is seen as important. The second variable is thus the importance of information.

The first concept is shared information gathering. The corresponding variables are: variety of sources (if enough different variants of information are used) and importance of information (if actors see the same information as important).

11.2.2. Shared interpreting of information

The second concept is shared interpreting of information. Shared interpreting is the collective cognitive process of becoming aware of the content of the knowledge (Moon et al., 2020). The interpreting of information results in a framework. The framework acts like a sort of simplification. Based on tentative explanations the environment is simplified. This results in a frame in which people sees the situation (Stephens et al., 2020). The framework creates a retrospective narrative account (McMaster et al., 2012). Past actions are explained based on this frames in a process called selection (Stephens et al., 2020). Interpreting is the recognition and fitting of data into an appropriate frame (McMaster et al., 2012; Paul et al., 2008). When information can not be fitted in an appropriate frame, a new frame will be made (Paul et al., 2008). Creating such a new frame when necessary needs improvisation (Son et al., 2020a).

The framework serves to structure chaotic stream of information into meaningful patterns (Comes, 2016a). The framework is mostly based on expertise and experience (McMaster et al., 2012; Son et al., 2020a). By creating such a framework it is possible to make the abnormal, normal (Gilstrap et al., 2016). People are painting a picture in such a way that the disaster situation or crisis can be retroactively understood to be a normal situation (Gilstrap et al., 2016).

Interpreting information contains sub-processes like framing, linking and adjusting information found from the shared information gathering (Alharthi et al., 2018; Baran and Scott, 2010; Gilstrap et al., 2016). Interpreting information is a continuous process of seeking order on the discrepancies between the state of the world as expected and as it in real life (Gatzweiler and Ronzani, 2019; Moon et al., 2020). When information is found, it is framed, linked and adjusted in such a way that the information is in line with the current view of the real situation. Information is in line with the current situation when understanding is reached about the current state of the environment and future states can be predicted (Alharthi et al., 2021). During interpreting of information, attention is guided towards filling in the missing elements of the frame and to search for information that tests the frame (McMaster et al., 2012).

It is difficult to grasp the concept of shared interpreting of information in variables. It have to be tested if a framework is composed collectively in order to interpret information. It shows that creating a collective framework results in the detection of conflictive information. Interpreting information is a continuous process of seeking order on the discrepancies between the state of the world as expected and as it in real life. The first variable is thus if conflictive information is found.

A consequence of the interpreting of information is the creation of external representations. Examples of external representations are: diagrams, maps, trees, graphs and tables. When people are faced with a lot of information, they tend to create these external representations (Paul et al., 2008; Wu et al., 2013). Interpreting information can be detected when people are asking themselves the following questions: ”What do I do?”, ”Why do I do it?” and ”What does it mean for me, as a professional and for the other professionals I work with and for?” (Wolbers and Boersma, 2013).

This means that another results of a collective framework are external representations. An outcome of interpreting information is that actors make external representations like diagrams, maps, trees, graphs and tables. This is the second variable related with the concept.

Interpreting information is a continuously process which happens again and again. Interpreting information guides data collection and influences if new information is being seen as relevant to the situation or not (McMaster et al., 2012). The resulted frame helps to prioritize found data (Paul and Reddy, 2010). It gives room to directly process new pieces of information when they arrive (Son et al., 2020a). Next to that, the ability for reorientation is important and the frame must be continuously be evaluated (Gatzweiler and Ronzani, 2019). This again can lead to a new frame which steers the interpretation of information. With the creation of a new frame, the above process starts over again. This cyclic process is described in more detail in section 11.2.9.

The second concept is shared interpreting of information. The corresponding variables are: conflictive information (if actors find and define conflictive information) and external representations (if actors make tables, graphs, drawings etc.).

11.2.3. Collective actions

The third concept is collective actions. In sensemaking processes this collective actions are described as collectively set up a shared planning or shared plans (Alharthi et al., 2018, 2021; Paul et al., 2008; Wu and Zhang, 2009). This shared planning or plan is a product of the joint conclusions made (Mansson et al., 2015). It proposes an anticipated sequence of actions in order to realize a shared goal (Alharthi et al., 2018, 2021; Paul and Reddy, 2010). Data is recognised and put together into an collective appropriate action frame (McMaster et al., 2012). Collective goals move frames from an individual purely 'in the head' view towards an collective mediated activity (McMaster et al., 2012). Defining these collective actions is a form of self organisation (Sanfuentes et al., 2021). This means that the first variable is: whether collective goals are defined or not.

The collective actions construct consist of more then only the defining of collective actions. It is also about being aware of the actions and activities of others (the second variable of this concept) and link those actions towards the common collective goal (the third variable of this concept) (Baran and Scott, 2010; Paul and Reddy, 2010; Paul et al., 2008). It is about observing the activities of others and individually and collectively think about how this aligns with and differs from the norms and collective goals (Paul et al., 2008; Toups et al., 2011). Collective actions results in creating actionable knowledge. This is knowledge which leads to immediate progress on a current action (Wolbers and Boersma, 2013). The fourth variable is if actionable knowledge is created or not.

The third concept is collective actions. The corresponding variables are: whether collective goals are defined or not, awareness of action of others, efficacy of the actions of others (if their actions are linked towards the common collective goal) and if actionable knowledge is created (knowledge which leads to immediate progress on a current action).

11.2.4. Shared leadership

Shared leadership means that there is not one exact leader within the collaboration but that multiple people are showing leadership to reach the defined goals of the collaboration. Shared leadership calls for making decisions altogether. It is important to not create a setting in which one person has a monopoly on decisions (Comes, 2016a). It is about including multiple perspectives in a decision (Wolbers and Boersma, 2013). Shared leadership is important in crisis situations. Having different leaders improves the openness of people to listen to each other. This results in meeting the agreements and working towards the actions defined (Sanfuentes et al., 2021). The first variable is: whether decisions are made altogether or not.

To reach shared leadership it is important to have a clarity of role structures (Gatzweiler and Ronzani, 2019). This means that everybody know each others positions and the knowledge the others are expected to have within their role (Gatzweiler and Ronzani, 2019; Paul et al., 2008; Son et al., 2020a). Communication about this is very important. It reminds people that they have a specific role and corresponding responsibilities within the collaboration (Wu et al., 2013). The second variable is the clarity of role structures. The roles of different actors must be clear in order to foster shared leadership.

The fourth concept is shared leadership. The corresponding variables are: whether decisions are made altogether or not and whether there is clarity of the role structures.

11.2.5. Conversation quality

The conversation quality concept is the next concept. Good conversation quality is linked with a high amount of shared information while taking the purposefulness of information into mind (Moon et al., 2020). Conversation quality is in literature the most noted concept within the collaborative sensemaking in disaster construct (Alharthi et al., 2018; Gatzweiler and Ronzani, 2019; Gilstrap et al., 2016; Krafft et al., 2017; Mirbabaie and Marx, 2020; Moon et al., 2020; Paul et al., 2008; Son et al., 2020a; Wu and Zhang, 2009; Wu et al., 2013). Conversation quality is important since individual people always sees only a subset of the available information (Krafft et al., 2017). A good conversation results in knowing which information others possess. This fosters the the collaborative sensemaking process (Toups et al., 2011; Wolbers and Boersma, 2013).

Sharing information is important to know the information of others. Sharing information only works when people are communicating accurately. The classical communication model, the Shannon and Weaver Model (Shannon, 1948), describes communication (and thus information sharing) as a process where a sender encodes information. They describe that information is sent through a channel. The receiver first decodes the information to understand it. After that, the receiver gives feedback to the sender. Noise affects the information sent from the sender to the receiver. Figure 11.2 illustrates this model.

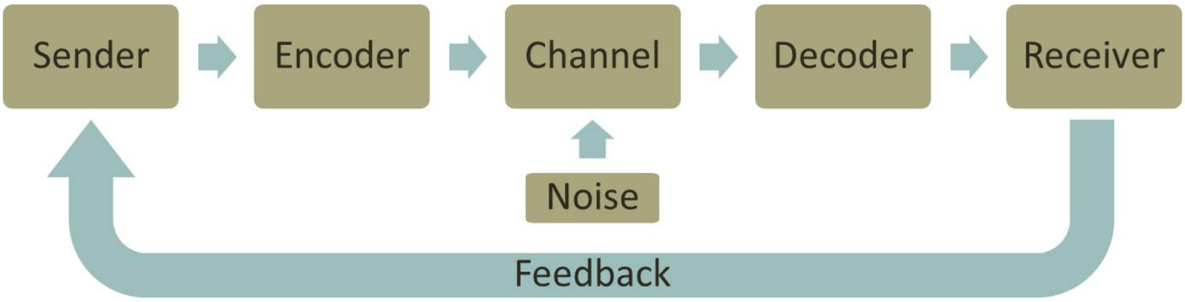


Figure 11.2: The classical communication model (Shannon, 1948)

The classical communication model shows that the purposefulness of the information sent is important. Purposeful information sharing means that the right information is shared and that this information is shared in the right way. It is not only about sharing knowledge, but also about appropriate interactions (Moon et al., 2020; Son et al., 2020a). This means that conversations must clarify, interpret and collectively examine the gathered information (Moon et al., 2020). Personal opinions, decisions judgements and assessments must be shared (Paul and Reddy, 2010; Wolbers and Boersma, 2013). Actors must inform one another about their actions, their personal status and status of the situation (Alharthi et al., 2021; Baran and Scott, 2010; Wolbers and Boersma, 2013). Also they must negotiate about conflicting information and remind each other about their view on the situation (Baran and Scott, 2010). However, it is important to think about the quantity of information shared. Communication overhead negatively impacts team performance (Toups et al., 2011). This means that the first variable is sharing the right information. The shared information must be essential.

Appropriate interactions are thus important. This is not easy during disaster relief effort. Different actors and groups have different own categorization distinctions and vocabulary. The meaning and significance of information is open to different interpretations (McMaster et al., 2012). This results that information is encoded and categorized different by different people (Mansson et al., 2015). There are three ways to overcome this problem: (1) information shared into an appropriate narrative story (Gilstrap et al., 2016), (2) information related to common scales or reference points (Mansson et al., 2015) and (3) add a lot of context or background information (Mansson et al., 2015). The context of background information ideally shows the path of sensemaking. This consist of the steps performed in the sensemaking process and the sense made at each step (Paul and Reddy, 2010). Sharing information in one or a combination of these three ways creates a shared narrative which is described in a shared language (McMaster et al., 2012). This means that the second variable is the way in which information is shared. This variable is called the modality of information sharing.

This means that giving feedback is important in collaborative sensemaking during disasters (Mansson et al., 2015). This is also described in the Shannon and Weaver Model (Shannon, 1948), shown in Figure 11.2. This makes it good practise in disaster situations to double check your own work and the work of others. This contains for example the repeating of shared information such that the sender and the receiver known from each other that consensus is reached about the meaning of and the understanding of the information (Baran and Scott, 2010; McMaster et al., 2012; Wu et al., 2013). This process of triangulation and verification ensures that everyone has the accurate information and it confirms the receipt of information (Tham et al., 2020; Wu et al., 2013). The last variable is the information sharing process.

The fifth concept is conversation quality. The corresponding variables are: efficacy of information sharing (sharing the right and essential information), modality of information sharing (the way in which information is shared) and process of information sharing.

11.2.6. Conversation participation

The participation of actors concept consist of gathering all the relevant actors (Gilstrap et al., 2016) and of maximising the participation of people within the conversation (Gatzweiler and Ronzani, 2019). Mansson et al. (2015) argue that face to face contact foster the collaborative sensemaking during disasters. Face to face contact makes it more easy to share opinions, exchange thoughts and come to joints conclusions. Meeting each other face to face, fosters the creation of a shared mental model (Tham et al., 2020).

The conversation participation concept has three variables. The first two are related to maximising the participation of people within the conversation. The first on is the time needed for a person to share information. The second one is the amount of interaction a person has within a collaborative sensemaking in disaster process. The third one is getting all the relevant actors together to meet face to face.

The sixth concept is conversation participation. The corresponding variables are: time needed for an actor to share information, amount of interaction of an actor and whether all relevant actors are together to meet face to face.

11.2.7. Feelings

Finally the last concept is the sharing of feelings. Humans experience highly intense emotions during disasters. Room to share these emotions is important. Otherwise this hampers the sensemaking process (Sanfuentes et al., 2021). Sharing emotions helps in building collaborative relationships which fosters the collaborative sensemaking in disasters (Sanfuentes et al., 2021). The first variable is whether there is room available to share emotions.

On the other hand, a good sensemaking process creates a good sense of the situation which allows people to create real emotions about the situation (Sanfuentes et al., 2021). Difficulties in collaborative sensemaking leads to improved feelings of frustration and even pointlessness (Mansson et al., 2015). The second variable is whether actors have feelings of frustration or even pointlessness.

Next to that, anxiety operates as an emotional signal which positively impacts sensemaking (Sanfuentes et al., 2021). During a disaster people have the psychological desire to mentally cope with the situation (Mirbabaie and Marx, 2020). Feeling anxiety to the consequences of not dealing properly, results in being highly motivated to make a precise and flawless sense of the situation. However, balance is key. It is important to avoid overconfidence and overcautiousness. Communication about feelings is key in finding this balance (Son et al., 2020a). The third variable is whether actors experience feelings of anxiety.

The seventh concept is feelings. The corresponding variables are: whether there is room available to share emotions, whether actors have feelings of frustration and even pointlessness and whether actors experience anxiety.

11.2.8. Overview of the construct, concepts and variables

This chapter discusses all the different concepts and corresponding variables. In the end it is possible to create an overview about the construct of collaborative sensemaking in disasters. Figure 11.3 shows this overview in the form of a tree consisting of the construct, concepts and corresponding variables.

Construct	Concepts	Variables
Collaborative sensemaking in disasters	Shared information Gathering	Variety of sources Importance of information
	Shared interpreting information	Conflictive information External representations
	Collective Actions	Collective goals defined Awareness actions of others Efficacy actions of others Actionable knowledge
	Shared Leadership	Taking decisions altogether Clarity of role structures
	Conversation quality	Efficacy of information sharing Modality of information sharing Process of information sharing
	Conversation participation	Time needed to first information sharing Amount of interaction All relevant actors together
	Shared feelings	Emotion sharing Frustration Anxiety

Figure 11.3: Tree of construct, concepts and variables

11.2.9. Relation between concepts

The process of collective sensemaking in disasters is a reoccurring process of the constructs of: shared information gathering, shared interpreting information and collective actions. In this order, these three constructs form a cycle process (Paul and Reddy, 2010; Son et al., 2020a). Figure 11.4 shows this cyclic process.

The following example illustrates this cyclic process. Imagine a situation in which a disaster just happened. At that moment, information about the needs of affected people is gathered. From all these information it is interpreted that there is a need for food. The collective action is determined to deliver 1000 kg of rice to the affected people. When delivering this food, new information is gathered and it is interpreted that a less amount of food will suffice and that they also need some clothes. Again new collective actions are determined. This cycle happens again and again during a disaster.

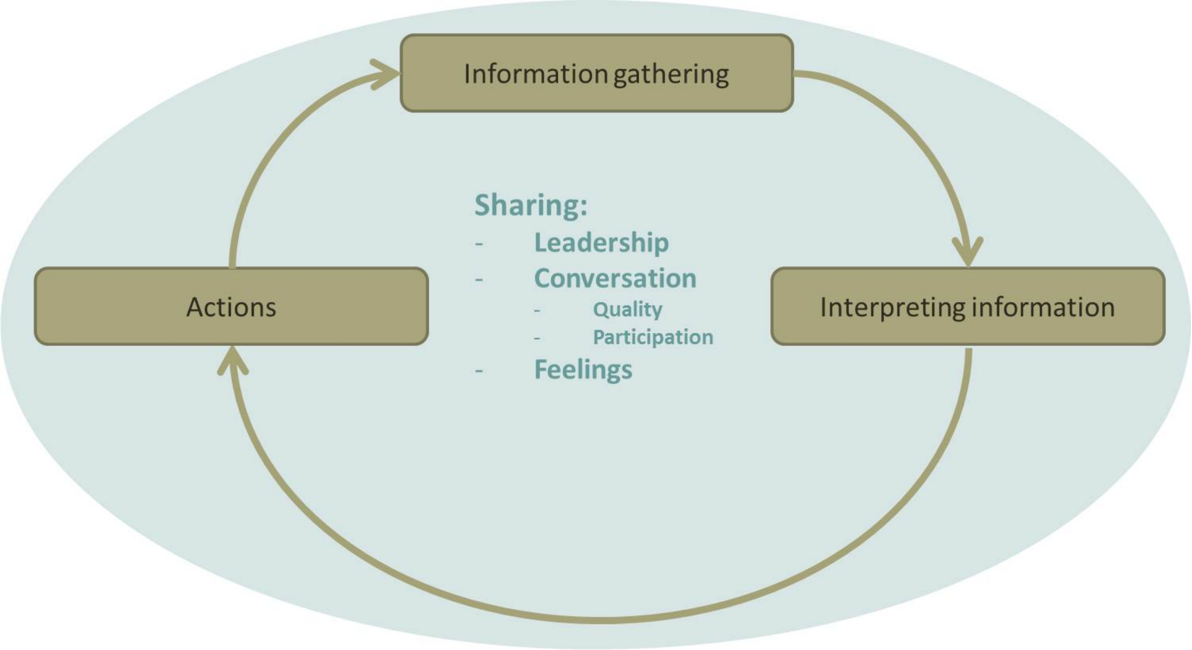


Figure 11.4: Cycle process of collaborative sensemaking in disasters

It is this cycled process which makes it a sensemaking process. It calls for adaption and flexibility. The courses of actions are adapted again and again (Moon et al., 2020; Wolbers and Boersma, 2013). By running through the cycle multiple times, preferences and alternatives are constructed. These alternatives and preferences are added into the interpreting and collective action frame (Comes, 2016a). The unfolding situation is grasped through actions ensuing from its discovery (Gatzweiler and Ronzani, 2019).

After the forming of collective actions it is important to engage with the circumstances in order to gather data (Paul et al., 2008; Stephens et al., 2020). Collective actions are performed in order to gather data. Individual’s actions influences further sensemaking and actions (McMaster et al., 2012). Next to that the cyclic process calls for reflection on goals and actions which improves sensemaking (Sanfuentes et al., 2021).

Note that this cyclic process relates with the theory of social learning. Chapter 4.2.6 describes this process in more detail and shows that social learning takes place when competence is in tension with experience. At the moment that courses of actions are adapted, this is because competence is in tension with experience and thus because of social learning. The actors are learning from each others information and point of view that the course of action need to be adapted. Actors engaging in such kind of activity are finding themselves in a boundary process.

Müller-Seitz and Macpherson (2014) argue that social learning during crisis is a sensemaking process. Sensemaking is an ongoing social interaction to negotiate the meaning of what is interpret. Sensemaking happens trough interactions and actions (Müller-Seitz and Macpherson, 2014). Sensemaking activities always are involved when actors work together during crisis. It is necessary to judge the appropriateness of actions by all different actors (Müller-Seitz and Macpherson, 2014). Since crisis are open and continually unfolding, sensemaking changes over time. This makes sensemaking a cycle between interpreting the crisis and re(acting) upon the crisis (Müller-Seitz and Macpherson, 2014). During crisis, actors need to work together and form a new community of practise. To create this community of practise, participants must coordinate and negotiate their sensemaking. This to form a unified meaning of the situation. This means that the boundary process of creating a new community of practise goes hand in hand with sensemaking (Müller-Seitz and Macpherson, 2014).

Chapter 4.2.6 also describes that a successful boundary process needs to take several factors into account. These are: coordination (interpret actions and objects in different practices in a way that enables coordinated action), transparency (give access to the meanings of actions and objects in different practises) and negotiability (provide a two-way connection between practises to make sure that multiple voices are heard). Note that a shared leadership fosters coordinated action and provides a two-way connection. Conversation quality fosters coordinated action and makes it easy to give access to the meaning of shared actions. Conversation participation helps in providing a two-way connection. Finally shared feelings gives access to the meaning of actions. This means that those concepts of the collaborative sensemaking in disasters constructs are related to social learning. Figure 11.4 shows this social part in the middle of the circle. This sharing components are involved in all steps of the cycle.

Note that the tree of construct, concepts and variables, Figure 11.3, together with the described relation between concepts forms the answer to the fifth research question. This question asks which factors influence a collaborative sensemaking process during disasters. The communication experiment of this research continues by measuring the variables above in two groups. One group which can use the FFM seaport and one group which can not. The experiment simulates a disaster situation and the participants need to make choices which corresponds to choices which need to be made in a real disaster situation. The goal of the experiment is to evaluate how the FFM seaport influences the collaborative sensemaking during disasters. Chapter 12 describes the experiment and the way in which the variables are measured in more detail.

There is a relation between the seven concepts mentioned in this chapter. Information gathering, interpreting of information and collective actions are forming a cycle process. Information gathering leads to interpreting of information which in turn leads to collective actions. After the forming of collective actions it is important to engage with the circumstances in order to gather data and the cycle starts again. This cycle process makes it a sensemaking process.

This cycle process relates with the social learning theory. At the moment that courses of actions are adapted, this is because competence is in tension with experience and thus because of social learning. The actors are learning from each others information and point of view that the course of action needs to be adapted. This means that collaborative sensemaking is related with social learning. Social factors are in that case always present in the cycle of sensemaking. This social factors are the concepts of: shared leadership, conversation quality, conversation participation and shared feelings.

12

Emergency simulation role playing exercise

Research question six asks how it can be evaluated if and how the usage of a FFM seaport influences the collaborative sensemaking process. Chapter 11.2 describes the theoretical framework which explains the concepts and variables involved in the construct of collaborative sensemaking in disasters. The usage of a FFM seaport can be seen as the usage of an intervention in order to foster the collaborative sensemaking process. This chapter describes the experiment created in order to test the effectiveness of the usage of this intervention during a disaster relief effort. Next to that, it identifies which concepts and variables will improve a lot and which less. This information is later used to design the conceptual design of the intervention (the FFM seaport) in such a way that it improves the collaborative sensemaking process.

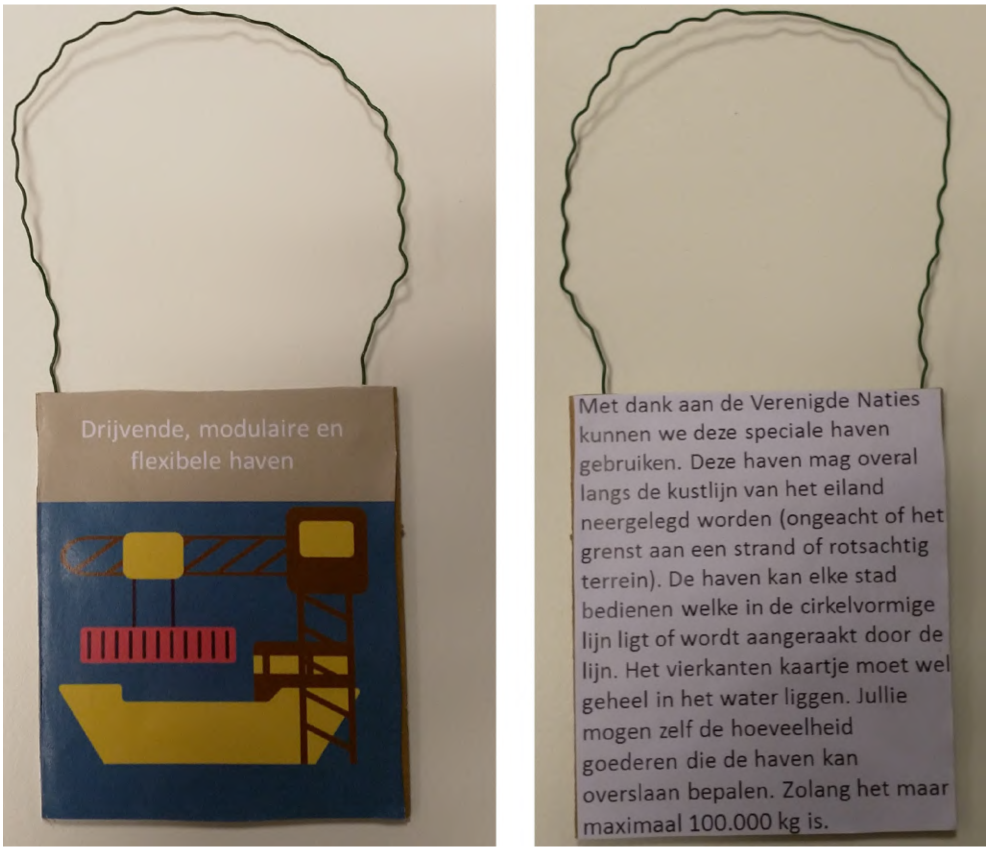
The remainder of this chapter discusses the experiment in detail. First it explains the design of the experiment. After that it describes the way in which the variables are measured.

12.1. Design

The experiment is designed by the author of this thesis. After the theoretical framework the idea of this experiment came to mind naturally. A first version was played once and after that some adjustments were made. This led to the final experiment used in this research. Within the design of the experiment already the necessary variables to measure were taken into account. For example the presence of conflicting information was necessary in order to measure such a variable. Section 12.2 describes how the variables are measured in more detail.

The experiment simulates a disaster relief effort. The participants first got a letter from the president of an affected island. This letter illustrated the current situation. It was told that a destructive disaster affected an island just 24 hours ago and that they are the logistics experts needed to help the affected people as best as possible. They had to create a plan of action for the logistics part of the disaster relief effort. In order to define this plan of action they had a game board which gave an overview of the affected island with the location of the different cities located at the island. Next to that, every participant had a lot of tables full of information. Within the letter they were told that most certainly not all information tables were necessary. The letter stated that the plan of action consist of the amount of goods sent to the affected cities and how these goods must be delivered to these cities with the goal to reduce the suffering the most. The letter also pointed out that there is a fill-in form which must be completed in order to express their plan. In the letter they were told that the goal was to create a plan where the suffering is the least, but that it is also important to define the plan of action as soon as possible. Time is, after all, limited during a disaster relief effort. Next to that, the participants were told that multiple other experts groups were also asked to define a plan of action. The amount of time to define the plan and amount of suffering reduced of these other expert groups is showed on a scoring sheet. Lastly there is told in the letter that the president is very busy and is only able to answer questions for two minutes.

The goal of the experiment is to test the usage of an intervention (the FFM seaport). This results in performing the experiment in control groups (which were not in the possession of the intervention) and in experimental groups (which were in the possession of the intervention). Within the letter for the experimental group there was told that the participants were able to use this intervention. This intervention is the FFM seaport which was represented by a special card. Within the letter the experimental group was told that they first had to read this special card before they start with developing a plan. Of course, the control group was not told about this special intervention. The special card consisted of a square foundation with on top of that a circle which represented the reach, see Figure 12.1. The special card stated that a special FFM seaport was available and could be used to deliver an additional maximum amount of 100,000 kg of goods. It was allowed to place this seaport everywhere around the coastline as long as the square foundation is located completely in the water. The seaport was able to serve every city which is inside the circle or every city which was touched by the circle. The placement of the seaport had to be performed on the game board. Figure 12.2 shows this game board. Figure 12.3 shows an example of a possible placement of the special card on the game board.



Met dank aan de Verenigde Naties kunnen we deze speciale haven gebruiken. Deze haven mag overal langs de kustlijn van het eiland neergelegd worden (ongeacht of het grenst aan een strand of rotsachtig terrein). De haven kan elke stad bedienen welke in de cirkelvormige lijn ligt of wordt aangeraakt door de lijn. Het vierkanten kaartje moet wel geheel in het water liggen. Jullie mogen zelf de hoeveelheid goederen die de haven kan overslaan bepalen. Zolang het maar maximaal 100.000 kg is.

Figure 12.1: The special intervention card. Left is the front side and right the back side of the card

Note that the special intervention card is written in Dutch. The experiment was performed in Dutch and all material was written in Dutch. This because it was easier for the participants to communicate in their native language. Off course, during a real disaster relief effort language barriers are an interesting phenomenon. However, studying this phenomenon is not a goal of this research. Also this experiment needed an observer to observe the groups performing the experiment. For this observer it was also easier to observe when people were communicating in their native language.

Next to the game board and introduction letter, and special intervention card (for the experiment group), also every participant got a lot of information. Tables represented this information. The author of this

Figure 12.2: The game board

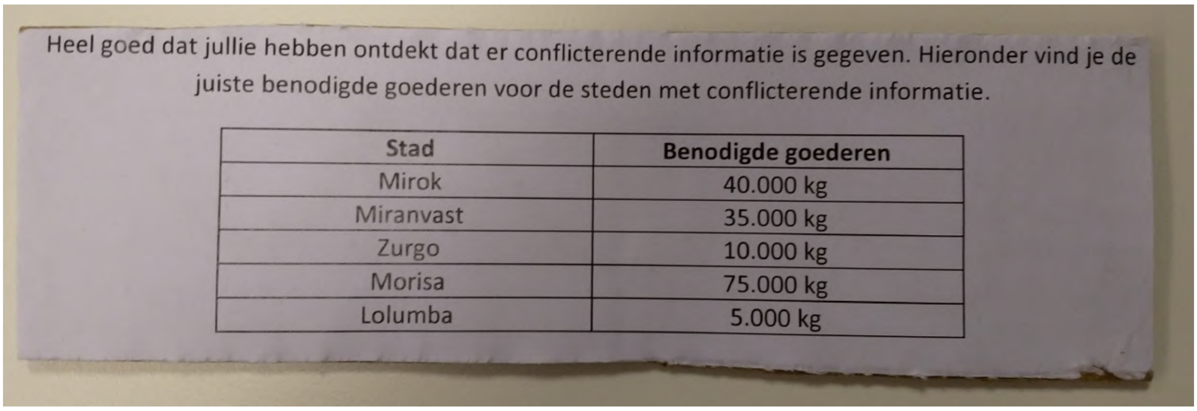
Figure 12.3: The game board with a possible placement of the special card. The cities of Wontak, Anadasia, Landar, Kitumba and Urnul can be served by the FFM seaport in this example

thesis published the tables and introduction letters online (Bakker, 2022). The tables were different for every participant and every participant had information from a certain expertise area. The first one had information about the assessment, the second one about the supply chain and the third one about the logistics status of the island. The underlying goal for the participants was to filter this information and to find the relevant information necessary to define the plan of action. In total there were 40 tables.

The assessment expert had 12 tables, the supply chain expert had 12 tables and the logistics expert had 16 tables. From all this information only two tables from the assessment expert, three tables from the supply chain expert and five tables from the logistics expert were necessary in order to develop a plan of action.

It is good to note that every expert had some information about the amount of goods necessary for a city to be helped. None of the experts had however exactly the same information about these necessary goods. Some experts had information about more or other cities then the other experts. The most important difference is that for some cities the different experts had conflicting information. This means that one expert had for example information that a certain city needs 10,000 kg of goods while another expert had information that the same city needs 20,000 kg of goods. If this conflicting information was detected, a card was presented to the participants which contained the right amount of necessary goods for these particular cities. Figure 12.4 shows this card.

Next to this card, there was some more conflictive information. For example, the assessment expert had some information about the accessibility of the cities which are in need of help and the conditions of the roads. The logistics expert had information which roads are crossing which city. In principle, this means that it was possible to look at the road condition and if this road is crossing a city or not. This information could be compared with the information if a certain city is accessible or not. However, the information about the status of the roads and the accessibility of the cities was filled in randomly and do not directly match. It was possible that a city scores positively on accessibility while the road crossing that city is not in a good state. This is one example, but more conflictive information was presented.



Heel goed dat jullie hebben ontdekt dat er conflicterende informatie is gegeven. Hieronder vind je de juiste benodigde goederen voor de steden met conflicterende informatie.

Stad	Benodigde goederen
Mirok	40.000 kg
Miranvast	35.000 kg
Zurgo	10.000 kg
Morisa	75.000 kg
Lolumba	5.000 kg

Figure 12.4: The card presented when conflicting information was detected about the amount of goods necessary for every city

The necessary amount of goods was thus presented in the information tables of every participant. Next to that, the assessment expert had among other things a table which contain the reduction of suffering when a city will be helped. The supply chain expert had among other things information about the amount of goods which can be delivered by a supplier and the amount of increase of suffering when this supplier will be used. The logistics expert had among other things information about which airports can serve which cities, which seaports can serve which cities, the amount of handling capacities of the airports and the amount of handling capacity of the seaports. On top of these tables the different experts had more information, but this was the only information necessary in order to create a plan of action.

This plan of action had to be filled in with help of the fill-in form. The author of this thesis published additional documents about the emergency simulation role playing exercise online (Bakker, 2022). This documents contain, among other things, this filled-in form. Within the fill-in form the participants had to state which cities they help, the amount of suffering reduced because these cities are helped, the suppliers used to sent the goods to these cities, the amount of goods the suppliers sent to these cities, the amount of suffering increasing because the goods are delivered by this supplier and the airport or seaport used to deliver these goods from this supplier to this cities. There are two rules which were clearly stated on the fill-in form and on the corresponding tables. The first rule was that a city can only be helped completely or not. So in total, the amount of goods delivered to a city had to always be add up to the total amount of goods necessary for that city. Next to that, the increasing of suffering because a certain supplier is used only needs to be increased once. No matter how many goods are delivered by this supplier and which city or which cities are served by this supplier.

The participants together defined the end time of the experiment. If they think their plan is good enough, the experiment was stopped. The score and time were noted on the overall scoring sheet and the results could be compared with the other groups which performed the experiment. To make sure that the participants were aware of the time passed, a stopwatch was lying in the middle of the playing field. Next to that, also extra pens, paper and post its were present. The participants could draw and write everything they think are necessary. Figure 12.5 illustrates the setting in which participants were playing the game.

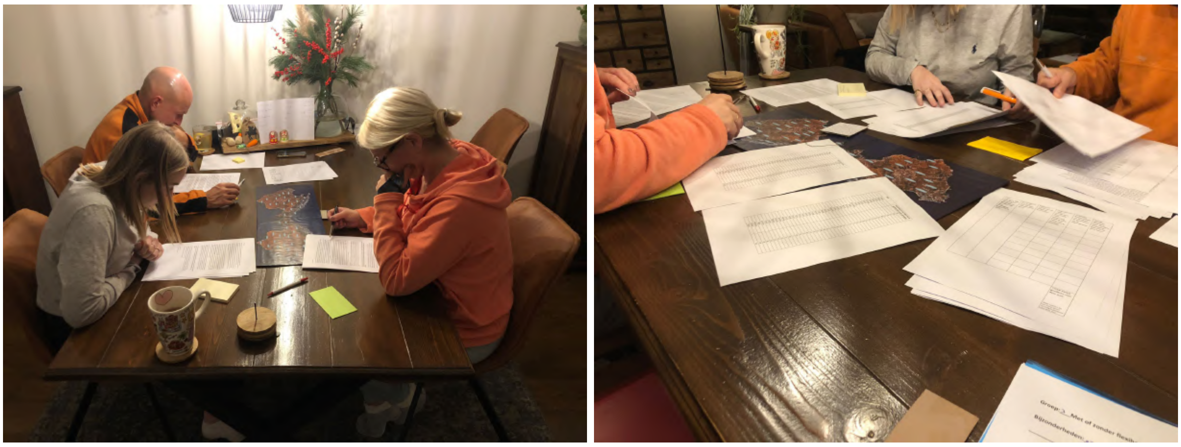


Figure 12.5: Setting in which participants were playing the game. Left illustrates the start of the game where participants were reading the starting letter. The right picture presents the game phase, when participants were making sense of the situation by going through the available information

An experiment is created in order to evaluate how the usage of a FFM seaport influences the collaborative sensemaking process. Within this experiment, groups are asked to define a plan of action in response to a fictive disaster. The groups have to define this plan of action based on a lot of information. Every participant has different information. Within the process of creating a plan of action some groups are given the use of a FFM seaport. These are defined as the experimental groups. The others, the control groups, could not use a FFM seaport. The groups had to define the plan of action as quick as possible and also had to create a plan which reduced the amount of suffering the most.

12.1.1. Evaluation of design

The emergency simulation role playing game needs to create a realistic disaster scenario setting. Son et al. (2020a) describes certain design factors for increasing the realism. This are: (1) risk - the consequences of actions during the experiment, (2) dynamism - situations that will change during the experiment, (3) tempo - how fast these changes occur, (4) stress - gap between current knowledge and available knowledge, (5) information structure - distribution of information among the participants, (6) feedback - current state of the actions, (7) roles - the distribution of multiple different roles among the participants and (8) uncertainty - expected or unexpected events happening. Based on these factors they propose some ideas which increases the realism of the experiment. These are: including time pressure, providing participants with new information during the experiment, increasing the number of events happening during the experiment, increasing the randomness of events and increasing the situational complexity.

This experiment incorporates certain factors and others not. First, there is a certain risk when participants are not creating a good plan of action. When they don't perform well, they score below other groups. Toups et al. (2011) discuss that the threat of failure and as an opposite the possibility of a high score, motivates players and providing meaningful stress which simulates crisis. In this experiment the score of other groups was shown during the experiment. Also scores of non existing groups with a very good score were shown. This all to increase the risk of failure. Second, there is a situation that changed during the experiment. When the participants were identifying the conflicting information they got new information. Third, the tempo about this changes was not taken into account in this experiment. Fourth, there was a gap between the current knowledge and the available knowledge. Especially in the beginning the participants did not know which information they had available and who had what information available. They had to interact with each other to find this information and to make sense about the situation in order to define which information is important and which information is not important. Fifth, not every participant had the same information available. There was a certain distribution of the available information. Sixth, a stopwatch was lying in the middle of the table and thus the participants were constantly aware about the amount of time which was passed by. They were aware about their current score and how they perform compared with the other groups. This means that there was feedback constantly. Seventh, everyone had another type of information available and thus everyone had another role. It was not that one had the form of a leader and another of information collector. The teams were free to define this roles if they found it necessary. Lastly, there was not really a component of uncertainty involved. Off course at the beginning the participants were uncertain about what they need to do and about their understanding of the current situation. Once they developed this understanding there was not a new uncertain event happening which questioned this understanding.

The above shows that most factors are incorporated in the design of the experiment. Only the tempo, the role differentiation and the uncertainty factors are not present like they are present during a real disaster. All five other factors are incorporated in such a way that it increases the realism of the experiment. This concludes that the experiment simulates a real disaster relief situation. Next to that, the experiment have to measure the right variables in order to evaluate if and how the usage of a FFM seaport influences the collaborative sensemaking process. The next section explains the way in which the variables which relates to collaborative sensemaking in disaster are measured.

Emergency simulation games needs to create realistic disaster scenario setting. Certain factors are typical for disaster situations and these factors have to be the same as in a disaster situation. These factors are: risk, dynamism, temp, stress, information structure, feedback, roles and uncertainty. The created emergency simulation role playing exercise mimics all these factors except for the tempo, the role differentiation and the uncertainty.

12.2. Measuring variables

The experiment is designed in such a way that it measured the relevant concepts and variables related to the collaborative sensemaking in disasters construct. Chapter 11 describes how the concepts and variables are found and relates to each other. The analysis shows that the following seven concepts and related variables have to be evaluated in order to say something about the collaborative sensemaking in disasters:

1. Shared information gathering
    (a) Variety of sources
    (b) Importance of information
2. Shared interpreting information
    (a) Conflictive information
    (b) External representations

3. Collective actions
    (a) Collective goals defined
    (b) Awareness actions of others
    (c) Efficacy actions of others
    (d) Actionable knowledge
4. Shared Leadership
    (a) Taking decisions altogether
    (b) Clarity of role structures
5. Conversation quality
    (a) Efficacy of information sharing
    (b) Modality of information sharing
    (c) Process of information sharing
6. Conversation participation
    (a) Time needed to first information sharing
    (b) Amount of interaction
    (c) All relevant actors together
7. Shared feelings
    (a) Emotion sharing
    (b) Frustration
    (c) Anxiety

One of those variables is not measured in this experiment. This is the variable of getting relevant actors together of the conversation participation concept. The experiment starts with everyone necessary already involved within the experiment. It could be that usage of the FFM seaport in real life will help in getting all relevant actors together. This is a recommendation for further research.

The measuring of variables was performed in two different ways. First, during the experiment, an observer observed the participants and wrote down several things which relates to the variables. Second, after the experiment, participants filled in a questionnaire. This questionnaire was a little bit different for the control groups then for the experimental groups. The questionnaire for the experimental group contained some extra questions. These extra questions for the experimental group did not directly relate to the variables. These questions help with integrating the results of this communication experiment with the results of the logistical part of this research. The observer focused on the same factors when observing the control groups as when observing the experimental groups. The author of this thesis published additional documents about the emergency simulation role playing exercise online (Bakker, 2022). These additional documents contain, among other things, the two different questionnaires and the fill-in form for the observer.

The remainder of this section describes the different concepts and the way in which the experiment measured the variables. Next to that, the final subsection explains some other things which are measured in the experiment. This relates not directly to one concept or variable but the result can give additional interesting insights when analyzing the results.

It is important to measure the variables in order to analyse how the experimental groups differ in their collaborative sensemaking process with respect to the control groups. Some variables are measured using a questionnaire. The participants filled in a questionnaire after the experiment. The remaining variables are measured using an observer. This person wrote down notes related to the variables.

12.2.1. Shared information gathering

The first concept is the concept about shared information gathering. The first variable which had to be measured is the knowledge about the variety of sources. This was measured with the first question in the questionnaire. It is asked if the participant knew which information the other participants had available. Note that the design of the experiment was made in such a way that every participant had other information and they are not known beforehand which information the other participants had.

The other related variable with this concept is the knowledge about which information is important and which not. This was measured with the second question in the questionnaire. This question asked if the participant were able to identify if information was important to the group or not. The design of the experiment was made in such a way that not every information given was necessary.

With both questions people were asked if they could indicate if they strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree or strongly disagree with the statement.

12.2.2. Shared interpreting of information

The second concept is about a shared interpreting of information. The first related variable is if the group could identify if their is conflictive information. This was detected by the observer. On the fill-in form it was written down at which timestamps conflictive information was found. Next to that, it was observed if the participants identified the conflicting information about the goods necessary for cities. If so it was written down at which timestamp the card which contain the right amount of goods was handed over to the participants. Note that the experiment was designed in such a way that conflictive information was present.

The second variable is external representations. With respect to that variable, the observer wrote down at which timestamps external representations like shared maps, drawings, notations and/or diagram making was performed. Note that the experiment is designed in such a way that participants were invited to make external representations. Pens and paper were supplied at the beginning of the experiment.

12.2.3. Collective actions

The collective actions concept has four variables. The first variable is collective goals. The related question asks if the participant knew the collective goal. This variable was measured by asking if participants strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree or strongly disagree with the statement. Next to that the questionnaire asks about the exact collective goal according to that participant. It was asked if the collective goal was more related to reaching the quickest time or to reducing the amount of suffering the most. By comparing the answers of participants in the same group it is checked if this collective goal was actually defined and if they are all agreed on the same collective goal. Note that the experiment was designed with the idea that one main goal had to be chosen out of two possibilities: reducing the suffering the most or creating a plan the quickest.

The second variable of the collective actions concept is the awareness of actions of others. The questionnaire asked if participants strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree or strongly disagree with the statement that stated if they were aware about what other group mates were doing. Note that the experiment was designed in such a way that every participant had other information and multiple things had to be sorted out. This results in the idea that everyone could do something else during the experiment.

The third variable is the efficacy of the actions of others. This was measured with the questionnaire. This question again used the agreeing scale as described above to ask if participants agree with the statement that the actions of others were in line with the common goal. Note that this does not had to be the case since the experiment was designed in such a way that different participants could have a different idea about the collective goal.

The last variable of this concept is actionable knowledge. When actionable knowledge is shared, participants immediately need to know what to do. The questionnaire asked if participants knew about which actions others were expecting from them. This is again asked by using a statement and letting participant rank with the same agreeing scale if they agree or not. Since the experiment asked for multiple actions the idea was that participants also would indicate what to do to other participants in order to divide the tasks.

12.2.4. Shared leadership

The fourth concept of shared leadership has two variables. The first variable is about taking decisions together. This variable was measured by the questionnaire. It was asked if participants had the feeling that decisions were made together. Note that the experiment was made in such a way that it was possible to make decisions alone or together.

The second variable is about the clarity of role structures. Also this variable was measured by asking a question in the questionnaire. A question asked if the participants knew their own role in the experiment. Note that the experiment was designed in such a way that everyone had different information and thus everyone had different roles.

Both variables were measured by asking if people agreed or disagreed with the statement. The same raking scale as for measuring the variables of the other concepts was used.

12.2.5. Conversation quality

The fifth concept of conversation quality has three variables. The first variable is about the efficacy of information sharing. The questionnaire asked if participants had the idea that the right information was shared or not. The questionnaire asked if not to much unnecessary information was shared. The second variable is about the modality of information sharing. The questionnaire asked if participants could understand each other quickly when information was shared. Those three questions were again asked by using a statement and letting people agree or disagree with it while using the same scale as for the other variables. The last variable is about the process of information sharing. To create insight into this variable the observer wrote down at which timestamps a participant shared information from his tables to the other participants. Combining these timestamps lead to insights in the involved process.

The experiment was designed in such a way that every participant had different information and thus information had to be shared to define a plan of action. However there was also a lot of unnecessary information and thus it was possible that this information was shared.

12.2.6. Conversation participation

The sixth concept about conversation participation has three variables, but only two of them are measured within this research. The first variable is about the time needed till the first information was shared. This tells something about how quickly someone dared to share information. The second variable is the amount of interaction. Both variables were measured by using the timestamps about when information was shared by the participants which was written down by the observer. The first entry of every participant tells something about the time needed to first information sharing. The amount of timestamps written down tells something about the amount of interaction.

Off course this was not the total amount of interaction. Sharing information is one form of interaction. In this experiment information sharing was necessary in order to fulfil the assignment. Because of that, this sharing information gives a good indication about the amount of interaction. It was not possible to count all interactions with only one observer.

12.2.7. Shared feelings

The last concept is shared feelings. This concept has three variables and all three variables were measured using the questionnaire. In total four statements were used and it was asked if participants agreed or did not agreed with the statements by using the same agreeing scale as with the other concepts. The first variable is emotion sharing and participants were asked if they had the feeling that emotions could be shared during the experiment. The second variable is frustration and participants were asked if they had feelings of frustration during the experiment. Another question asked if they had feelings of pointlessness during the experiment. The last variable is anxiety. The questionnaire asked if the participants had a feeling of anxiety to make the wrong decisions during the experiment.

Note that the design of the experiment included the time pressure by showing the time passed on a stop watch and the time of other groups. Son et al. (2020a) describes that adding time pressure gives participants more or less the same feeling of urgency as during real disasters. The design of the experiment uses this feeling of urgency to influences the participants feelings.

12.2.8. Other measurements

The above sums up every variable. However, the questionnaire and fill-in form for the observer also measured some other things. Two questions of the questionnaire relates to multiple variables. Both questions asked if the participant could fill in which kind of information the other participants had available. The first question for the first other participant and the second question for the second other participant. The answers on these questions tells something about the variety of sources. It tells if people were really aware about which information others had available and if both other participants also reached consensus about the information that the third participant had available. This is possible since the experiment was created in such a way that everyone had different information which was necessary in order to solve the problem.

The experiment was also created in such a way that the role of participants is related to the information they had. This means that the answers on these questions also tells something about the role which participants had in the experiment. This indicates that the answer on these questions also tells something about the clarity of role structures and if indeed everyone agreed on the role that everyone had during the experiment.

Next to measuring these variables, the questionnaire also measured some other things. There were two questions related to integrating the communication and logistics part of this research. These questions were only asked to people which were doing the experiment with the communication intervention. The first question asked how they made a choice about the placement of the FFM seaport. The second question asked which advice they would give to the designer of this FFM seaport.

The fill-in form of the observer contained some room to fill in any remarks the observer had. Also there was some room to wrote down if the experimental group had used the FFM seaport. It is possible that the experimental groups in the end did not used the FFM seaport. Next to that, also two other factors were measured and written down in the fill-in form. These two factors are not directly related to any concept or variable but it tells something about the speed of the collaborative sensemaking in disasters. It is the timestamp at which time the participants asked for help and the time that the participants filled in the score form. This last two factors, together with the overall score (time to create the plan of action and amount of reducing of suffering) is analysed to tell something about the overall quality of the construct.

For every group which played the experiment, the fill in form of the observer and the questionnaires are collectively stored and numbered such that this data can be seen per team. This made it possible to compare the results of the groups which had the communication intervention available and the groups which did not had the intervention available. The difference in the results tells something about the difference in variables and thus in the difference in concepts and the overall construct. This comparison helps in answering research question seven which asks how the factors which improves a collaborative sensemaking process during disasters can be integrated in the conceptual design of a FFM seaport. The results of this comparison identifies these factors and show how they are improved by using such a communication intervention. Chapter 13 gives the results. Note that the description of the experiment and how the variables are measured is the answer on the sixth research question. This question asks how it can be evaluated how the usage of a FFM seaport influences the collaborative sensemaking process.

For every variable, either a question is asked in the questionnaire or notes from observation are written down by the observer. The questionnaire of the experimental groups contained some extra questions. These questions were related to how the group used the FFM seaport and if they had any design tips when the FFM seaport would become a reality. The answer on these questions are asked gain a deeper understanding of choices made by the participants.

13

Results emergency simulation role playing game

To analyse the effect of the communication intervention (the usage of the FFM seaport) the emergency simulation role playing game is played with six groups. Three groups had the possibility to use the communication intervention. They are forming the experimental groups. Three other groups did not had the possibility. They forming the control groups. This chapter presents the most important results of the experiment. Appendix J shows all other results.

The results consist of the filled in questionnaires and the filled in observer forms. This chapter first presents the overall performance of the groups. This overall performance is not related with one concept but it tells something about the overhanging construct of collaborative sensemaking in disasters. After that it shows per concept the most important results corresponding by that concept.

13.1. Overall performance

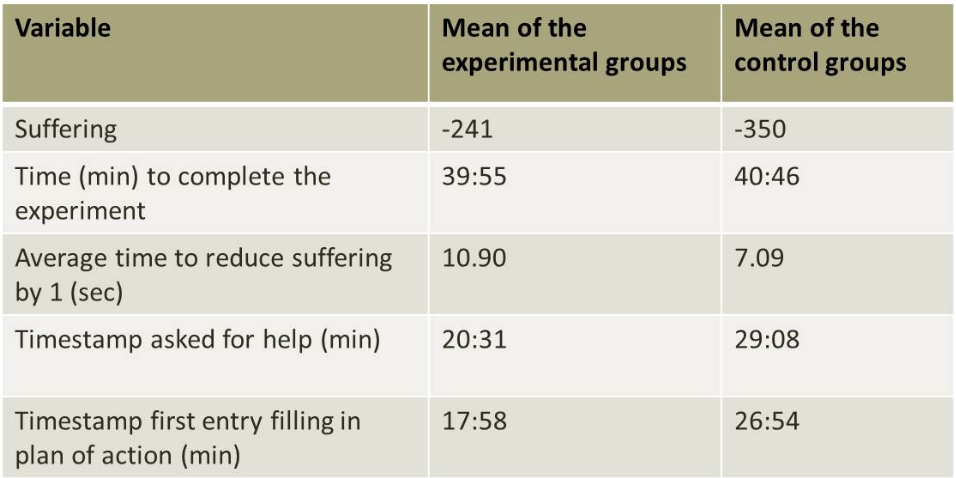
Chapter 12 explains the groups have to make an action plan as quick as possible. They need to define the best possible action plan with respect to the amount of suffering. These two goals are in conflict. It generally takes more time to define a plan which scores good on the suffering part. Table 13.1 shows the average score of the three control groups and the three experimental groups. The lower the suffering score, the better the plan. In that case more people are helped.

Table 13.1 shows that the experimental groups and control groups need on average the same amount of time to come up with their plans. However, the experimental groups define on average plans with a more amount of suffering reduced then the control groups. This means that that the average time to reduce suffering by one point is more in the experimental groups then the control groups.

Table 13.1 also shows that the experimental groups asked on average quicker for help than the control groups. One control group even did not asked help at all. Also the table shows that the experimental groups were quicker with starting to define their action plan. They only needed more time to complete their action plan.

A final note is that the observer wrote down some remarks. An interesting observation is related to the usage of the FFM seaport. Participants in experimental group two had the possibility to use it, but they never did. Another interesting note was the fact that experimental group three was the only group consisting of persons whereby nobody did know each other beforehand. All other groups consisted of three persons which are well familiar with each other. Next to that, one person in experimental group three had to leave a little bit earlier. This means that the final five minutes of the experiment were finished with two players. At that time they already defined a strategy about their plan. The two remaining players only carried out that plan. The sensemaking process was thus more or less finalized. A final remark is about experimental group one. They were very aware of the time pressure. One participant

Table 13.1: The average values over the three experimental groups and the average values over the three control groups for the amount of suffering reduced, the time needed to complete the experiment, the average time to reduce suffering by 1, the timestamp when the groups asked for help and the timestamp at which the groups begin filling in the plan of action.



Variable	Mean of the experimental groups	Mean of the control groups
Suffering	-241	-350
Time (min) to complete the experiment	39:55	40:46
Average time to reduce suffering by 1 (sec)	10.90	7.09
Timestamp asked for help (min)	20:31	29:08
Timestamp first entry filling in plan of action (min)	17:58	26:54

shouted: “Why do I feel that time pressure? It is not like there is an actual disaster happening”.

The goal of this research is to investigate the collaborative sensemaking during disasters. This is investigated by measuring several variables related with that. These variables are clustered in concepts. The results which are showed in Table 13.1 gives some insights in the overall quality of the different groups their collaborative sensemaking process. The remainder of this chapter shows how the different groups performed with respect to the concepts.

Several results give some insights in the overall quality of the collaborative sensemaking process of the different groups. These variables shows that on average the experimental and control groups took the same amount of time to finish the experiment. However the control groups did define on average a better plan with respect to the amount of suffering reduced.

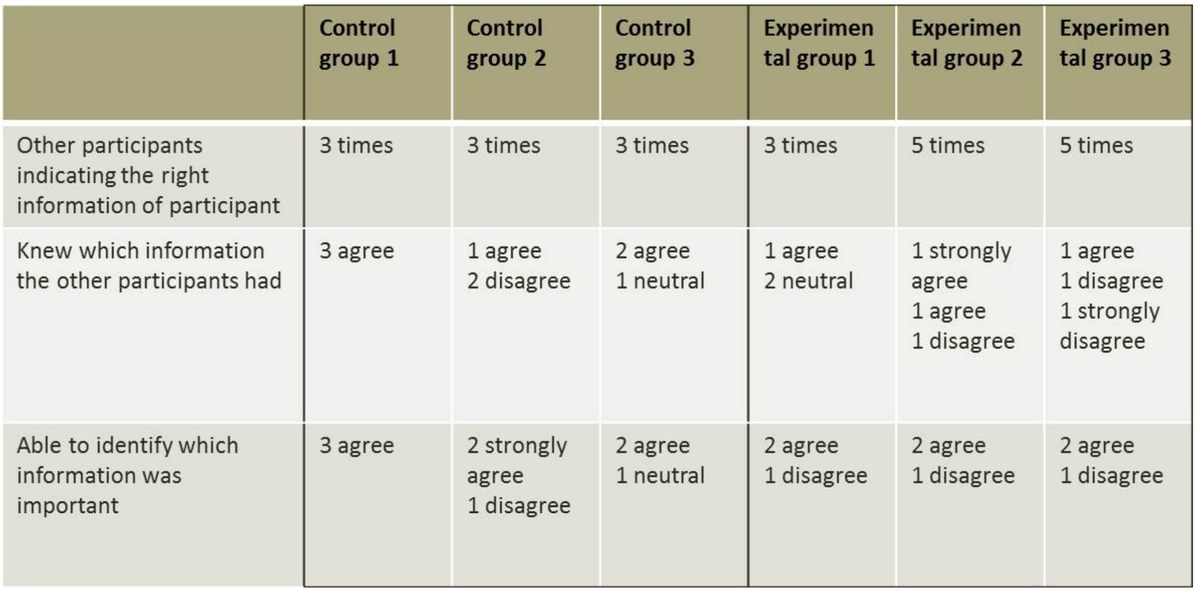
13.2. Shared information gathering

The shared information gathering concept has two variables. The first is the knowledge about the variety of sources. Within the questionnaire it is asked if the persons knew which information the other participants had available. Table 13.2 shows how the different control groups and experimental groups agree with the statement. There is not a remarkable difference between how the experimental groups and the control groups agreeing with that statement.

However, agreeing with this statement don’t have to mean that the participants are also actually aware about the information of others. They only think they know which information the others had available. Therefore, the participants were asked which information they thought the other participants had available. Table 13.2 also shows if the other participants had indicated the right information which a participant had available. It shows that the experimental groups were better aware of the information of other participants.

The second variable is about having the knowledge if information is important or not. Within the questionnaire there is asked if the participants were able to identify if information is important or not. Table 13.2 also shows how participants agree with that statement. It shows that participants within the control groups agreed a little bit more with this statement then participants in the experimental groups.

Table 13.2: The results of the shared information gathering concept. The table shows how the different control groups agree with the statements that they knew which information the others participants had and that they were able to identify the important information. Next to that, the table shows if the other participants had indicated the right role of a participant.



	Control group 1	Control group 2	Control group 3	Experimental group 1	Experimental group 2	Experimental group 3
Other participants indicating the right information of participant	3 times	3 times	3 times	3 times	5 times	5 times
Knew which information the other participants had	3 agree	1 agree 2 disagree	2 agree 1 neutral	1 agree 2 neutral	1 strongly agree 1 agree 1 disagree	1 agree 1 disagree 1 strongly disagree
Able to identify which information was important	3 agree	2 strongly agree 1 disagree	2 agree 1 neutral	2 agree 1 disagree	2 agree 1 disagree	2 agree 1 disagree

Some other remarks related to shared information gathering were observed by the observer. In experimental group two there was someone who did not read the card about the FFM seaport at the beginning of the experiment. The person read it seven minutes after the experiment started. Control group three found after 27:10 min the information which contains the amount of suffering reduced when a certain city is helped. In control group two it took 8:10 min after they found that all participants have different information. Other groups did identify this much quicker.

The shared information gathering concept has two variables. The first variable is the variety of sources. This variable shows that the experimental groups were better aware of the information of other participants while participants from both groups agreed with the same extent to the statement that they knew which information the other participants had. The second variable is having knowledge if information is important or not. Participants within the control groups agreed a little bit more with the statement that they were able to define which information was important and which information not.

13.3. Shared interpreting of information

The shared interpreting of information concept has two variables. The first variable is if a group could identify if there is conflictive information. The observer wrote down the time passed after the beginning of the experiment when the participants identify that information is in conflict with each other. An example of conflictive information was that the amount of affected persons in a city did not always correspondents with the amount of reduced suffering by helping that city. Sometimes a city with a small amount affected persons has a higher amount of reduced suffering then a city with more affected persons. Next to that, there is checked if the participants identify the conflicting information about the amount of goods necessary for a city. The information tables which were handed over to every participant contained one table that all the participant received. Some values in that specific table had a different value over the three participants for exactly the same city. When they noticed that, they would get a card which presents the right information. It was noticed by the observer if they identified this conflictive information and if yes at which timestamp the card with the right information was handed over. Appendix J shows all these timestamps. It is good to know that the timestamps after they found conflictive information and the amount of found conflictive information does not alter significantly between the control groups and the experimental groups.

The second variable is the external representations variable. External representations are for example maps, drawings, notations and diagrams. The observer wrote down at which timestamps these external representations were made. It is interesting to see that the first control group made four external representations. The second control group made two external representations. The third control group made three external representations. The first experimental group made two external representations. The second experimental group made three external representations and the third experimental group made six external representations. This shows that the experimental groups made more external representations then the control groups.

It was remarkable that the control groups made their external representation without using the playing board. This playing board contained an map of the affected islands and the location of cities. Only one group made use of the playing board by sticking post its at the game board. The other external representations were diagrams and tables made without using the playing board. While of the experimental groups more then 50% of all external representations made use of the playing board. Post its sticking to the game board was a popular choice, but also a group drew circles around cities.

The shared interpreting of information concept has two variables. The first variable is whether conflictive information is indicated or not. This does not alter significantly between the experimental and the control groups. The second variable is the creation of external representations. It shows that the experimental groups made more external representations.

13.4. Collective actions

The collective actions concept has four variables. These are measured with questions in the questionnaire. The first variable is asked by letting participants agree with the statement if collective goals are defined. Next to this, it is also asked what participants thought to be the collective goal. If it was developing a plan within the quickest time or developing the plan which reduced the suffering the most. Table 13.3 shows how the experimental groups and control groups agree with the statement and what they thought to be the collective goal. The results show that the control groups agreed to the same extent as the experimental groups with the statement that collective goals were defined. However when asking about the actual goal, every participant in the experimental groups fully agreed that it was reduce suffering. Participants of the control groups differ in their choice between reduce suffering or setting the quickest time.

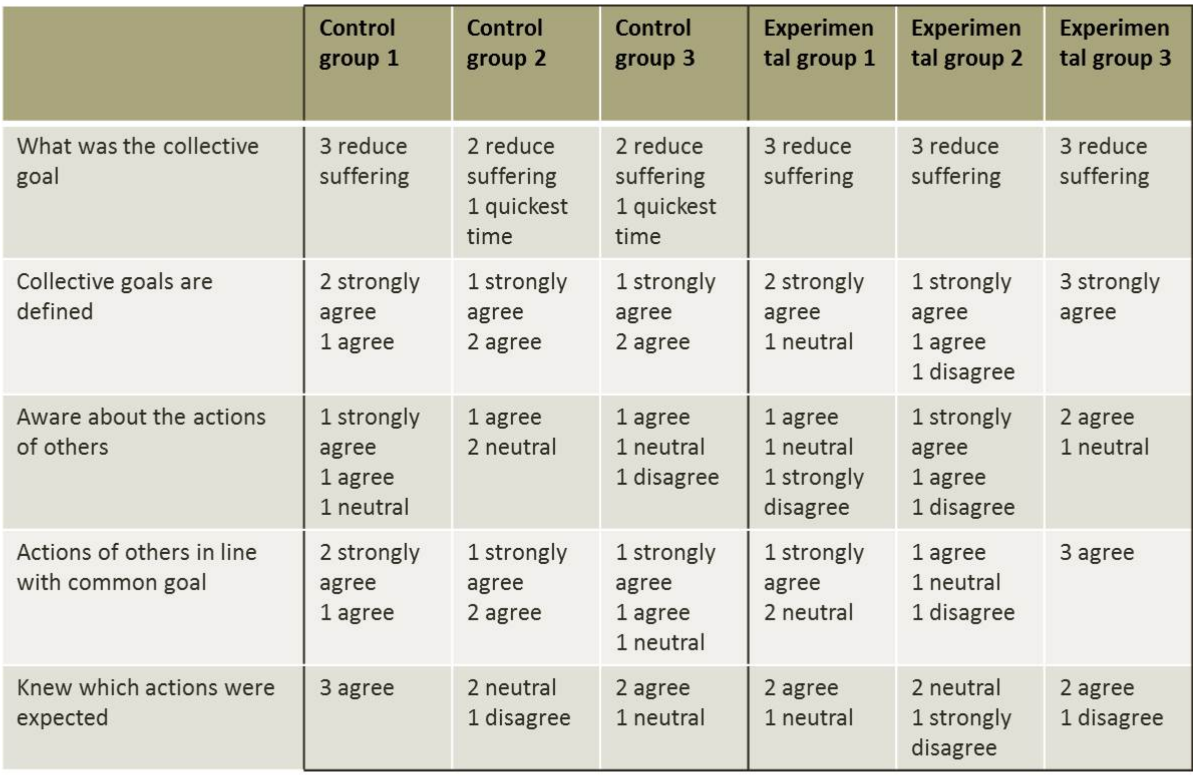
The second variable is the awareness of the actions of others. It was asked with a statement in the questionnaire if people do agree with the statement that they were aware of the actions of others. The results show that participants in the experimental groups and participants in the control groups agree to the same extent with this statement.

The third variable is about the efficacy of the actions of others. It was asked if the participants agree with the statement that the actions of other participants were in line with the common goal. The results show that participants in the control groups agree more with this statement then participants in the experimental groups.

The fourth variable is actionable knowledge. This is a certain knowledge that when it is shared, participants immediately know what they need to do. It was asked if people agree with the statement if participants knew which actions other expecting from them. The results show that the participants in the control groups slightly agree more with this statement then the participants in the experimental groups.

Table 13.3 shows how the participants of the different groups agree with all the statements related to the collective actions concept.

Table 13.3: The extent to which participants agree with the statements related to the collective actions concept. Next to that, it is also indicated what participants thought to be the collective goal.



	Control group 1	Control group 2	Control group 3	Experimental group 1	Experimental group 2	Experimental group 3
What was the collective goal	3 reduce suffering	2 reduce suffering 1 quickest time	2 reduce suffering 1 quickest time	3 reduce suffering	3 reduce suffering	3 reduce suffering
Collective goals are defined	2 strongly agree 1 agree	1 strongly agree 2 agree	1 strongly agree 2 agree	2 strongly agree 1 neutral	1 strongly agree 1 agree 1 disagree	3 strongly agree
Aware about the actions of others	1 strongly agree 1 agree 1 neutral	1 agree 2 neutral	1 agree 1 neutral 1 disagree	1 agree 1 neutral 1 strongly disagree	1 strongly agree 1 agree 1 disagree	2 agree 1 neutral
Actions of others in line with common goal	2 strongly agree 1 agree	1 strongly agree 2 agree	1 strongly agree 1 agree 1 neutral	1 strongly agree 2 neutral	1 agree 1 neutral 1 disagree	3 agree
Knew which actions were expected	3 agree	2 neutral 1 disagree	2 agree 1 neutral	2 agree 1 neutral	2 neutral 1 strongly disagree	2 agree 1 disagree

This section finishes with two remarks about the collective actions. First a remark about control group three. They covered the scoring form with some other white paper and thus could not directly compare their time and score with other groups. They only compared their performance after the experiment. It is possible that this effected the collective action forming process. Second, a remark about control group one. They directly at the beginning of the experiment defined their collective goal and talked a little bit about their strategy.

The collective actions concept consist of four variables. The first variable is whether collective goals are defined or not. The result show that participants in the experimental groups agree with the same extent as participants of the control groups to the statement that collective goals were defined. However when asking about the actual collective goal, every participant in the experimental groups fully agreed that it was reduce suffering. Participants of the control groups differ in their choice between reduce suffering or setting the quickest time. The second variable is awareness of the action of others. This variable does not alter between the experimental and control groups. The third variable is the efficacy of the action of others. It shows that the control groups agree slightly more with the statement that actions of the other are in line with the common goal. The fourth variable is actionable knowledge. Participants in the control groups agree slightly more with the statement that they knew which actions were expected from them.

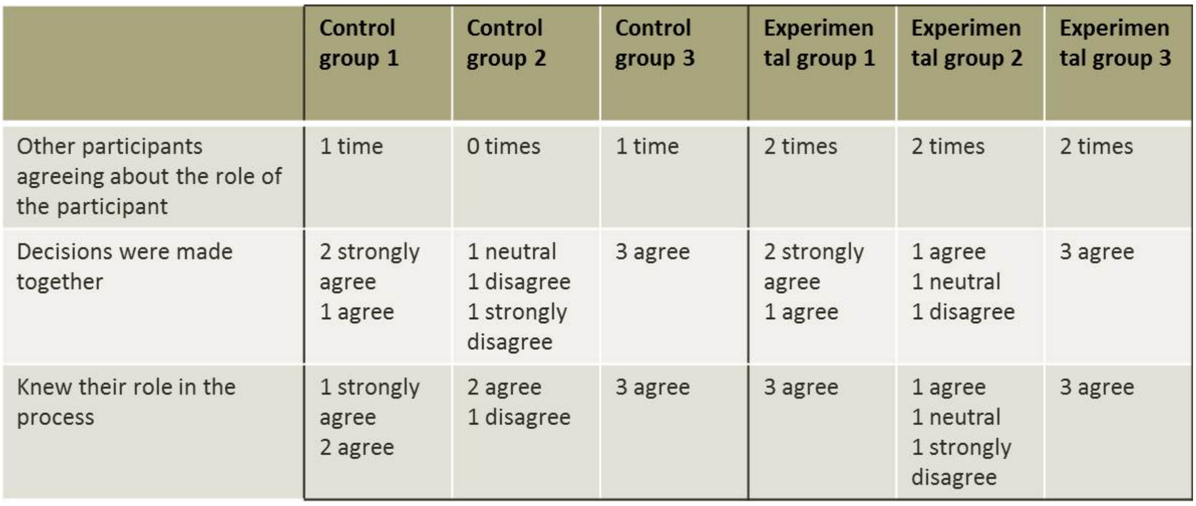
13.5. Shared leadership

The shared leadership concept has two variables. The first variable is about taking decisions together. The questionnaire asked if participants agree with the statement that they had the feeling that decisions were made together. Table 13.4 indicates how the participant agree with the statements. The results show that the participants within the experimental groups slightly more agree with this statement.

The second variable is about the clarity of role structures. The questionnaire asked if people agree with the statement that they knew their role in the process. Table 13.4 indicates how the participant agree with the statements. The results show that participants within the control groups slightly agree more with this statement.

Next to letting participants stating how much they agree with the statement about if they knew their role in the process, it was also asked from the participants what they believe was the role of others within the group. This also tells something about the clarity of role structures. It tells if the participants agreeing on the role that everyone had during the experiment. There was asked from all participant to describe the role of the other two participants. Table 13.4 indicates also how often the other participants agree about the role of a participant. The table shows that the participants in the experimental groups agreed more about the role of the other participants.

Table 13.4: The extent to which participants agree with the statements related to the shared leadership concept. Next to that, it is also indicated how often the other participants from a group, agree about the role of a participant.



	Control group 1	**Control group 2**	**Control group 3**	**Experimental group 1**	**Experimental group 2**	**Experimental group 3**
Other participants agreeing about the role of the participant	1 time	0 times	1 time	2 times	2 times	2 times
Decisions were made together	2 strongly agree 1 agree	1 neutral 1 disagree 1 strongly disagree	3 agree	2 strongly agree 1 agree	1 agree 1 neutral 1 disagree	3 agree
Knew their role in the process	1 strongly agree 2 agree	2 agree 1 disagree	3 agree	3 agree	1 agree 1 neutral 1 strongly disagree	3 agree

The shared leadership concept consist of two variables. The first variable is taking decisions together. The result show that participants in the experimental groups agree slightly more when asked if decision were made together. The second variable is clarity of role structure. The questionnaire asked if participants agree with the statement that they knew their role in the process. Participants within the control groups slightly agree more with this statement. However, the questionnaire also asked to describe the role of the other participants. The results show that participants in the experimental groups had more conformity when describing the role of others then participants in the control groups.

13.6. Conversation quality

The concept of conversation quality has three variables. The first variable is about the efficacy of information sharing. This relates in this research to sharing the right information without sharing to much information. Within the questionnaire it was asked if participants had the idea that the right information was shared. Next to this question, it was also asked if participants had the idea that not to much information was shared. Table 13.5 shows how the participant agree with those statements. The results show that participants of the control groups agreed more with both statements then participants of the experimental groups.

The next variable is about the modality of information sharing. The questionnaire asked if participants agree with the statement that they could understand the others quickly when they shared information.

Table 13.5 shows how the participant agree with those statements. The results show that participants of the control groups agreed more with the statement then participants of the experimental groups.

Table 13.5: The extent to which participants agree with the statements related to the conversation quality concept.

	Control group 1	**Control group 2**	**Control group 3**	**Experimental group 1**	**Experimental group 2**	**Experimental group 3**
The right information was shared	2 strongly agree 1 agree	1 agree 2 neutral	2 agree 1 neutral	1 agree 2 neutral	1 agree 2 neutral	1 agree 2 neutral
Not to much information was shared	2 agree 1 neutral	1 agree 2 disagree	1 agree 2 disagree	1 agree 2 disagree	1 strongly agree 2 strongly disagree	2 neutral 1 strongly disagree
Could understand the others quickly	3 strongly agree	1 strongly agree 1 neutral 1 disagree	2 agree 1 neutral	2 agree 1 disagree	1 agree 1 neutral 1 strongly disagree	3 agree

The third variable is the process of information sharing. The observer wrote down at which timestamps a participant shared information from his or her table to the other participants. These timestamps are put in a chart. Figure 13.1 shows the chart for the control groups. Figure 13.2 shows the chart for the experimental groups. The figures show that the experimental groups shared more information at the beginning minutes of the experiment then the experimental groups.

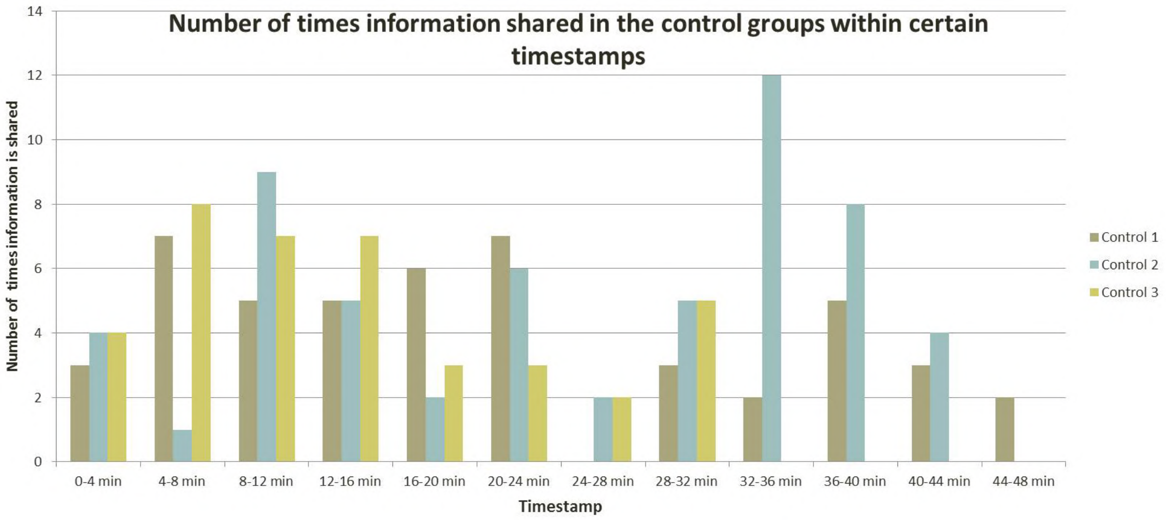


Figure 13.1: The amount of times information is shared in the control groups within certain timestamps

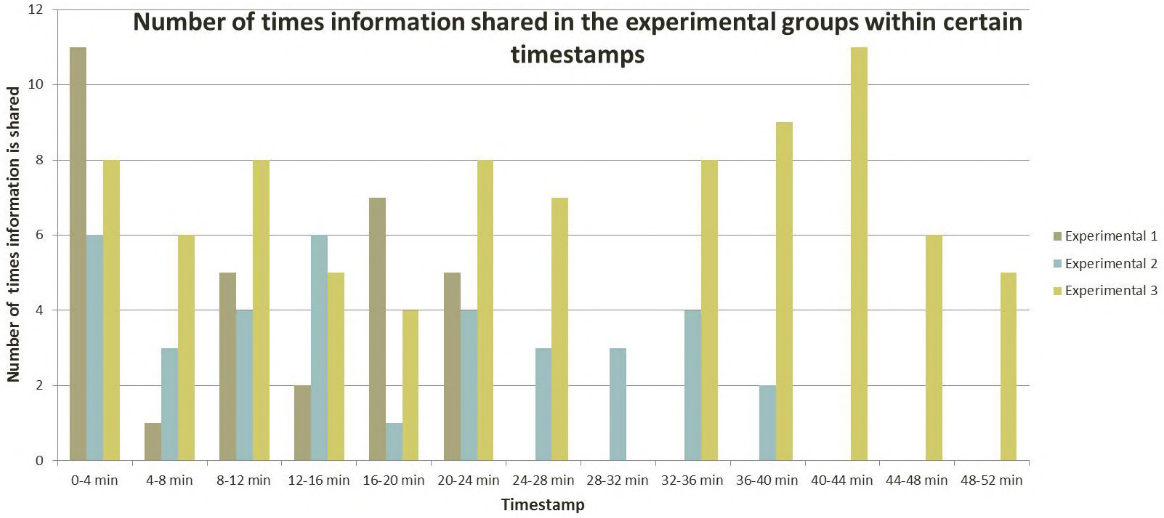


Figure 13.2: The amount of times information is shared in the experimental groups within certain timestamps

The conversation quality concept consist of three variables. The first variable is efficacy of information sharing. This relates to sharing the right information without sharing to much information. Participants in the control groups rate their efficacy of information sharing better then participants in the experimental group. The second variable is modality of information sharing. Participants of the control groups agreed more with the statement that they could understand the others quickly. The third variable is the process of information sharing. This process shows that the participants of the experimental groups shared more information at the beginning of the experiment then the participants of the control groups.

13.7. Conversation participation

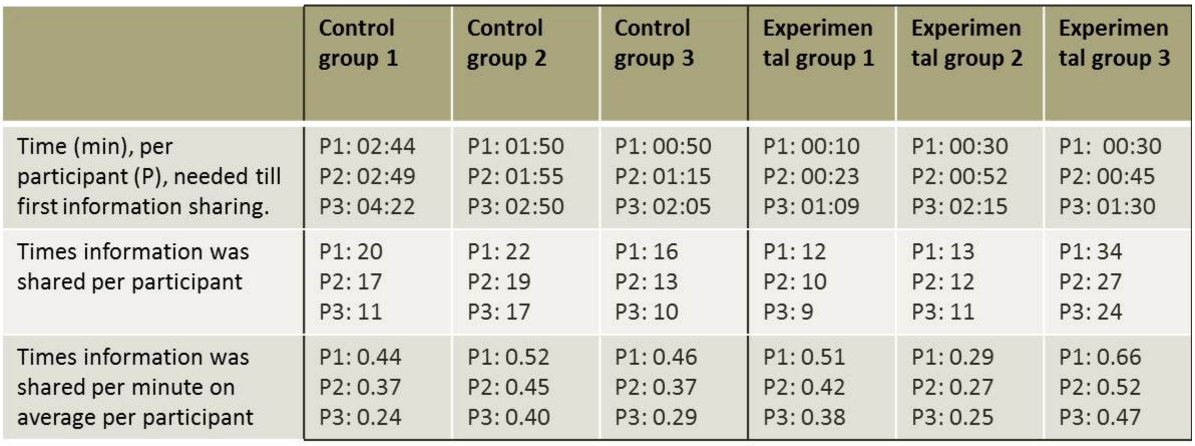
The conversation participation concept consist of three variables whereby two variables are measured in this research. The first variable is about the time needed till the first information sharing. The observer measured this by writing down the first time that information was shared. This shows that the participants in the experimental group quicker started with information sharing.

The other variable is the amount of interaction. The observer wrote down the timestamps when information was shared. Summing these timestamps gives the amount of times a participant had shared information during the experiment. This amount of interaction is normally higher for groups which had a long playing time in comparison with groups with a low playing time. In order to compare all groups, the time is also divided in the amount of time information was shared on average per minute. The results shows that the average amount of information sharing per minute did not differ between participants in the control groups and participants in the experimental groups.

It is good to note that participant three in experimental group three had to leave earlier. The other two players in experimental group three continued playing the experiment when this person leaved. Table 13.6 gives an overview about how the different groups performed with respect to these variables.

The conversation participation concept consist of two variables. The first variable is the time needed till the first information sharing. This time is less for participants of the experimental groups than for participants of the control groups. The second variable is amount of interaction. The results show that there is not a big difference about the amount of interaction between the participants in the experimental groups and participants in the control groups.

Table 13.6: Overview of the results of the conversation participation concepts



	Control group 1	Control group 2	Control group 3	Experimental group 1	Experimental group 2	Experimental group 3
Time (min), per participant (P), needed till first information sharing.	P1: 02:44 P2: 02:49 P3: 04:22	P1: 01:50 P2: 01:55 P3: 02:50	P1: 00:50 P2: 01:15 P3: 02:05	P1: 00:10 P2: 00:23 P3: 01:09	P1: 00:30 P2: 00:52 P3: 02:15	P1: 00:30 P2: 00:45 P3: 01:30
Times information was shared per participant	P1: 20 P2: 17 P3: 11	P1: 22 P2: 19 P3: 17	P1: 16 P2: 13 P3: 10	P1: 12 P2: 10 P3: 9	P1: 13 P2: 12 P3: 11	P1: 34 P2: 27 P3: 24
Times information was shared per minute on average per participant	P1: 0.44 P2: 0.37 P3: 0.24	P1: 0.52 P2: 0.45 P3: 0.40	P1: 0.46 P2: 0.37 P3: 0.29	P1: 0.51 P2: 0.42 P3: 0.38	P1: 0.29 P2: 0.27 P3: 0.25	P1: 0.66 P2: 0.52 P3: 0.47

13.8. Shared feelings

The last concept is shared feelings. The concept has three variables. The first variable is emotion sharing. Participants were asked if they agree with the statement that emotions could be shared during the process. The results show that participants in the experimental groups thought they were more able to share emotions then participants in the control groups.

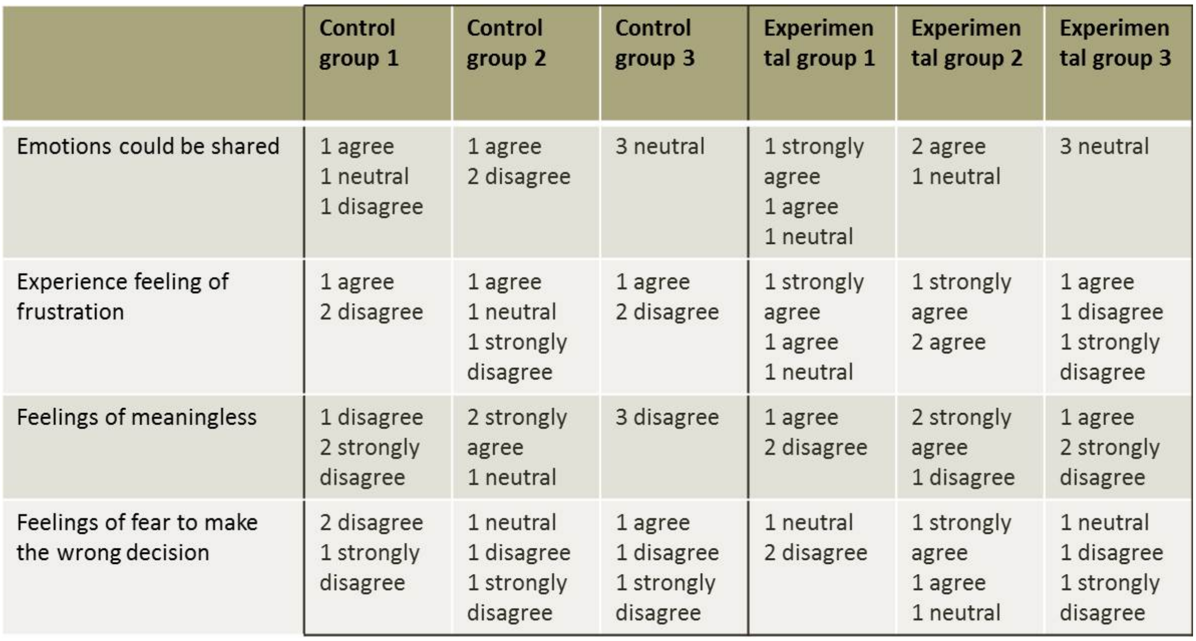
The next variable is frustration. The participants were asked if they agree with the statement that they had feelings of frustration during the experiment. Next to that, the participants were asked if they agreed with the statement that they felt meaninglessness. Feeling of meaninglessness also indicates frustration. The results show that participants in the experimental groups felt more frustration then the participants in the control groups.

The final variable is anxiety. It was asked if participants agree with the statement that they had feelings of fear to make the wrong decision. The results show that participants in the experimental groups had more fear to make the wrong decision then participants in the control groups.

Table 13.7 gives an overview of how the different groups agree with the statements.

The shared feelings concept consist of three variables. The first variable is emotion sharing. The results show that participants in the experimental groups thought they were more able to share emotions than participants in the control groups. The next variable is frustration. The results show that participants in the experimental groups felt more frustration then the participants in the control groups. The final variable is anxiety The results show that participants in the experimental groups had more fear to make the wrong decision then participants in the control groups.

Table 13.7: The extent to which participants agree with the statements related to the shared feelings concept.



	Control group 1	Control group 2	Control group 3	Experimental group 1	Experimental group 2	Experimental group 3
Emotions could be shared	1 agree 1 neutral 1 disagree	1 agree 2 disagree	3 neutral	1 strongly agree 1 agree 1 neutral	2 agree 1 neutral	3 neutral
Experience feeling of frustration	1 agree 2 disagree	1 agree 1 neutral 1 strongly disagree	1 agree 2 disagree	1 strongly agree 1 agree 1 neutral	1 strongly agree 2 agree	1 agree 1 disagree 1 strongly disagree
Feelings of meaningless	1 disagree 2 strongly disagree	2 strongly agree 1 neutral	3 disagree	1 agree 2 disagree	2 strongly agree 1 disagree	1 agree 2 strongly disagree
Feelings of fear to make the wrong decision	2 disagree 1 strongly disagree	1 neutral 1 disagree 1 strongly disagree	1 agree 1 disagree 1 strongly disagree	1 neutral 2 disagree	1 strongly agree 1 agree 1 neutral	1 neutral 1 disagree 1 strongly disagree

13.9. Integrating logistics within the emergency simulation role playing

The three experimental groups were able to use a FFM seaport during the experiment. They had the possibility to choice where to place the seaport. On top of that they were, between certain bounds, free to choice how many goods handled from the sea to the land with the help of this seaport. This situation is a simplification of how the real decision makers use the seaport. The way in which the experiment participants made decisions about the seaport gives some insights in the process of using the FFM seaport. This leads to some tips on how to use the seaport in real situations. To create these insights two questions were asked in the questionnaire for the experimental groups. Every participant was asked to describe how they made the decision about the location of usage and the size of this FFM seaport. This gives some interesting answers.

Experimental group one and three made the decision to place the seaport at the first city which had a high need and did not had a sea or airport. For them, the FFM seaport was a way to reach inaccessible areas. This observation is in line with the research focus on islands. Islands are inaccessible areas after a disaster.

The other question was if participant could indicate their focus points for the designer of such a FFM seaport. The things to take into account when this seaport will actually be designed. Many answers were related by increasing the size and the reach of the seaport. This makes sense since within the experiment the reach of the FFM seaport was limited to cities nearby. Another interesting answer was to incorporate flexibility with the seaport. So that it is possible to move the seaport during the disaster relief effort. This is an interesting advantage of such a seaport and something which is possible in real life. The assembly and disassembly time of the seaport is important in that case.

The above answers focuses on the logistical, physical process. However, two participants also state some tips which are more in line with the communicative part of this research. One participant state that it have to directly be clear on for what the seaport can be used. The different actors which will use the seaport in reality have to directly see the opportunity for such a seaport. They have to directly be sure on how and for what instances the seaport can be used. Training of these actors on the usage of this seaport is important. In that way they gain beforehand some experience. Another remark was that clarity about the exact capacity and exact placing locations of the FFM seaport could help. This reduces the amount of choices that have to be made during the relief effort itself. It seems like the more choices have to be made, the more stress. This means that it can be of great help to determine upfront some interesting locations for every island at which the seaport could be placed during a disaster. Together with creating some guidelines about how big the seaport must be after certain disaster of after a certain amount of people which are affected on a certain island.

This concludes the important result of the emergency simulation role playing game. These results leads to the factors which improves a collaborative sensemaking process during disasters. Chapter 14 describes these factors in more detail. After that this research integrates these factors in the conceptual design in order to meet the final goal of this research: to create the conceptual design which enables such a FFM seaport to reach its full potential to help during humanitarian logistics.

14

Evaluation of the results of the emergency simulation role playing game

The previous chapter shows the results of the emergency simulation role playing game for the experimental groups and the control groups. The next step is to evaluate these results and take a look at what the results mean. This chapter compares the results of both groups. The experimental group had the FFM seaport available, while the control group did not. The results gives some insights and shows how the usage of the FFM seaport influence the collaborative sensemaking process during disasters.

The first insight is related with an increased complexity. This chapter first describes that insight. The second insight which is described by this chapter is the direct start of information sharing. The third insight are the consequences of direct information sharing. The final insight which this chapter describes is the relation between those insights.

14.1. Increased complexity

The first insight is the difference in performance of the control and the experimental group. Within the experiment groups are asked to define the best plan of action in a short amount of time. The best plan of action is a plan which reduced the suffering the most. The overall performance of the collaborative sensemaking during disasters construct is measured by looking at the time to complete the experiment and the quality of this created plan. This shows that the control groups performed slightly better. The average time to reduce suffering by one is almost two seconds quicker in the control group than in the experimental group.

During the experiment the different groups were allowed to asks for help once. The noted time which contain time passed after the participants asked for help shows that the experimental groups quicker asked for help then the control groups. Next to that, participants in the control group did quicker start with filling in the final fill in form which contain their action plan. It took also more time to finalize this fill in form when compared with the control group. Participants within the control group started later with filling in their action plan, but also finished the fill in process quicker.

A hypothesis which explains this difference between the experimental groups and the control groups is that the more complex the task, the more time it takes to finish the assignment and the harder it is to come up with a plan. Since the task is more complex, participants also ask quicker for help. The hypothesis is supported by the suggestions made by participants of the experimental groups. They were asked to make suggestions to the designers if the FFM seaport will be realised. Their suggestions were about reducing the amount of complexity upfront. They suggest to directly make clear for what the seaport can be used, the exact capacity and the exact place of interest. The amount of choices to be make are reduced. Less choices have to be made which reduced the complexity.

The shared interpreting concept also shows the increase in complexity. It shows that the experimental groups made more external representations, like diagrams, drawing and tables. On top of that the experimental groups also started quicker making these external representations. (Kirsh, 2009) concludes that more external representations are made when tasks become more complex.

Also the conversation quality concept shows that the participants got the feeling that the tasks became more complex when they could use the FFM seaport. The results show that less participant agree with the statement that the participant could understand the other participants quickly. This is one of the variables of the conversation quality concept.

The increased complexity had also an influence on the shared feelings concept. The variable of feeling of frustration shows that the experimental group had more frustration then the control group. It is possible that this increased frustration is coming from a worse sensemaking process. However, when looking at other variables from other concepts it did not show that the experimental group had a worse sensemaking then the control group. Next to that, Olsson et al. (2011) concludes that increased complexity leads to more frustration. This leads to the conclusion that due to increased complexity participant had more feelings of frustration. On top of that, the feeling of fear to make the wrong decisions was more present within participants of the experimental group then participants of the control group. Dörner (1980) concludes that this feeling indeed is increased by an increased complexity.

Chapter 11.2.9 describes that the collaborative sensemaking in disasters is a social learning process. It is interesting to couple this social learning process with complexity. Garmendia and Stagl (2010) concludes that in order to deal with complexity, actors uses social learning. In this research collaborative sensemaking can be seen as part of that social learning. However, complexity also effects the involved actors individual psychological learning process. Feldman (2003) concludes that simplicity plays a central role in individual learning. The more complex the more different to learn. Learning involves the extraction and simplification from examples. So this means that balance is important. One can say that adding complexity with holding simplicity is the way to go.

When evaluating the results it seen that the overall performance of the control group is slightly better than the experimental group. A second observation is regarding the opportunity to ask for help during the experiment once. The experimental groups were quicker to ask for help than the control groups. The hypothesis for this experiment is that the usage of the FFM seaport increases the complexity of the tasks which has to be performed. This increased in complexity leads to less overall performance. This hypothesis is backed up by, among other things, the fact that (1) the experimental group made more external representations, (2) within the experimental groups less participants agreed with the statement that the participants could understand each other quickly and (3) by the fact that participants within the experimental group felt more frustration and fear to make the wrong decision.

14.2. Direct information sharing

It is interesting to analyse how the participant deal with this increased complexity. One of the variables of the conversation quality concept is the process of information sharing. This variable shows that within the experimental groups, the sharing of information is more concentrated at the beginning of the experiment. Almost every experimental group shared the most information within the first four minutes. For the control groups the timestamp in which the most information was shared is later. For all groups, both the experimental as control groups, the results shows that the process of sharing information follows a wave. Much information sharing is followed up by less information sharing which again is followed up by more information sharing. However, the control groups are at the lowest point of the wave at the start of the experiment. The experimental groups, on the other hand, are at the highest point of the wave at the start of the experiment.

The conversation participation concept contains a variable which measures the time needed till first information sharing. This variable shows that the amount of time needed till the first information was shared is also less for the experimental group then for the control group. Next to that, the conversation participation concept contains also a variable which measures the amount of information sharing per participant. This variable shows that the amount of information sharing between the different participant within the experimental group is less distributed then in the control group. The participation of participant is more equal within the experimental group then in the control group. Note however, that there is a big difference in amount of information sharing between person one and person three within the experimental group three. This is partly because person three had to leave earlier and thus could also share less information. Next to that, it is interesting to notice that the total amount that information was shared over all participants is almost the same for both the control groups and the experimental groups.

The results show that participants in the experimental groups were more quick to start with information sharing than participants in the control groups. They also shared more information at the start of the experiment. On top of that, the amount of information sharing between different participants within the experimental group was less distributed then in the control group.

14.3. Consequences of direct information sharing

This sharing of information within the first few minutes directly had certainly an impact on other things. For example, the results of the shared feelings concept showed that the participants of the experimental group agreed more on the statement that emotions could be shared than the participants in the control group. This implicates that sharing a lot of information in the first minutes lead to an environment in which emotions are shared quicker. The participants quicker build a familiar environment.

The shared leadership concept has two variables: taking decisions together and clarity of role structures. The results show that participants from both groups agree with the same extent that decisions ware made together and that the participants knew their role in the process. However, zooming in on the roles by investigating how the participants did answer on the question about which role the other participant had, shows something interesting. It shows that the other two participants did not agree on the role of the third participant within the control group as much as in the experimental group. This means that in the experimental group the participants agree more about the role that everyone had then within the control group. It is good possible that this is because participants were more informed about which information the other participants had.

The results of the information gathering concept shows some interesting things. This concept has two variables: importance of information and variety of sources. The results show that the participants of both groups agree that they were able to identify which information was important. The control group agrees a little bit more. The results show that the participants in the control group and the experimental group did agree within the same extent to the statement related with the variety of sources variable. However, to measure the variety of sources variable the participants were also asked to describe the role of the other participants in the group. This shows something remarkable. It shows that the experimental group is much better aware of the role and information that other participants had available then the control group.

It is possible to explain why the control group agreed a little bit more to the statement that they were able to identify which information was important while they actually were less able to identify the correct information. Since the different groups saw the scores of the other groups, the groups were able to compare their score with others. Normally the score of the control groups were a little bit better then the experimental groups. Overall seen this leads to the control groups being more satisfied with their performance. Since they were more satisfied with their performance they are most likely agreeing more with statements which implies that the participants performed well. This process of linking positive performance to their own attributes is called the self-serving bias (Shepperd et al., 2008). However, participants in the experimental groups were in fact more aware of the information of the other participants than participants in the control groups. This can be because of two reasons. First because the information sharing between participants was more unified distributed over all participants. This results in participants know more about the information of others. Second, it shows that the information shared directly at the beginning is remembered more. Participants were more listening to each other at the beginning of the experiment and due to that participants were better aware of the information of others.

The direct information sharing is also the reason why there is a difference in the results of the collective actions concept. This concept has four variables: awareness of the actions of others, collective goals defined, efficacy of the actions of others and actionable knowledge created or not. Participants of both the control groups as the experimental groups were somewhat neutral about their feeling that they were aware of the action of others and about the statement related to the actionable knowledge variable. Next to that, both the experimental groups as the control groups were agreeing to the same extent on the fact that collective goals were defined. However, the collective goals variable shows that all participant in every experimental group agree with the fact that the reducing of suffering was the main goal. In the control group there was some disagreement on the exact collective goal. The hypothesis is that this difference is also due to the fact that participants shared more information at the beginning of the experiment within the experimental group and that within the experiment group the amount of times that information was shared is more uniformly distributed over all participants. This leads to a more uniform goal setting process.

There are two last consequences of the fact that the experimental group did communicate more in the beginning, shared more information at the beginning and had a more equal distributed information sharing process. Participants of the control group agreed more with the statement that not too much information was shared than participants within the experimental groups. Maybe as a consequence of that the control groups also agree more on the statement that the right information was shared when compared to the control group. Both statements relate with the efficacy of information sharing variable of the conversation quality concept. The hypothesis is that starting earlier with information sharing increases the feeling of an overflow of information and of the feeling that not direct the right information was shared.

The quicker start of sharing of information, the larger the sharing of information within the start of the experiment and the more equally distributed participation of the participants. In the experimental group this lead to several positive factors being more present. These are: more emotions shared, more awareness of the role of others, more awareness of the information of others and more agreement on the common goal. However, there is also a negative consequence. Starting earlier with information sharing increased the feeling of an overflow of information and of the feeling of not sharing the right information directly.

14.4. Relation between insights

So what is happening. The hypothesis is that using a FFM seaport increases the complexity of the situation. Due to this increased complexity the different experimental groups did not score as good as the control groups. This increased complexity leads to more and quicker created external representations and an increase of the feeling of frustration and the feeling of fear to make the wrong decision. The increased complexity leads to quicker sharing of information, more information sharing in the beginning of the process and a more equally distributed participation of all participants in the process. This leads to more emotions being shared, more awareness of the roles and information of others and a more settled common goal. In the end the increase of the above leads to a better collectively sensemaking process within the experimental groups then in the control groups.

This better collective sensemaking process is backed up by the social learning theory. Chapter 11.2.9 describes that shared leadership, conversation quality, conversation participation and shared feelings are necessary in order to foster the social learning process and that an improved social learning process leads to an improved collaborative sensemaking during disasters process. The results of the experiment show that there was more room to share feelings within the experimental group. The results of the conversation participation and conversation quality concepts show that the experimental group started quicker with a more intensive conversation. The results of the shared leadership concept shows that participants agreed more about the role of other participants. It looks like indeed the usage of the FFM seaport fosters the social learning process which fosters the collaborative sensemaking process.

However, this increased complexity does also negatively affects some other things not related with the actual collaborative sensemaking process during disasters itself. The participants of the control groups rate their collective sensemaking process better then participants in the experimental group. The experimental group had an increased perception of a bad collective sensemaking during a disaster process. The fact that this own perception was better within the participants of the control group can be because they were influenced by the self-serving bias (Shepperd et al., 2008). Another explanations could be that things became complex for the experimental groups and since simplicity plays a central role in individual learning this complexity hinders the way in which the participants rate their own social learning process. The hypothesis is that this changes when complexity is added while holding simplicity. When simplicity is not hold, adding complexity is a pain and a gain.

Next to that, the overall performance of the control groups was better. The lower final score is explained by the fact that the experiment is a simplified version of the real world. Solving the experiment is thus also easier then defining a plan of action in the real world. It is not the most complex task at hand. In that case, adding complexity only makes it harder to come up with a good plan. So a good score of the experiment is not directly related to a good sensemaking process.

Figure 14.1 illustrates the described process. It shows the way in which an increased complexity leads to a better collective sensemaking during disasters.

Another interesting observation separated from the complexity was the fact that external representations (like drawings and graphs) were made more by using the board by the experimental group then by the control group. The hypothesis is that this is because of the fact that the experimental groups had to made use of the game board by placing the FFM seaport. The control groups did not have to use the game board at all. The hypothesis is that prompting participants to use something visual (a game board in this case) leads to the fact that this visualisation is used during in order to create external representations.

This chapter presents an answer to sub research question seven. This question asks about the factors which improves a collaborative sensemaking process during disasters. This chapter describes that several variables are already improved by using the FFM seaport. This are: more external representations, more equally distributed participation, more information sharing at the beginning, quicker start of information sharing, increased fear to make the wrong decision, more emotions shared, more awareness of the role of others, more awareness of the information of others and more agreement on the common goal. Due to this improved variables the collaborative sensemaking process is improved. The hypothesis is that adding complexity leads to more improvement. Note that Figure 14.1 shows the framework on how to influence the collaborative sensemaking process during disasters. This is the second sub goal of this research which correspondents with the communication part of this research. Chapter 15 applies this framework on the conceptual design of the seaport. In the end this results in the conceptual design which enables such a FFM seaport to reach its full potential to help during humanitarian logistics. This corresponds with the main goal of this research.

This is the last chapter of the communication part of this research. The next part concludes and discusses the logistical as well as the communication part of this research. This part also includes Chapter 15 which applies the communication framework on the logistical conceptual design of the seaport.

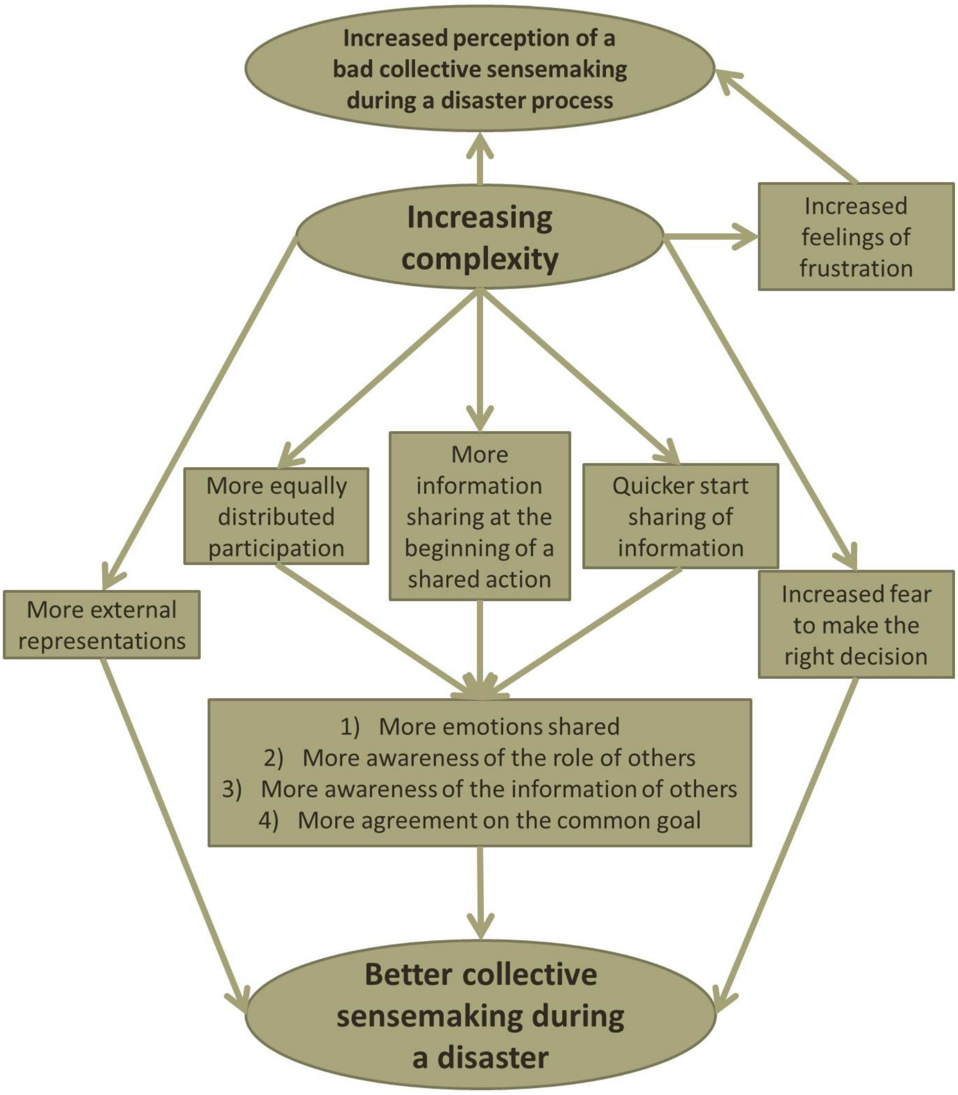


Figure 14.1: The way in which an increased complexity leads to better collective sensemaking during disasters, but also to an increased perception of a bad collective sensemaking process during a disaster

The evaluation of the results show a process. This process starts with an increased complexity. Because of that: more equally distributed participation, quicker start of sharing of information happens and more information sharing in the beginning. This increases the emotions shared, more awareness of the role of others, more awareness of the information of others and more agreement on the common goal. Together with more external representations and increased fear to make the right decision this increases a collective sensemaking during a disaster. However, increasing complexity leads to an increased perception of a bad collective sensemaking during a disaster process. This is, among other things, due to an increased feeling of frustration.

IV

Discussion, conclusion and recommendations (logistics and communication research)

15

Combining logistics and communication results

Chapter 10 evaluates the logistics results from a logistics perspective and Chapter 14 evaluates the communication results from a communication perspective. The next step is to evaluate these results from a combined communication and logistics perspective.

When analysing the results of the logistics and communication part of this research there are two ways of integrating both researches. The first is the direct influence of using a new technology on collaboration. The second is the adaption of that technology to help improving the collaboration even further.

Figure 15.1 shows the relation between the communication and logistics researches. The brown arrow (arrow one), represent the first influence. Technology, influences the collective sensemaking but the collective sensemaking does not influence the technology. However, it is also possible that the collective sensemaking part influences the design of the technology. When designing the technology, thinking already about things to incorporate to maximize the collective sensemaking process when using the technology. For example, when in the implementation of the technology the decision makers are guided to make external representations. It is possible to achieve this by requiring to use certain forms to start using the technology. This process is shown with the blue arrow (arrow two).

Note that both influences (arrow one and arrow two) leads to an iterative circle when redesigning the technology is possible: the design of the technology, leads to a better sensemaking process. This better sensemaking process leads to deeper learning about the technology itself. This deeper learning results in better understanding about factors which smoothen the sensemaking process. These factors can be incorporated during the redesign of the technology in order to smoothen this sensemaking process even more. When the seaport is used, the actors incorporate improvements in the design due to a better sensemaking process and this circle will go on and on. Over time, it is believed that the blue arrow (arrow two) will thus happen anyway. Off course, it is better to think about things to incorporate in the design phase and not in the usage phase of the new technology. More modifications are possible in that phase. This cycle process also shows the importance of testing designs of new technology.

So let's first zoom in on the brown arrow (arrow one). This arrow shows that if the FFM seaport is considered to be something like a new technology, then this new technology influences the communicative part: the collective sensemaking during disasters. In that case, having the option to use the FFM seaport results in a communication process in which the participants create more external representations and there is an increased fear to make the wrong decision. Compared with when it is not able to use such a new technology. Next to that, the technology leads to more equally distributed participation, more information sharing and quicker start of information sharing in the communication process. This leads to more emotion sharing, more awareness of the roles and information of others and more agreement on the common goal. So only using this technology, without any changes and any thoughts about the communication aspect incorporated in the design of the technology, leads in this

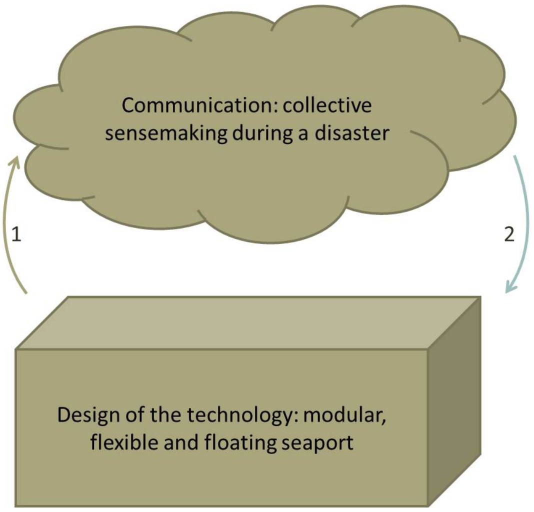


Figure 15.1: The relation between the communication part and logistics part of this research. The design of the FFM seaport always influences the communication process (arrow one). It is also possible that factors the design of the seaport incorporates factors which improves the communication process (arrow two)

case already to a better collective sensemaking aspect. The hypothesis is that this is because of the added complexity when a technology is used. By increasing the complexity the depth of the interaction increases, when people use artefacts such as technology.

Second, take a look at the blue arrow (arrow two). This arrow shows that it is also possible to take the important communication factors into account when designing the seaport. There are some possibilities to incorporate in the design of the seaport in order to improve the collective sensemaking process. For example, it is possible to create a certain web page or application in which organizations must administrate the goods they want to transfer from boat to land with the seaport. In this application important information can be shared. Or the fear to make the right decision can be improved by asking sometimes if they have fill in the right information and that the wrong information can lead to problems. Or, for example, presenting an overview of which organizations are using the seaport. The hope is that this results in actors recognizing that certain important organization are not involved and invite them to participate. Note that this list is certainly not complete.

Another interesting opportunity arises when the hypothesis that adding complexity leads to a better collective sensemaking is is true. In that case, the question is how to adjust the conceptual design of the FFM seaport in such a way that it increases the complexity of using it. The logistical results of this research presents a possibility. Chapter 10 chooses from a logistical point of view to open only two facilities. It argues that this gives the best change of an applicable design of the FFM seaport. However, now it is interesting to analyse how to make the design more complex. It is more complex when a lot of different facilities have to deliver their stored handling capacity to help a demand point.

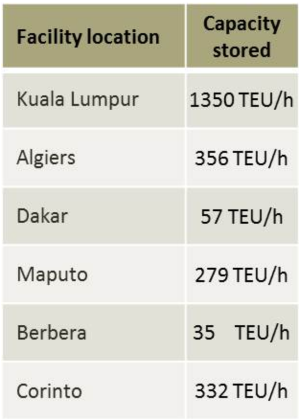
So the next step is to analyse the different facility locations which are opened in the different runs of the logistical experiment. A run consist of a certain input configuration which differs over the different runs. The difference in this input configuration leads to different results. The results of the logistical experiment consist of, among other things, the facility locations to open and the amount of stored handling capacity at those locations. The results shows that in total 11 different facilities are opened over the different runs. However, not all 11 are used that much. It shows that Kuala Lumpur is opened in every run, while Los Angeles is only opened in two runs. Opening all 11 facilities is maybe a little bit too much. It is important to find a balance between adding complexity and the possibility of realisation the actual FFM seaport.

From that perspective it looks like Kuala Lumpur (which is opened in every run and thus over every situation setting), Algiers (which is opened in five runs over three situation settings), Dakar (which is opened five times over two situation settings), Maputo (which is opened in seven runs over three situation settings), Berbera (which is opened six times over all situation settings) and Corinto (which is opened in seven runs over three situation settings) are the facilities to open. This leaves Panama City (which is opened in three runs only in one situation setting), Sokhna (which is opened in three runs over two situation settings), Luanda (which is opened in three runs over two situation settings), Ho Chi Minh City (which is opened in two runs over one situation setting) and Los Angeles (which is opened in two runs over one situation setting) unopened.

The next step is to look at the amount of handling capacity which have to be stored at those facilities in the plan described above. To increase complexity the amount of capacity stored over all runs of these locations is compared. Out of this set of stored handling capacity the lowest amount is chosen. This leads to the highest possibility of more facilities needed to help one demand point. That leads to the design which is shown in Table 15.1.

This design leads to a total capacity stored of 2409 TEU/h which corresponds with 0.62 km^2. This is less then the outcome of the other runs. Since the total capacity stored is less, this also means that the cost to store handling capacity is relatively low. This cost is 7,433,300,000 USD. Since this is biggest part of the total cost this also means that this design probably doesn't lead to costs which are way higher then the other designs. The costs to open facilities in this design is 30,814,656 USD. This is somewhat average compared to other runs. This makes sense since six different, but cheaper, locations are opened in this design.

Table 15.1: The design of the facility locations and amount of capacity stored at those locations when combining the results of combination and logistics.



Facility location	Capacity stored
Kuala Lumpur	1350 TEU/h
Algiers	356 TEU/h
Dakar	57 TEU/h
Maputo	279 TEU/h
Berbera	35 TEU/h
Corinto	332 TEU/h

Within this design the lowest amount of stored handling capacity is chosen. The logistics results shows that in most of the logistics experiment results around two facilities or more were needed to help one demand point. This means that in this design a lot of different facility points are necessary to help one demand point. This increases complexity. Next to that, choosing the lowest amount of capacity means that it is possible that the design is not able to help all people in need in some instances. This is especially true since no other result of the logistics experiment results in such a less capacity stored. This makes the usage of the FFM seaport even more complex since in that case hard choices must be made.

The above design presents the conceptual design which enables such a FFM seaport to reach its full potential to help during humanitarian logistics. This was the main goal of this research. This chapter also discusses the answer on the main research question. This question asked how the FFM seaport contribute to an effective and efficient disaster relief effort. The next chapter discusses the research.

The results of the communication and logistics part of this research can be integrated in two ways. First, using the FFM seaport influences the collaborative sensemaking during disasters. This means that the usage of every design of the FFM seaport will increases the collaborative sensemaking during disasters. The second way is that the collective sensemaking part influences the design of the technology. This can be done by thinking to incorporate aspects to maximize the collective sensemaking process when using the technology in the design phase. When applying this second way of integration into the design of the FFM seaport, example adjustments to the design can be: create a web page or application in which organizations must administrate important information before they can use the seaport, indicating that wrong information can lead to problems or presenting an overview of which organizations are using the seaport.

Another interesting opportunity arises when the hypothesis that adding complexity leads to a better collective sensemaking is true. In that case it is argued that the conceptual design of the FFM seaport has to be adjusted in such a way that it increases the complexity of using it to an extent. For example by opening a lot of facilities at different locations and storing a low amount of handling capacity at those facilities in order to require several different facility points are necessary to help one demand point. This means that defining a plan of action where enough handling capacity is sent to a demand point becomes more complex. This results in a design of opening facilities in Kuala Lumpur (with 1350 TEU/h stored), Algiers (with 356 TEU/h stored), Dakar (with 57 TEU/h stored), Maputo (with 279 TEU/h stored), Berbara (with 35 TEU/h stored) and Corinto (with 332 TEU/h stored).

16

Discussion

This research consist of a logistics as well as a communication part. The discussion of this research is divided into two parts. The chapter first discusses the logistics work. After that the communication work is discussed.

16.1. Logistics

Liberatore et al. (2013) describes some limitations with humanitarian models. Some of them are applicable to the model used in this research. First, a lot of the input parameters are thorough estimates. This research has done everything possible within the scope and time frame to make the best estimations, but these are still estimations. It is possible that these estimation leads to misleading values. For example, it is possible that the costs to open a certain facility or to store a certain amount of seaport handling capacity does not match reality. Since the model optimizes for costs, different input parameters lead to a difference in the outputs.

Second, Liberatore et al. (2013) states that a limitation is the use of historical data. There is the possibility that parameters change over time. Within this research, history determines three different disaster situation sets. These disasters happen will not happen one-to-one in the future. This leads to the possibility that the design of the FFM seaport is not optimal to deal with those disasters. To reduce this probability, this research also investigates a demand situation set in which every demand point is affected once independently from each other. This situation set is not based on history. The results of those runs are meant to compare the runs which are based on history. This places the limitation of historical data into perspective.

Third, Liberatore et al. (2013) states that uncertainty is a limitation. Because of uncertainty it is always possible that in the end something happens which is not predicted. No matter how you deal with uncertainty. This research does not incorporate the uncertainty in the model. The pre-processing step uses an approximation technique to define a certain distance which is probably good enough. Regarding demand, the research estimates the demand and uncertainty is kept out of scope. It is possible that this leads to errors in the result.

This research does incorporates uncertainty in the maximum service distance. If the probability for a disaster or the possible impact of a disaster is low, the model allows a bigger distance between the demand point and facility location. The problem is that this is not in line with the speed characteristics. There is the possibility where the FFM seaport is not available at the right time when a disaster occurs at a location where a disaster is not predicted. Incorporating uncertainty in the amount of demand necessary is also possible, but this creates the probability that the appropriateness characteristics is not met. (Liberatore et al., 2013) argues that the best way to incorporate uncertainty is by the geographical location. Not incorporating uncertainty is also possible, but in this situation the uncertainty characteristics are not met. The above indicates the difficult balance between the different humanitarian relief logistics characteristics: speed, costs, appropriateness and uncertainty.

A discussion point is if this way of incorporating uncertainty is indeed better. It leads to less complicated mathematical optimization models. The assumption is that this less complicated models are easier to work with for humanitarian organisations. But is this true? And if yes, how do this model performs in comparison with the current complicated models? This are questions which remains unanswered in this research and thus are interesting for further research.

Another interesting question which remains unanswered is the performance of the two conceptual designs. This research describes two conceptual designs. One design is more applicable opening two facilities. Another design incorporates complexity by opening six facilities. It is not clear which of the two perform better over different multiple future disaster possibilities. This is also interesting for further research.

Another discussion point of this research are the assumptions made within the inputs for the mathematical optimization model. A lot of different assumptions have been made. Appendix I.8 describes them in detail. An example is the choice to install the FFM seaport at the coastal town the closest to the biggest city on the island. This decision can have great consequences as for example it takes 2390 km to travel with boat from one side of New Guinea to the other side. Also, most of the inputs are based on the disaster relief effort analysis. This analysis investigates islands with more than 100,000 inhabitants. From this analysis it was concluded that islands of interest are those with 265,000 inhabitants. The inputs could vary if leaving the smaller islands out of the disaster relief effort analysis was considered.

The final discussion point is that the model assumes all costs to be fixed costs. This would implicate the cost to for example store one TEU of handling capacity is the same at an empty facility and at a facility where 10 TEU is stored. In reality this is not always the case considering scale up of facilities can influence cost.

Certain aspects of the logistics part of the research need to be discussed. The most important point of the discussion is that a lot of the input parameters for the mathematical optimization model are best estimates. These are mostly based on historical data. The question remains if this inputs mimics the real world data. Next to that, this research incorporates uncertainty in the maximum distance. One can argue that this is not in line with the speed characteristic, since a bigger distance between the demand point and facility location is allowed in the case of a low disaster probability. A final discussion point is that this research argues that this way of modeling uncertainty leads to a less complicated mathematical optimization model than used in current humanitarian logistics literature. However, the performance of this model in comparison with current models is currently unclear.

16.2. Communication

The first discussion points are that the emergency simulation role playing game has some limitations. There are some adjustments for the experiment of the emergency simulation role playing game which improves the research. First, the clarity of role structures variable only investigates how the two other participants saw the role of the third person in the process. The answers of the two other participants were compared in order to analyse if the two other participants agreed on the role of the third participant. There is however not asked how this third participant sees their own role within the process. It was better to include a question which asked how participants saw their own role to create a complete overview.

Another interesting fact was that not all groups knew directly that they all had different information. Actually within most of the groups a participant asked after some time: “do we all have the same information?”. This is interesting information since it is an important aspect of the collective sensemaking process. It indicates something about the interpreting of information. It is possible that this time after the participants found out that they all have different information alters for the experimental and control groups. Especially since the experimental group shares more information in the beginning.

Another discussion point for the emergency simulation role playing game is the groups forming process. The groups were not all equally divided with respect to age, profession, level of education, social economic statuses, the rate in which participants are familiar with each other and so on. For example, some groups consisted out three family members and in other groups participants were total strangers from each other. Since the experiments were performed during Covid-19 times it was hard to find participants. It was hard to create groups of equal participants. This is a point which in further research have to be taken into account. There are multiple different psychological characteristics which can alter between every person. For example a Belbin (Stephens et al., 2020) test should performed beforehand in order to really create equal groups. In that case groups need to be created according to the results of such a test.

Another limitation is that most of the participants were not professionals normally working within the humanitarian logistics field. Performing the experiment with participants that working in that field will give the best results. However, when looked at it from another angle it is clear that in a normal humanitarian logistics operation experts and non-experts are working with each other. So a research performed with non-experts can still be useful.

Obviously this is an experiment, but normally the choices made are life of death decisions. It is imaginable that making this decisions in real life is far more complicated then only delivering a theoretical action plan in an experimental setting. Next to that, most of the time actors are emotionally involved directly with the affected people. The non-experts even more since they are mostly local inhabitants of the affected area. They give some insightful information out of their own community or are able to access local resources. The effect of being emotionally involved to the effected people is not studied in this research. As one can imagine this can have a major impact.

Another discussion point is the surrounding in which the experiment was performed. Every group did the experiment in another environment. It is possible that the environment impacted the groups process. For example, one group did the experiment in a surrounding which contained hard background noises. Others played the experiment within their own calm and quiet living room. This also means that the table size was different in every experiment. Since creating an overview of all information is important this table size also plays a major factor. The larger the table, the more papers could be easily visible and accessible laying on the table.

Another thing which was not keep equal over all experimental and control groups is the order in which the tables of information was presented at the beginning of the experiment. Person one of all groups did get the same information and this was also the case for person two and person 3. However, the order in which the information tables were presented altered over them. It is not that the first information table of person one was exactly the same over all groups. The research shows that this order is of major importance. Most of the participants only look closely at the first few tables of information that they have. How further away the table was presented in their sets of tables,how less time they spend looking at that table. So when the most important information is more at the beginning of the table information set it will possibly lead to a more quicker collective sensemaking process then when it is more at the end.

Another thing which was not equal over all groups was the scores of other groups on the score sheet. Every time a group finished the experiment their score was noted and written down at this sheet. This means that the last groups had more scores to compare themselves the first groups. To also let the first group compare some scores, two made up scores were noted at the sheet at the beginning. This affects the process of the participants and their collective sensemaking process. The observer noted that the more scores were shown from groups which took longer to complete the experiment, the more time groups took to finish the experiment. This makes sense since participants thought they had more time to at least score better than most of the teams. Since the comparison of the own results with others also influences the way in how people think about their own abilities (Shepperd et al., 2008), this also affects how participants filled in the questionnaire at the end.

Some conclusions about the results of the experiment take the time that the groups needed to complete the experiment into account. This assumes that the collectively sensemaking process took the same amount of time as finishing the experiment. This is not necessarily true. It is possible that the groups finished the collectively sensemaking process quicker than that it took to complete the experiment. For example because they were writing down their plan. Or they know what to do and how to do it, but keep on doing the same actions to reach a higher score of reduce suffering. It is thus better, for next research, that the time of the collective sensemaking process is more detailed written down.

Another discussion point is that the quality of the plan of actions is not checked. It is not checked if the plan that the participants delivered is indeed possible to carry out following the information and rules of the experiment. Sometimes plans were made without using all necessary information. This while the information does give some interesting information about the overall quality of the collaborative sensemaking process.

Next to the emergency simulation role playing there is also a discussion points related with the theoretical framework of this research. The theoretical framework contains the important factors for collaborative sensemaking in disaster situations. This description of the special situation is important. However, the question remains open how the factors change when comparing it with collaborative sensemaking in any situation. Are there other factors involved in that situation? The theoretical framework is based on a literature search which only takes literature about disaster situations into account so based on this research it is hard to tell. However the assumption can be made that mainly the shared feelings concept and the corresponding anxiety about wrong decisions variable is more important during collaborative sensemaking in disasters. Next to that the assumption can be made that every variable which is related with time pressure is more important during disasters. This are: the creation of actionable knowledge variable, the time needed till first information sharing variable and efficacy of information sharing variable.

Another discussion point is that this research uses technology in order to improve a collaboration. This is very interesting and something which is not studied a lot. However, in the experiment this technology was represented by a simple cardboard card. It was really a simplification of a technology. Not the real technology but the possibility of using a certain technology was investigated. It remains very interesting to investigate how a real usage of a technology in practise influences the collaborative sensemaking during disasters.

A final limitation of the research is that this research assumes that the important stakeholders are already working with each other. They are already communicating with each other. Chapter 4.2 explains that this is not necessarily true. A major advantage of using the FFM seaport could be the fact that the important actors are coming into contact with each other and start communicating with each other. This effect is not researched within this study. This is the only variable of the theoretical framework which is not researched. Further research to this variable is thus interesting.

Certain aspects of the communication part of this research need discussion. First of all there is room for improvement in some aspects of the emergency simulation role playing game. For example: (1) divide every group more equally with respect to age, profession, level of education etc, (2) ask participants about the description of their own role, (3) performing the experiment with humanitarian logistics experts and (4) performing the experiments in the same surrounding. Another aspect is the fact that not everything was keep equal over all experimental and control groups. For example: the scores of other groups on the score sheet and the order of the tables of information.

Next to the emergency simulation role playing game also the theoretical framework contains some discussion points. The exact difference between a collaborative sensemaking process in general and a collaborative sensemaking process in disasters remain unknown. It is argued that the process during disasters contains more factors related to time pressure and emotions.

Finally, this research assumes that the important stakeholders are already working with each other. The variable of getting all participants to the table is not measured within this research. Further research into this variable can be interesting. A major advantage of the FFM seaport could be the fact that the important factor is needing to collaborate with each other when they use the FFM seaport.

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Conclusion

The main goal of this research is to create the conceptual design (facility locations and amount of handling capacity stored) which enables such a FFM seaport to reach its full potential to help during humanitarian logistics. To create this design this research has two sub goals. These sub goals must be met in order to reach the main goal. The first sub goal is to design the logistical conceptual design of a FFM seaport. This design comprehend the determination of the place and quantity of stored modular and floating terminal parts, in order to make sure that a sufficient amount of floating terminal parts will be on time at the affected location. The second sub goal is to create a framework, which comprehend factors, processes, elements and the relationships between them on how to influence the collaborative sensemaking process in disaster situations. By applying this framework on the logistical conceptual design a FFM seaport is created which contribute the most in humanitarian logistics.

The main research question is thus how the FFM seaport can contribute to an effective and efficient disaster relief effort. This research contains of seven sub questions guiding the main research question. All sub questions relates with minimal one of the two sub goals. This conclusion gives an answer on all research (sub) questions.

Important factors for the conceptual design

The first sub question relates with the logistical as well as the sensemaking goal of this research. **The question asks about the important factors which the conceptual design of the FFM seaport must take into consideration**. This research concludes that the FFM seaport helps in reducing the material convergence problem. This problem states that during disaster relief operations a lot of unnecessary, irrelevant and useless goods are sent to the disaster area, while the handling capacity of the infrastructure is limited.

To reduce this problem an improved collaborative sensemaking during disasters is important. Improving this, leads to: (1) an improved coordinated, cooperated and collaborative disaster relief effort, (2) a common language between the relevant actors, (3) reducing the quantity of sent goods and (4) more information shared. These four factors reduces the material convergence problem.

Next to that, also the usage of a FFM seaport reduces the material convergence problem. The FFM seaport deals with the inflow of huge quantities of relief goods by transfer them from ships to shore. It is concluded that the FFM seaport is of most use for islands with more then 265,000 inhabitants. When an island has less affected people, the military can assists. When mainland is affected ships are deflected to a seaport further away. In order to be of maximum help it is important that the FFM seaport takes the speed, appropriateness, costs and uncertainty into account.

The costs aspect shows that the costs have to be minimized while determining the conceptual design. It is allowed that a demand point is helped by multiple facilities to keep the costs low. Speed shows that there is a maximum service distance. This is the maximum distance between a storage facility and a demand point for which a storage facility can service that specific demand point. Appropriateness shows that enough handling capacity must be stored to help every demand point and every demand point need to have a storage facility within their maximum service. Uncertainty shows that the FFM have to deal with uncertainty about the exact striking area and with the fact that multiple disasters can happen simultaneously.

Current humanitarian optimization models

The second sub question is **how the factors which determine the logistical conceptual design of the FFM seaport are used in humanitarian optimization models until now.** This research concludes that there is no model right now which let uncertainty influence the maximum service distance. There is only a model which state that a facility is able to serve a demand point if the probability that the distance between those points is lower then a certain distance. Next to that, the research concludes that there is no model which keep enough goods stored to supply every demand point without stating other conditions. With respect to modeling uncertainty most models uses scenarios. A scenario represent a disaster happening with the probability that this disaster happens again. This results in multi objective and multi stage models. A scenario can represents multiple disasters happening simultaneously. There are at this moment some models which combines the objectives and decision variables necessary for this research. Next to that, a lot of models allowed that a demand points is served by multiple facilities. Finally, the standard set covering model incorporate constraints which incorporates a maximum service distance, assign every demand point to at least one facility within this maximum service distance and let every demand point have his own individual maximum service distance.

Optimization model to determine the factors which determine the logistical conceptual design

The third sub question asks about **the best optimization model to optimize the factors which determine the logistical conceptual design of the FFM seaport.** The model used in this research consist of three preprocessing steps and a mathematical optimization model. The preprocessing steps determine if a demand point can be covered by a possible facility location or not and the different demand situations that will happen in the future. If a demand point can be covered by a possible facility location or not is among other things based on the probability that a disaster will happen at that demand point. The higher this probability the closer a facility point must be located in order to cover that demand point.

The output of the preprocessing steps together with the cost to store one unit of handling capacity, the costs to open a facility, the cost to transport and operate one unit of handling capacity and the necessary handling capacity per demand point are inputs for the mathematical optimization model. The model minimizes the total costs which consist of the cost to open facility, to store handling capacity and to transport and operate handling capacity. This while all constraints are met which are described under the first sub question. This gives in the end the location of the facilities, the amount of capacity needed to store those facilities and the amount of handling capacity sent from a facility to a demand point. This research state that this is the best way to optimize the factors which determine the conceptual design of the FFM seaport.

Logistical conceptual design

The fourth sub question asks about **the applicable logistical conceptual design of the FFM seaport in order to help with disaster relief efforts**. Within this research multiple different runs of the mathematical optimization model are performed. Every run consist of a different input configuration. The inputs differs with respect to the demand situation set. This set consist of demand situations which indicates which demand points want to get help at the same time. Another input which differs is the handling capacity tactic. This is the amount of handling capacity necessary to help a certain demand point. The outcome of the models differs when a different input configuration is used. This different input configurations were necessary since it is not possible to exactly predicts the exact disasters that will happen in the future. The different input configurations represents different possibilities of which disasters will happen and about the impact of these disasters.

All the different outcomes shows that the more facilities are opened, the higher the average amount of facility locations needed to help on demand point, the higher the total distance travelled and the higher the average distance to reach a demand point. The results concludes that it is possible to reach every different demand point when opening a facility in Kuala Lumpur and in Algiers. Next to that, the research concludes that it is financial wise possible to realize the FFM seaport. The different actors which need to invest in such a seaport are financial able to do so. With respect to the amount of handling capacity stored it shows that a very big number of capacity is stored. The exact number depends on the input configuration, but the amount of handling capacity stored is always more then the handling capacity of the fifth largest seaport. The different input configurations represents future disaster possibilities. It is possible to rank those possibilities from best case to worst case. With respect to the average cost to help one person the medium case scenario scores the best.

On basis of the above the research concludes that the logistical conceptual design is to place facilities in Kuala Lumpur and Algiers. This in combination with copying the total amount of handling capacity stored from the run which scored the most favourable with respect to the average costs to help one person. The results show that in the run which opened only Kuala Lumpur and Algiers, Kuala Lumpur helped in serving 72% of the demand points and Algiers in 30%. Note that together this adds up to more then 100% because some demand points are served by both facilities. The amount of handling capacity stored at those two facilities is calculated by taking these percentages of the total stored amount of capacity. This leads to opening Kuala Lumpur and store 1,950 TEU/h over there and opening Algiers and store 812 TEU/h over there. Note that by defining the conceptual design the first sub goal of this research is met.

Factors influencing collaborative sensemaking in disasters

Sub question five is **which factors according to literature influences a collaborative sensemaking process during disaster.** This question relates to the collaborative sub goal. Literature shows that seven concepts are important. These concepts exist of corresponding variables. It is possible to measure these variables in order to say something about the corresponding constructs and in the end about the collaborative sensemaking process during disaster.

The first concept is shared information gathering. This deals with the variables of gathering information from a variety of sources and know which information is important and not. The second concept is shared interpreting of information. This deals with the variables of indicating if conflictive information is found and the creation of external representations like maps and drawings. The third concept is collective actions. This deals with the variables of defining the collective goals, awareness of the action of others, the efficacy of other's actions and the creation of actionable knowledge so that the others know directly what to do when information is shared. The fourth concept is shared leadership. This deals with the variables of taking decisions together and defining a clear role structure. The fifth concept is conversation quality. This deals with the variables of efficacy of information sharing, the modality of information sharing and the process of information sharing. The sixth concept is conversation participation. This deals with the variables of amount of interactions, timing of interactions and if all relevant actors are together or not. The seventh concept is shared feelings. This deals with the variables of sharing emotion, frustration and anxiety.

There is a relation between the seven concepts. Information gathering, interpreting of information and collective actions are forming a cycle process. Information gathering leads to interpreting of information what leads to collective actions. After the forming of collective actions it is important to engage with the circumstances in order to gather data and the cycle starts again. This cycle process makes it a sensemaking process. This cycle process relates with the social learning theory. At the moment that courses of actions are adapted, this is because competence is in tension with experience and thus because of social learning. The actors are learning from each others information and point of view that the course of action need to be adapted. This means that collaborative sensemaking is related with social learning. Social factors are in that case always present in the cycle of sensemaking. This social factors are the concepts of: shared leadership, conversation quality, conversation participation and shared feelings.

Evaluate how the usage of a FFM seaport influences collaborative sensemaking

The sixth sub question asks **how it is possible to evaluate how the usage of a FFM seaport influences the collaborative sensemaking process.** This research uses an emergency simulation role playing exercise to evaluate the collaborative sensemaking process during disasters. A disaster is simulated and participants are asked to work together to make sense of the situation and to create a plan of action. This plan of action consist of the logistical plan about how many goods are delivered to a certain location and in which way. The goal was to define the plan of action as quickly as possible and to make a plan which reduced the amount of suffering the most. Several groups had the possibility to use a FFM seaport to deliver goods while others had not. This research investigates the difference in the collaborative sensemaking process between those two groups.

This difference is measured by using a questionnaire and an observer. The participants of the experiment filled in a questionnaire after the experiment. This questionnaire measures some of the variables corresponding with the collaborative sensemaking process. The remaining variables are measured by the observer. This person wrote down notes related to the variables. Only one variable is not measured. This is the variable of getting all relevant actors together. It is not investigated if using the FFM seaport during a real disaster is getting the important actors together.

In order to measure the variables the design of the experiment is made in such a way that, among other things: not every given information is necessary, participants not know beforehand which information the other participants have, conflictive information is present and multiple different goals can be chosen as the most important goal.

Factors which improves a collaborative sensemaking process during disaster

The seventh sub question asks **about the factors which improves a collaborative sensemaking process during disasters.** This research shows that the usage of the FFM seaport leads to more external representations and an increased fear to make the right decision. Next to that at the beginning more information is shared, quicker information is shared and information is shared more equally over participants. This leads to more emotions shared, more awareness of the role and information of others and more agreement on the common goal. The main driver of the increasement of these factors looks like to be complexity. This means that just the usage of the seaport already improves the collaborative sensemaking process. Answering this question means that the second sub goal is met. This sub goal was to create a framework, which comprehend factors, processes, elements and the relationships between them on how to influence the collaborative sensemaking process in disaster situations.

Conceptual design

Since the two sub goals are met, this means that the main goal is also met. The main goal of this research is to create the conceptual design which enables a FFM seaport to reach its full potential to help during humanitarian logistics. In the end this research concludes that just using the FFM seaport already increases the collaborative sensemaking in disasters. So every design which helps logistics wise, also helps communicative wise. This means that the design described as answer to the sixth sub question is already a design which contribute from a communication as well as a logistics perspective to humanitarian logistics. On top of that, this research results in the hypothesis that adding complexity leads to a more improved collaborative sensemaking process during disasters. So to contribute the most, it is argued that the conceptual design of the FFM seaport have to be adjusted in such a way that it increases the complexity of using it. For example by opening a lot of facilities at different locations and storing a low amount of handling capacity at those facilities. This in order to require that a lot of different facility points are necessary to help one demand point. This results in a design of opening facilities in Kuala Lumpur (with 1350 TEU/h stored), Algiers (with 356 TEU/h stored), Dakar (with 57 TEU/h stored), Maputo (with 279 TEU/h stored), Berbara (with 35 TEU/h stored) and Corinto (with 332 TEU/h stored). Note that this design also gives an answer to the main research question: **how could a FFM seaport contribute to an effective and efficient disaster relief effort**.

So imagine a disaster happening and affecting multiple islands in the world. The seaports on that islands are destroyed and a lot of relief goods are necessary at those islands. The first two weeks after a disaster these goods will be transported by airplane. However, in order to deal with the huge quantities of relief goods necessary, ships are used after these two weeks. So in order to deal with those goods it is necessary that more seaport handling capacity is available. This handling capacity can be created with a floating, flexible and floating seaport. Different amount of handling capacity is stored all over the world and when necessary this handling capacity is shipped from those storage location to the disaster area with big semi-submersible heavy lift vessels. The biggest amount of capacity is sent from Kuala Lumpur, Algiers, Maputo and/or Corinto. If necessary some extra handling capacity can be sent from Dakar or Berbara. When arrived this seaport is installed and connected to the mainland. After that, the seaport is transferring goods from ships to shore for 24 hours a day seven days per week. This until the seaport is not necessary anymore at the moment that the port on the islands is restored and the amount of relief goods is decreasing. At that moment the flexible, floating and modular seaport is getting uninstalled and is transported back to its original storage location wit the semi-submersible heavy lift vessels. Waiting till the next disaster relief operation which they can assist.

18

Recommendations and implications

This chapter first describes the recommendations for further research for the logistics part of this research. After that the recommendations for further research for the communication part are described. Finally this chapter presents the implications of this research. This implications are described from an integrated perspective.

18.1. Recommendations logistics

This section gives recommendations about three different areas of the logistics research. First, it gives recommendations with respect to the experimental plan. Second, with respect to the mathematical optimization model. Third, with respect to the realization of the FFM seaport.

18.1.1. Recommendations experimental plan

The logistics part of this research contains interesting points to follow up on. One of the biggest recommendations is to research which different future disasters are likely to happen. Translating this to an input configuration leads to the demand situation set and the handling capacity tactic which represents the future the best. Solving the model with this input configuration gives the best design of the FFM seaport for the future.

Another interesting recommendation is to analyse the proposed conceptual designs. The conclusion describes two possible designs. One which opens two facilities and one which opens six facilities. It is interesting to analyse how these two designs perform when evaluating them over multiple different future disaster settings. Which of the two performs the best with respect to travel time, costs and amount of persons that can be helped over different possible future disaster settings? Then more can be concluded for a conceptual design which performs better over multiple different future disaster settings.

The research assumes that the FFM seaport returns to the facility location after every usage before it is used for another disaster. More research could indicate if the situation is more favourable economically if a seaport can transfer directly from a disaster relief effort to another disaster relief effort.

This research assumes that one big FFM seaport is used to help one island. However, it can be interesting to put multiple different smaller seaports around the island in order to be of the best help during the disaster relief effort. Multiple, over land, hard to reach locations could receive help in this way. This is interesting for further research.

This research assumes that during a disaster relief effort all goods will be transported to the islands by ships and is transferred from ship to the island using the FFM seaport. However, in real situations this is maybe different. It is possible that existing seaports also handles some relief goods. This can also differ over the different disaster situations. Currently, the research assumes that for every disaster situation a demand point always needs the same amount of goods. It is a recommendation to do research about the exact amount of goods necessary, integrate this numbers into this input and evaluate how this changes the results.

It is also interesting to do more research towards the different inputs which were assumed non variable in this research. For example, the costs to transfer and operate the FFM are assumed to be the same for every situation. However, it is possible that the fuel price is higher in a certain demand situation when that disaster will influence the fuel prices. Also the matrix which determines if a demand point is able to reach a facility location does only alter over the different demand situations if a disaster hits a facility location. In that case the facility location can not be of help. However, there are more scenario to think of where certain facility points can not help a demand point in a certain disaster situation. For example, due to political motivations or the fact that a certain disasters block the transport routes.

A final recommendation with respect to the experimental plan is to dive deeper into the different inputs which do not differ over the various runs in simulation, but do in reality. For example, this research assumes a certain costs to transport one TEU of handling capacity. It is possible that these costs are in reality different. This makes sense because this research assumes a linear relation between, among other things, the weight of the FFM seaport and the amount of handling capacity of the FFM seaport. Next to that, this research assumes that the costs to store a certain amount of handling capacity at a facility is dependent on which organisation is the owner of that facility. A certain amount of collaboration is assumed to use this facility. For several different facility providers this amount of collaboration is assumed to be more then for others. This differentiate the costs. It is interesting to analyse the change in the results if no collaboration is assumed and thus that the full costs have to be made to open a facility no matter where.

18.1.2. Recommendations mathematical optimization model

Currently, the model only takes the uncertainty of the exact disaster location into consideration. The model does not take the uncertainties about the amount of demand needed into consideration. There is always uncertainty to what extent the location is affected. Liberatore et al. (2013) concludes that most of the humanitarian logistics research until now focus on demand uncertainty. They state that underestimating demand might result in delays in the distribution. This research does not underestimate demand as it takes the worst case scenario. However, it is recommended for further research to also take the uncertainty of the demand into consideration. The results could show less demand necessary and thus have a different input configuration which results in other outcomes.

Another way of incorporating uncertainty is by taking the probability of a disaster situation happening into account. This research concludes that this leads to multi objective multi stage models. A new solving method has to be created in that case.

A final recommendation with respect to the mathematical optimization model is the choice to use a set covering model. This research concludes that it is possible to reach every demand point with opening two facilities. This makes it possible to also use other types of models like P-median or P-center models. This models minimizes the total travel distance between all demand points and facilities or the maximum travel distance between one demand point and one facility given the amount of facilities to open. Since two facilities are sufficient it is possible to create such a model and solve it with stating that two facilities are allowed to open.

18.1.3. Recommendations for the realization of the FFM seaport

One of the conclusions is the fact that the stored seaport capacity is not necessary at all times. On top of that a large amount of capacity is stored. This leaves an opportunity for the stored capacity to be used for something else. A recommendation is to take a look at which kind of usage is possible when the seaport capacity is not necessary.

This research only takes handling incoming cargo into account. However, after a disaster also a lot of waste and debris needs to be handled. So a recommendation is to look at the implementation of the

FFM seaport to help with the waste processing.

This research focuses on natural disasters that occur suddenly. However, there are also slow onset disasters. During these disasters affected people also need a lot of disaster relief goods. These disasters are for example food insecurity due to economic sanctions. There is also the possibility of seaports being destroyed by war (NOS, 2021). Further research has to answer the question if in that situations the FFM seaport is also able to provide.

Another recommendation is about the research field of disaster relief logistics. It is about the speed characteristic. Walton et al. (2011b) states that at this moment there is no standard definition of speed. There are no guidelines and thus no standard definition of what is being perceived as too fast or too slow. Second, disaster relief organizations don't measure the timeline of their effort. This research proposes a first step in making guidelines for speed. It defines for every bigger island on the world a certain maximum amount of time till the seaport have to reach that point. However, more research towards this and the factor speed in disaster relief efforts have to be performed, to use this guideline in practise.

A final note is about the choice to create a seaport. The disaster relief effort analysis shows that airports are more frequently damaged by natural disasters. On top of that airport capacity is more of a problem then seaport capacity during disaster relief efforts. Even when airports are fully operating, capacity is mostly still a problem. This while airports have the advantage that they are able to transport goods quicker. Especially the most essential goods are transported by airplane. Switching from seaports to airports is an interesting topic for further research.

There are a several recommendations for further research related to the logistics part of this research. With respect to the experimental plan the biggest recommendation is to investigate which exact disaster will be the most likely happen in the future. Feeding these disasters as input into the mathematical optimization model will lead to the design of the FFM which deals cost wise the best with the future disasters. A second recommendation is to analyse the two proposed conceptual designs (one which opens two facilities and one which opens six facilities) performance with respect to travel time, costs and amount of persons that can be helped. A recommendation regarding the mathematical optimization model is to incorporate the uncertainty with respect to the amount of goods necessary. A recommendation with respect to the actual realization of the FFM seaport is to investigate whether the stored handling capacity can also be used for other implementations. Within the current design the FFM seaport is just doing nothing when waiting for the next disaster to respond to.

18.2. Recommendations communication

There are some things interesting for further research based on the outcomes and the experiment of the emergency simulation role playing game. One of the most important recommendation is to investigate the relation between an increased complexity and an increased collective sensemaking process during disasters. Increasing the complexity was not the initial focus of this research. This means that within this research and within the emergency simulation role playing game the complexity was only increased by using an extra card which represents the FFM seaport. It only asked for a small amount of extra actions from the participants. However, there are of course more ways of increasing complexity. For example, experiments which continuously increased complexity or experiments where multiple extra actions are asked from the experimental group. This results in experiments which investigate the effect between complexity and collective sensemaking during disasters even more. Maybe it is possible to set up multiple experiments with multiple levels of complexity in order to fully gasp the phenomenon. When analyzing this complexity, the role of simplicity is also interesting. Is it indeed true that increasing complexity leads to an actors own increased perception of a bad collaborative sensemaking process. Is it possible to increase complexity, while maintain simplicity?

A second recommendation is related with the fact that the game is now used to investigate the collective sensemaking during disaster. However, this collective sensemaking process can also be increased with training. When participants are aware of the fact that they have to communicate, share more information and have to divide the communication participation equally this will increase the collective sensemaking during disasters. Better communication leads to more emotions shared, more awareness about the role and information of others and more agreement on the common goal. Playing the emergency simulation role playing game holds the power to increase this awareness by the participants. Off course, some elements of the game have to be adjusted for this goal. The questionnaire which is asked at the end of the experiment, have to be changed to an evaluation. This evaluation need to have a conversation leader who is asking the participants about how things went from a sharing communication perspective. He or she asks everyone to evaluate their own sensemaking process as well how they perceived the collective sensemaking. Investigating if this game is indeed working as a training tool to improve the sensemaking process is a recommendation. It is proposed to play games with two different groups. One group plays first the emergency simulation role playing game of this research and after that another different game to investigate if they indeed improve the sensemaking process. Other groups only play that second different game. This makes it possible to compare the performance of the groups within this last game between the groups which have played the emergency simulation playing game developed in this research and teams which had not.

Another interesting recommendation was noticed by the observer of the experiments. The observer analysed how all the groups, thus the control groups as well as the experimental groups, expressed themselves during the experiment. It looked like in the beginning the teams were pretty motivated and positive that they were able solve the experiment and maybe even reach a high score. At the beginning they found interesting information and think most of the information is necessary. Most of the information made sense to them. However at every experiment, after some time, a disruption moment was happening. This disruption moment could consist of conflicting information. Another possibility was that a participant found information which proposes a problem for the group. For example one group thought they had indicated all important information. At that moment someone just found other information which the group thought was also important. The problem was that this information was not in line with the other information found. After the disruption moment the participants realized that the problem is more complex then they thought at first sight. Things go afterwards more and more from that moment on. More and more problems and conflicting information is indicated. This is the moment that, according to the author of this thesis, a very important moment of the collective sensemaking process is started. Most of the collective sensemaking process is happening at that time. Because of that sensemaking process the participants got answers on the problems. They started working on the problem collectively and found solutions on to how to finish the assignment. More and more choices were made and solutions were found. In the end this delivers a plan which all participants were satisfied about. Figure 18.1 shows an overview of this process. However, this observation is not really tested with the help of variables during the experiments. It is something the observer only noticed. So this hypothesis needs more research.

So this means that there is a certain disruption moment. Figure 18.1 shows this disturbance moment. At that moment one of the participants felt that there was some disturbance within the group. This participant dared to appoint this disturbance and this created a certain chaos inside the group. The group members acknowledged this disturbance since their information was not in line with their first thoughts. The group members stepped into this disturbance in order to find out what was happening and how to deal with the situation. The hypothesis is that going inside this disturbance boost the collective sensemaking process. At the beginning of the assignment, participant were confident and had the feeling that they were able to solve the assignment. They got a lot of information and tried to make a simplification of the real situation in order to assess which information was important and which not. However, not every information is in line with this simplification and thus participant felt the disturbance more and more. The created simplification of the situation did not hold anymore. When someone was brave enough to pinpoint this and discusses their feelings about it, participants saw that the situation was more complex then their simplification. The hypothesis is that this leads to more communication, better working together and more collective sensemaking. It is in peoples nature to work together at moments that we don't think that the problem can be solved by our own. At this moment the above process is only a hypothesis. More research is necessary if indeed this is the actual process happening.

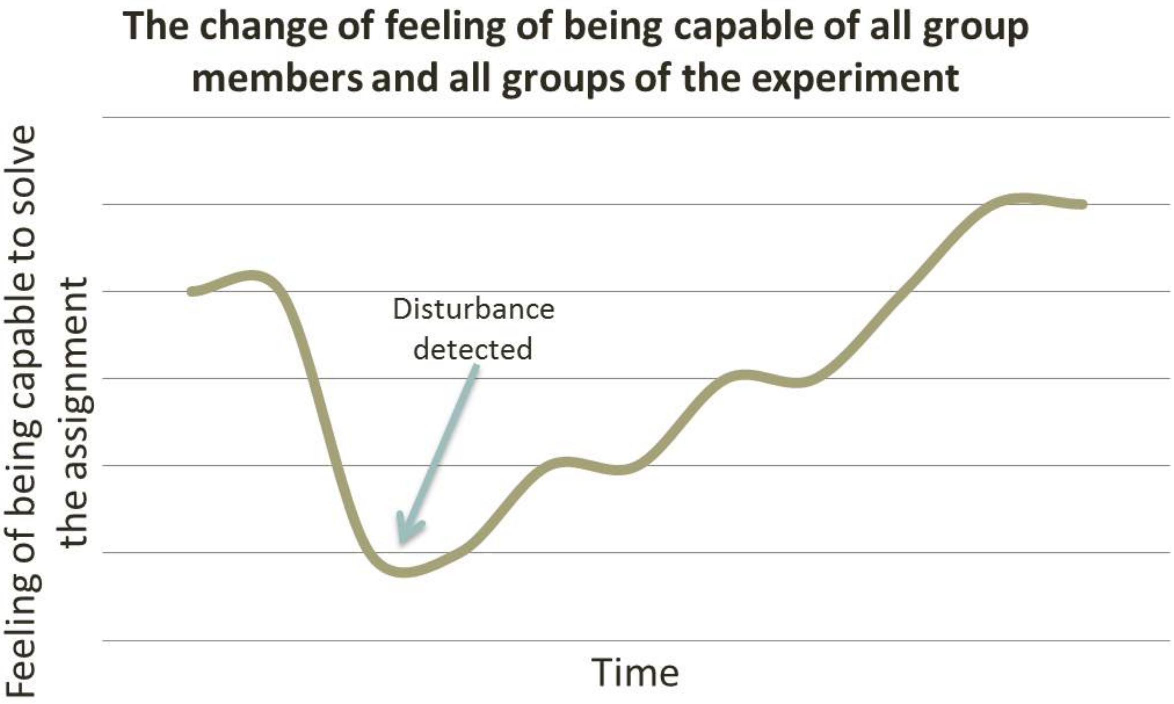

Figure 18.1: The change of feeling of being capable to solve the assignment over the duration of the experiment. This is for all groups and all group members. This is noted by the observer

Another recommendation is to also look at time pressure when investigating the complexity and sensemaking. This research shows that time pressure clearly has an effect on persons. This was noticed by the observer and it is even mentioned by one of the participants. An interesting opportunity arises in the question how time pressure affects this process. Müller-Seitz and Macpherson (2014), also indicates that this time effect is important, but also highly understudied at this moment.

A final opportunity arises in the fact that this thesis assumes that the communication structure is decentralised. This is normally the case within a disaster relief effort (Wankmüller and Reiner, 2020). However, there are also other actors which deals with complex disaster situations which have a centralised communication structure. For example: the police, military, ambulances, fire workers and so on. Most of the literature on inter organisation cooperation is focused on these last centralised structures (Tatham et al., 2017). An interesting opportunity would be to redesign the experiment in such a way that the communication between the participants is centralised instead of decentralised and to investigate the effect of this change on how they make sense of the situation.

There are a couple of different recommendations for further research for the communication part of this research. The most important recommendation is to investigate the relation between an increased complexity and an increased collective sensemaking in further detail. Another recommendation is to investigate if the emergency simulation role playing exercise also could be used as a training tool in order to train actors in their collaborative sensemaking process during disaster situations.

18.3. Implications

The question remains what the results mean in practice. The research calls for an increased complexity within the humanitarian logistics operation. Something which is very counter-intuitive. It is peoples nature to solve problems as efficient as possible. However, adding complexity and embracing this complexity leads to a qualitative better solution. Off course, a balance between those two elements are important when working in a humanitarian logistics operation. However, focusing solely on efficiency does not create the best action plan and qualitative best operation. This research advice to show complexity to the decision makers. Humanitarian logistics uses a lot of maps and small status reports. This maps are used to simplified the real situation and pinpoint the important information. However, it can increase the quality of the operation when complexity is shown within those maps and reports. Showing them which assumptions are made, which information is not shown, showing eventual disturbance and so on.

A good practical example of embracing complexity is now happening with the Department of Waterways and Public Works. At this moment they try to begin working with volunteers. They openly state that in the past they were not keen about working with volunteers. They thought this only brings complexity. Now they openly agree that volunteers help them. They are looking for ways in which they can work together with them (Riesenkamp, 2021). In a way this is all about embracing complexity and acknowledging that embracing complexity can improve the quality of the operation.

When this hypothesis is true and complexity leads to a better collective sensemaking, increasing complexity and embracing complexity helps in all kinds of complex issues. The normal way to go for people in that kind of situations is to make things more simplified in order to efficient solve the task. Embracing complexity leads to a moment of evaluation. In dealing with some of the current very complex and societal problems (the Covid-19 pandemic, Dutch childcare benefits scandal) it is concluded that more reflection was needed (Koopmans, 2021; Visser, 2021). This would create a better plan of action. Adding this complexity and bringing persons into the disturbance leads to a moment in which they must reflect and adjust their view of the situation and problem. It means that adding complexity can be helpful in multiple settings and situations.

The results show a huge investment is needed from an economic perspective to create such an FFM seaport. This investment is even more when complexity is taken into account. However, in perspective it is only a small percentage of current financial resources or expenses of big disaster relief organizations. The largest problem in practicality is the sizes of the seaports. The seaports are very big and thus require very large storage facilities. It can be seen as a waste of resources to not use these kind of seaports when they are not in use for disasters. Maybe it even increases complexity when the seaports are in use when disasters happening and decisions have to be made which usage gets priority.

When the choice is made to use a FFM seaport, decision makers need to look at the different input configurations. They have to ask themselves which input confirmation (which handling capacity tactic and demand situation set) will most likely happen in the future. It is possible to take the resulting design of this run as a starting point when designing such a seaport. The facility locations and amount of handling capacity stored at those facilities is economic wise the best option for that settings. It is possible that the final design alter from this economic wise optimal solution by taking for example political consequences or increasing the complexity into consideration.

The results are also interesting when looking at places to store relief goods in general. Reaching every large island with ship within a certain amount of time is possible when opening a facility in Kuala Lumpur and Algiers. The islands with low risk of being affected by a disaster are able to receive help within four weeks. Islands which have a large risk can receive help within two weeks after the occurrence of a disaster. The research discusses that islands are more susceptible for disasters then other areas from a geographic point of view (Thomas et al., 2020; UN-OHRLLS, 2011; Veron et al., 2019).

Kuala Lumpur is already seen as an important basis as it is used as a location of the United Nations Humanitarian Response Depots (UNHRD). This research confirmed the importance of Kuala Lumpur as its facility is opened in every different run. No matter the input configuration, this facility is necessary. This is interesting since this means that storing relief goods at that location seems like a good strategy. From this perspective opening a depot in Algiers is considered a good move for the UNHRD.

The disaster relief effort analysis also contains some implications. The analysis shows a seaport is not often destroyed during a disaster. In the case a seaport is destroyed, in most cases only a little time is necessary to fully repair it. This implicates that a FFM seaport would contribute more in dealing with the overflow of goods by creating extra handling capacity.

Lastly, this research analyses every island with more than 265.000 inhabitants. It defines the probability that a disaster happens at that demand point and the consequences of a possible disaster. Secondly, disaster situation sets are composed based on history. These sets show which islands have been affected in the past or are connected to seas where events have taken place in the past. It shows the season of year that islands are affected. Both insights gives interesting information in the vulnerability of islands. These insights can help prioritize attention towards disaster preparedness of islands.

This research has a couple of implications for practise. The research calls for an increased complexity within the humanitarian logistics operation. Next to that, the research shows storing relief goods in Kuala Lumpur and Algiers is a good idea. Another important insight is that the FFM seaport is possible to realize from a financial point of view. However, a lot of handling capacity is stored in this situation. It can be seen as a waste of resources to not use this handling capacity when they are not used for disaster relief effort.

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A

Research Paper - logistics research

Incorporating uncertainty in a humanitarian logistics facility location model by using a preprocessing step

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Abstract

A lot of set covering mathematical optimization models are created to help in disaster relief logistics. These models need to incorporate uncertainty since this is a major characteristic of disaster relief operations. Currently, a lot of humanitarian logistics facility location set covering models uses scenarios to deal with the uncertainty. This leads to complex hard to solve multi objective and multi stage set covering models. This paper proposes to use a preprocessing step to incorporate uncertainty. Within this preprocessing step, based on uncertainty, there is determined which facilities can help which demand points. The outcome can be used in a deterministic single stage set covering model, easy to solve.

keywords: humanitarian logistics; disaster response; mathematical optimization; warehouse location; disaster relief effort; operations research; uncertainty; set covering; facility location allocation

Introduction

3,751 natural disasters have been recorded between 2008 and 2017. An estimated 2 billion people have been affected and $1,658 billion has been lost in damages due these disasters (Fisher et al., 2018). It is strongly believed that two factors increases the frequency and impact of natural disasters in the coming 20 to 30 years (Ehrhart et al., 2008; Keen et al., 2003). Climate change has and will increase the frequency and intensity of extreme weather events. Next to that, the impact of natural hazards also increases due to the concentration of population in urban area's.

Investments in disasters preparedness and response are necessary to deal with the expected rise of the frequency and impact of extreme natural hazards (Ehrhart et al., 2008; Keen et al., 2003). Logistics play an important role in effective disaster response and relief (Altay et al., 2009; Majewski et al., 2010; Thomas and Kopczak, 2005). It is estimated that around 60-80% of the income of humanitarian organizations is spent on logistics (Tatham et al., 2017).

Many, various facility location optimization models for emergency humanitarian logistics have been developed to deal with the logistics aspect of disaster relief efforts optimally (Boonmee et al., 2017; Hezam and Nayeem, 2021; Li et al., 2011). For most cases these models deal with two decisions: (1) which sites must be selected as depots for storing facilities and (2) what quantity of goods must be stored at these depots to serve the demand points (Li et al., 2011). Facility location optimization models help in strategic planning and design during pre-disaster operations (Boonmee et al., 2017).

Most humanitarian models use the minimization of costs as a main guideline (Anaya-Arenas et al., 2014; Caunhye et al., 2012). The resulting models are set covering models. The objective of these models is to cover all demand points within a predetermined maximum distance while minimizing the total costs of opening facilities (Li et al., 2011).

There are three key performance indicators and one characteristic of humanitarian logistics important when designing logistical models for disaster relief efforts (Bilgen and Ozkarahan, 2004; OCHA, 2017). First speed. The relief goods must arrive at the right place at the right time. Second appropriateness. The right type and amount of goods, must arrive at the right place before it is too late. Third costs. Some storage locations have a higher costs then other storage locations. The more goods have to be stored at a facility, the higher the costs of purchase and cost of purchase. Next to that transportation of the goods also costs money. Fourth uncertainty. Uncertainty in a disaster relief effort is related to the timing, geographic location, type of commodity and quantity of commodity (Liberatore et al., 2013). The uncertainty of the geographic location causes other uncertainties and is there the most important one (Liberatore et al., 2013).

To model uncertainty, these humanitarian logistics set covering models make use of scenarios. A scenario represents a situation in which one or several demand points are in need of supplies. One scenario represents the occurrences of a disaster. The logistical models give a probability on the chance of this particular scenario happening. Scenarios with a higher probability contribute more to the objective function and are thus more important to optimize than scenarios with a lower probability. This means that one decision variable can and will vary as scenarios differ.

However, the humanitarian logistics facility location models need to find the optimal location and amount of relief goods to be stored to respond to multiple disasters. The location and number of storage facilities as well as the amount of goods stored have to kept the same over all scenarios by the models to respond to any disaster. For example, it is not that in order to help for one disaster only a location in Oslo is opened and in response to another disaster only a location in Barcelona.

As a result only the transportation of the relief goods can vary over every scenario. These transportation cost of an relief operation are influenced by two main factors: the travel distance and amount of goods, that travel. For every disaster the amount of goods to sent from facility to demand point varies. However, the logistic models give problems when summing only the part of the objective function which minimizes the costs of transporting over all scenarios. This focuses on cost reduction in transportation caused by travel time which depends on the locations of the to be opened facilities. This means that the cost part related to transporting relief goods is also multiplied for certain scenarios by a certain possibility factor. Leading to the ratio of the costs between opening facilities and transporting relief goods changing. This results in an inappropriate way of taking the dependence of both costs into account. The current literature sees the same problem.

Current humanitarian logistics facility location set covering models deal with the problem by creating a multi stage, multi objective approach. Such an approach makes the problems difficult to solve. This makes them unpractical for disaster relief organizations, which have limited resources. This paper has the goal to find another way of dealing with this problem.

Current literature

Current literature shows two ways to deal with the uncertainty of the exact location of a disaster happens. The first is the way of Aly and White (1978). They state that a demand point can only be covered by a facility if a specific probability is above a certainty threshold. This is the probability of the distance between that demand point and the facility is lower then the individual maximum service distance. This individual maximum service distance is the maximum distance the goods can be stored from a demand point while being able to arrive on time at that demand point if needed.

Rawls and Turnquist (2010), Jabbarzadeh et al. (2014), Chang et al. (2007), Oksuz and Satoglu (2020) and An et al. (2015) all deal with the problem by creating a multi stage approach. Rawls and Turnquist (2010) for example, first determines the locations and supply allocation of facilities under the objective to minimize costs. In this initial stage the decision variables are just determined once. The second stage determines the route selection, the amount of unmet demand and the amount of unused relief goods. This is done under the objective to minimize the cost of the route, unmet demand and unused relief goods. Multiple scenarios are calculated in the second stage and the sum of all these scenarios including the probability of occurring of these scenarios is minimized. However, these two stages are dependant of each other. The decisions made in the first stage (the position of location facilities) influences the decisions made in the second stage (route selection). This makes the model computational complex. A heuristic algorithm referred to as the Lagrangian L-shaped method is developed to solve the problem. This method calculates the expected value of the second-stage and incorporates this in calculating the first stage while minimizing everything.

Jabbarzadeh et al. (2014), Chang et al. (2007) and Oksuz and Satoglu (2020), all use a similar approach as discussed above. The first stage in those four models locates facilities with the objective of minimizes the opening costs. The other objectives relevant for that specific model such as the operational costs, transportation cost, supply-shortage cost and inventory costs are minimized in the second stage. All three models first determine the first stage before a specific disaster scenario happens. The second stage is calculated over different scenarios. To deal with the dependency of the two stages the three models all uses a different strategy. Jabbarzadeh et al. (2014) formulated a robust model, Chang et al. (2007) used a sample average approximation to solve the problem and Oksuz and Satoglu (2020) assumed that the first objective, placing the facilities, is more important and thus the second stage is solved after the first stage.

An et al. (2015) used a different order of stages. The first stage assigns the traffic while minimizing the en-route travel cost over all scenarios. The second stage determines the facility location while minimizing the total cost of: facility set-up over one scenario and unsatisfied emergency service demand and in facility queuing over all scenarios. To deal with the dependency of the stages, a customized Lagrangian Relaxation algorithm is used to find near-optimum solutions.

Form the above can be concluded that using scenarios in order to model the uncertainty of the exact disaster area leads to multi stage and multi objective set covering models. These models are complex to solve. Most literature used non exact solving methods for them. Only the model of Oksuz and Satoglu (2020) does not use this complex solving strategy. However, this model first determines the location of every facility while minimizing only the cost of facilities to open. It afterwards optimizes the cost of storage and transporting the relief goods while minimizing the other costs. This method can lead to a solution in which the total costs are higher in the end than when the objectives would have been combined in one objective function.

Proposed prepossessing step

This paper has the objective to simplify solving of a logistic set covering model by keeping the model deterministic. It proposes to achieve this by the use of situations and incorporating the uncertainty within a preprocessing step. Situations are very similar to scenarios but differ. A scenario takes the probability that a given scenario will happen into account. A disaster situation does not take this into account. A situation consist of all demand points which need help within the same time frame.

The preprocessing step starts with defining a maximum service distance for every demand point. To define this distance the probability of a disaster happening and the consequences of a disaster is checked for every demand point. Together with the possible speed of sending goods, these two factors determine the maximum distance to be considered covered for every individual demand point. In case of a low occurring probability and/or the disaster impact, the maximum distance of coverage is larger for that specific demand point than if the probability and/or impact is high.

After maximum service distance determination, this preprocessing step determines whether a demand point can be covered by a potential facility location. This preprocessing step is inspired by the research of Aly and White (1978). Their model also contains a preprocessing step. The uncertainty is coupled with the maximum service distance by an equation. The following adjusted equation for the preprocessing step is used:

$$a_{ijs} = \begin{cases} 1, & \text{if } d_{ij} \leq Sd_j \\ 0, & \text{if } d_{ij} > Sd_j \end{cases} \qquad \text{(A.1)}$$

This equation states that demand point j is covered by a facility i if the distance between those two d_{ij} is lower than or equal to the predetermined maximum service distance of that demand point Sd_j.

Example application of preprocessing step

The resulting matrix from the preprocessing step can be used in a set covering mathematical optimization model. This papers presents an example of such a model which incorporates this preprocessing step. This example set covering model has the goal to define the storage locations for a certain necessary relief good, the amount of relief goods stored at those locations and the amount of relief goods transported from a storage location to a demand point. This while minimizing the amount of costs to response to multiple different disaster situations.

This results in the following model:

Indexes and Set:

I	Set of facilities indexed by $i \in I$
J	Set of demand points indexed by $j \in J$
S	Set of demand situations need to be responded to by the storage facilities indexed by $s \in S$

Input Parameters:

a_{ijs}	1 if demand point j can be covered by facility i in situation s and 0 otherwise. See equation A.1
R_{js}	The requested amount of relief goods at demand point j in demand situation s
M	A very big number
H_s	The amount of times a disaster situation happens
C_i^1	Cost to open facility i
C_i^2	Cost to place one relief item in facility i
C_{ij}^3	Cost to transport one relief item from facility i to demand point j

Decision Variables:

y_i	1 if a facility is located at candidate node i and 0 otherwise
x_{ijs}	The amount of relief goods sent from facility i to demand point j in demand situation s
q_i	The amount of relief goods stored in facility i

Objective function:

$$\text{Min} \sum_i y_i C_i^1 + \sum_i q_i C_i^2 + \sum_s H_s \left[\sum_i \sum_j x_{ijs} C_{ij}^3 \right] \tag{A.2}$$

Constraints:

$$\sum_i x_{ijs} A_{ijs} \geq R_{js} \qquad \forall j, \forall s \tag{A.3}$$

$$\sum_j x_{ijs} \leq q_i \qquad \forall i, \forall s \tag{A.4}$$

$$x_{ijs} \leq y_i * M \qquad \forall i, \forall j, \forall s \tag{A.5}$$

$$y_i \in \{0, 1\} \qquad \forall i \tag{A.6}$$

$$x_{ijs}, q_i \geq 0 \qquad \forall i, \forall j, \forall s \tag{A.7}$$

The objective function A.2 minimizes the total costs of opening facilities, storing the relief goods at those open facilities and the transport of relief goods from those facilities to the demand points.

Constraint A.3 states that (1) the sent relief goods from all facilities to a demand point is greater than or equal to the demand at that point for that given demand situation and (2) that relief goods will only be transported from facilities which are in the maximum covering distance of a demand point. Constraint A.4 ensures that the total amount of relief goods transported from a facility to all connected demand points is always less than or equal to the amount of relief goods stored at that facility for each demand situation. Constraint A.5 ensures that relief goods will only be transported from facilities which are open. Constraint A.6 defines the binary location variable. Finally, constraint A.7 represents the fact that the sent relief goods from a facility to a demand point and the amount of relief goods stored at a facility can not be negative.

To showcase the possibilities of this model the above model was solved with some quick estimated inputs. With the help of Yalmip, the mathematical optimization model was build in Matlab

(Löfberg, 2004). The model was solved with the Gurobi solver (Gurobi Optimization, 2019) to obtain the results. The set of facilities contained 62 facilities, the set of demand points contained 86 demand points and the set of demand situations contained out of 29 different disaster situations that happened. The time needed to solve the model was 7:10 minutes.

The results of the solved mathematical optimization model showcases how such a model can be applied for helping in real life decisions. The input parameters and indexes and set where quick estimated inputs. These inputs were based on the question where and how much relief goods have to be stored in order to be of help. Multiple different facility options all over the world were chosen as long as it were cities which had a seaport. The disaster situations contains of the disasters of the past 38 years affecting bigger islands. The distance to be considered as covered was determined for every island based on the probability that a disaster will happen at that island. Based on that, for every island there is determined which possible facility location can serve that island. The results shows that opening facilities in Kuala Lumpur, Dakar, Luanda and Berbara was the cheapest option. Next to that the results also indicates the amount of goods stored at those locations and how many goods there have to be transported from a facility to a demand point in response to certain disaster situations.

Finally, it is is interesting to show how the showcase model determined the maximum service distance. The showcase model compared every individual demand point in order to determine the maximum service distance. For every demand point the probability that a disaster will happen at that demand point and the consequences if a demand point is affected by a disaster are taken into consideration. The probability that a disaster will happen is based on the geographic vulnerability of the location of the demand point and the amount of previous big disasters. The consequences if a disaster affects a demand point are based on the likelihood of generally suffering damage, the amount and size of airports on the island and the amount and size of seaports on the island. The probability that a disaster will happen and the consequences if a disaster happen are combined. This determines the maximum distance for a demand point to be considered as covered. The showcase model assumes that demand points which score bad on the probability and consequence factor needed the relief goods 14 days after a disaster happened. If the demand points scored excellent on these factor, the time for the relief goods to reach that demand point is two times as much.

To calculate the exact amount of time allowed between the disaster happening and relief goods arriving a formula is used. This is the following Formula A.8:

$$MF = 1 + (0.5 * (0.5 * GV_c + 0.5 * PD_c) + \\ 0.5 * (0.33 * S_c + 0.33 * Air_c + 0.33 * Sea_c)) \tag{A.8}$$

Where MF stands for the multiplication factor, GV_c for the geographic vulnerability classification, PD_c for the previous disaster classification, S_c for the susceptibility classification, Air_c for the airports classification and Sea_c for the seaport classification. In order to determine these classifications the scores of the demand points on the individual factors are compared. The demand points in the highest risk/vulnerable quantile scored a 0 on that factors, the demand points in the second highest risk/vulnerable quintile scored a 0.25 and so on.

In the end the result of this equation, the multiplication factor, is multiplied with 14 days in order to determine the amount of time allowed between the disaster happening and relief goods arriving at that specific demand point. All facility locations which are able to transfer the relief goods within that amount of time to that specific demand point are able to help that demand point as is determined by equation A.1

Conclusion and discussion

Set covering facility location models are important in humanitarian logistics. They help to find the cost wise best facility locations to store relief goods. Uncertainty is a major characteristic of humanitarian logistics and thus the way in which uncertainty is modeled is important in humanitarian set covering facility location models. The problem is that until now scenarios are used to model this uncertainty. Scenarios take the possibility that a certain disaster will happen into account. This research concludes that using scenarios leads to complex hard to solve multi objective and multi stage set covering models. The best facility to open in one scenario can be different then the best facility to open in another scenario.

The research question of this paper is if it was possible to define another way of dealing with uncertainty in order to create a simple easy to solve model. This research concludes that this is possible by using a prepossessing step. This preprocessing step incorporates uncertainty in the maximum service distance. This maximum service distance is within set covering models the maximum distance a facility can be located from a demand point while still be able to serve that demand point. This research propose to define the maximum service distance by taking the probability of a disaster happening and the consequences of a disaster happening into account. When these two factors are low the maximum service distance is larger then when these two factors are bigger. The preprocessing step determines which facilities are able to help a demand point and puts this in a mathematical optimization model. This leads to a deterministic single stage model, easy to solve.

Note that incorporating this uncertainty in the maximum service distance creates a limitation. It is not in line with the speed characteristics. There is the possibility that the goods are not available at the right time when a disaster occurs at a location where a disaster is not predicted. Incorporating uncertainty in the amount of demand necessary is also possible, but this creates the probability that the appropriateness characteristics is not met. (Liberatore et al., 2013) argues that the best way to incorporate uncertainty is by the geographical location. Not incorporating uncertainty is also possible, but in this situation the uncertainty characteristics are not met. The above indicates the difficult balance between the different humanitarian relief logistics characteristics: speed, costs, appropriateness and uncertainty.

It is recommend to do further research towards the performance of models which incorporates the uncertainty in such a preprocessing step. A comparison between the complex probabilistic multi stage model and this deterministic single stage model. Interesting remaining questions is if it indeed is easier for humanitarian organizations to use such kind of model and how the performances between the models differ?

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B

Military aid in disaster logistics over sea

The military can help with personnel and equipment during disaster relief efforts. It is important to get an overview about their capacities with respect to disaster relief efforts. Within the conceptual design of the FFM seaport the capacity of the military can taken into account and the seaport will be an addition on this already existing capacity instead of replace it.

So a small investigation is performed about the connection between the military and disaster logistics. It is found that the military can affect disaster logistics in two ways. First, military can help in creating cargo handling capacity after a disaster occurred. Second, disaster logistics experts and employees can learn from military ship to shore operations. Think Defence (2015) has made a comprehensive overview of all past big, military involved, ship to shore operations. This chapter will highlight the most important aspects for disaster logistics of this overview by discussing the past military ship to shore operations.

When looking at past military ship to shore operations, D-day is perhaps the most well known. A similar operation was the amphibious operations during the Iraq war. During D-day and the Iraq war the operation was mostly focused on getting soldiers and roll on roll off equipment on the shore (Think Defence, 2015). These two operations are thus not further described.

B.1. Falklands war

During the Falklands war, the operations was not only focused on transferring soldiers and roll on roll off equipment to the shore. Before the war there was a small port in San Carlos. During the war amongst other infrastructures an airport had to be constructed. The seaport was too small to handle all the different construction personnel, equipment and materials necessary to construct these infrastructure. The military did not had experience in handling such amount of cargo because until that moment the military had only experience with using smaller ships with bow ramps. These ships can be seen in Figure B.1. These are ideal for amphibious operations, but could not reach the necessary handling capacity with respect to container handling (Think Defence, 2015).

To solve this problem six barges (90x27 metres and about 10,000 DWT each) were connected together to let them float before the coast. They were linked to the shore via a 180 metre causeway which was build on structural dolphins with a final and smaller barge acting as a floating linkspan between the causeway and the big barges. The barges also provided significant (refrigerated) storage, offices and accommodation. It took 5 months to build and install these construction. After the build was finished it was transported to the Falklands by two heavy lift FLO FLO vessels. These heavy lift ships were faster and safer than towing (Think Defence, 2015).

As a comparison this new seaport could unload 500 tonnes of general cargo and 60 containers in 30 hours, whilst it would cost 21 days to offload the same load by small ships with bow ramps. All this

Figure B.1: Smaller ships with bow ramps, normally used by military to transfer goods from ships to shore (Think Defence, 2015)

costed 55 million euro's in today's money. Within 2 years these investment costs were already recouped. A couple years after the initial deployment during the war the port is gifted to the government of the Falkland Islands and is still being used today (Think Defence, 2015). The transport of the barges and final construction can be seen in Figure B.2.

Figure B.2: The transport of the barges (left) used for the final construction of a floating seaport in Falklands (right) (Think Defence, 2015)

The company who had designed this port had developed the concept further and is now working under the name of Flexiport. By mooring custom designed and built pontoons in sufficient depth of water, a seaport is created. The pontoons are connected to the land with a prefabricated bridge or causeway. This design can handle 150 TEU's per hour. The port can be installed within hours. Within the new design the barges can still float in order to put them in the right orientation and place, but when they arrive they will lifted above the sea and put on their place by lowering a construction dolphin into the seabed. The barges can be relocated by moving this construction dolphins up, making the barges float again and ready to be towed to another location (Flexiport, 2015). However according to their website, not updated since 2015, they only have made some simulations and design and did not have made this design a reality yet (Flexiport, 2015).

The new design means that one of the key advantages of using floating barges is not valid anymore; the fact that they do not transmit any load to the sea bed and thus can be used independent from the sea bed characteristics. The Space@Sea project focuses on floating modules so this advantage is still valid for this research. A picture of the Flexiport design can be seen in Figure B.3.

Figure B.3: The Flexiport, flexible seaport, design (Flexiport, 2015)

B.2. Haiti earthquake

Military also played a huge role within the Haiti earthquake response. The 2010 Haiti earthquake completely destroyed Port-au-Prince which before the disaster handled around 450 TEU's per day, 95 % of the nations total (CSA, 2014; Noel, 2009; Think Defence, 2015). Haiti was the poorest country in the western hemisphere and due to the earthquake 230,000 people died, 197,000 were injured and over 1.2 million were displaced. It was estimated that a total of 140,000 tonnes of food and 160 tonnes of high energy biscuits, for places where no cooking fuel was available, would be needed. Almost immediately the US had contracted shipping companies to transport 10,700 tonnes of food, approximately 560 containers worth, to Haiti (Think Defence, 2015). The challenge was to get these food and supplies from ship to shore.

Other ports in Haiti were not damaged but much less capable of handling cargo, especially for containers. All cranes of Port-au-Prince were destroyed or in the water and the quays either submerged or significantly weakened. The port was in no state to receive the huge amount of cargo needed to provide aid to the affected people. However almost immediately militaries from different countries, mainly from the U.S. responded to this humanitarian crisis. The initial response was primarily focused on air transport, between 2 and 7 days after the disaster most of the goods were transported by air (Think Defence, 2015).

The first navy ship was at the scene 2 days after the disaster. The early ships were mostly involved with surveying the location and damage with their priority in locating and removing underwater debris. 6 days after the disaster the first navy ship was able to dock in the port since on of the piers, the south pier, was partially repaired. 8 days after the disaster military ships with a bow ramp (RORO vessels) arrived who can load and unload cargo via the beach (Think Defence, 2015).

However they quickly noted that the port was in no state to receive cargo of any significant volume. This means that other ports must handle the cargo. Ports in the Domincan Republic and outside of the earthquake damage zone in Haiti were used but quickly were severely congested, more handling capacity was necessary. The Ria Haina port in the Dominican Republic could only handle 56 TEU of cargo intended for the disaster relief effort in the first 10 days after the disaster (Think Defence, 2015). So in order to deliver goods to Haiti another solution was necessary. With the help of military equipment the sea port throughput after the earthquake which can be seen in figure B.4 could be realised. This was the theoretical throughput which could be reached during the disaster relief effort. The actual throughput was lower (Think Defence, 2015).

As can be seen in the beginning the south pier could operate and theoretically reach a throughput of 250 TEU per day. However due to the damage only small ships could dock the pier and since the pier could not accommodate a crane and multiple trucks, only small ships with a bow ramp could transfer

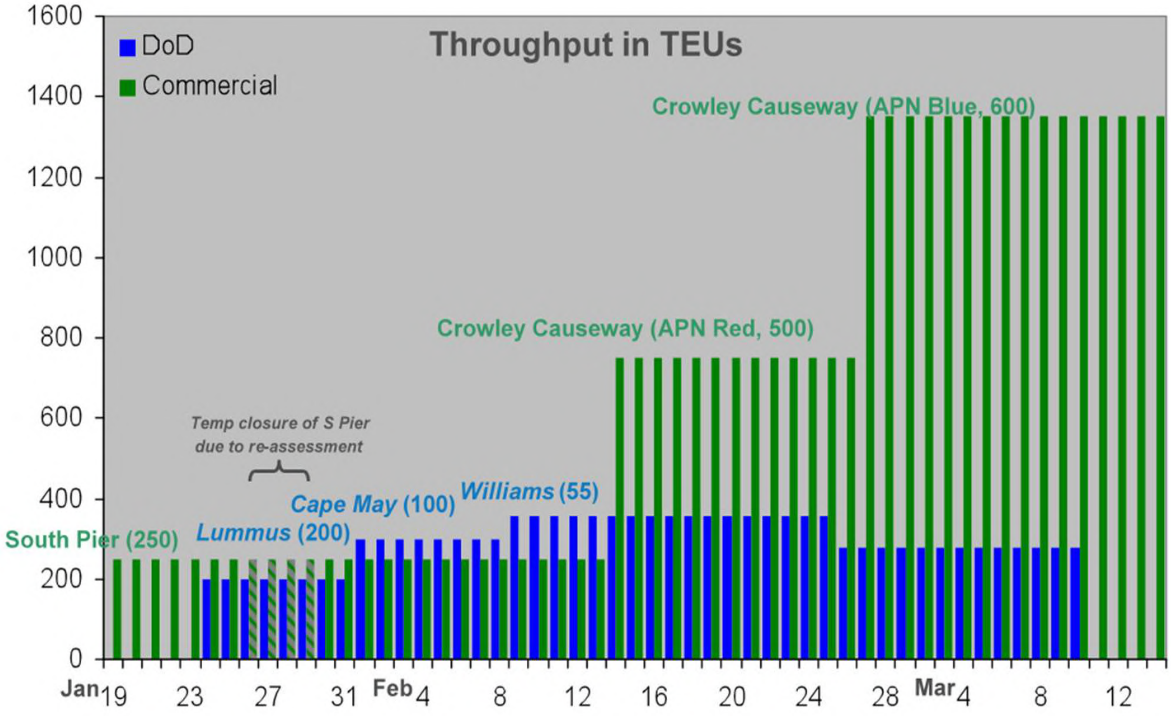


Figure B.4: Haiti sea port throughput after the disaster (Think Defence, 2015).

goods from the ship to the pier. Bigger container ships were laying in the port and by transferring this goods to small barges equipped with a bow ramp the containers could reach the pier. This means that goods need to be doubled handled before they reach the shore. This is very time consuming and thus the throughput of this process could not reach the necessary volume needed to help all affected people (Think Defence, 2015). Since other ports of the island were severely congested, cargo needed to go over the beach to be transferred to the damaged area. The military has some special ships and experience to deal with transferring cargo over beach. Big military ships as the Lummus, Cape May and Williams could store cargo and since they are equipped with equipment and bow ramps they could unload cargo via the beach. These ships and solutions are however designed to support an army force, not a damaged city with millions people in need (Think Defence, 2015). The low throughput of military material can be seen in the blue bars of figure B.4.

So it was necessary to have a working pier that would allow large cargo ships to dock and unload cargo directly to the shore. In the end this pier is created by using spudded barges to act as piers and equip this barges with mobile cranes (Think Defence, 2015). This meant that cargo could directly be loaded from ships to trucks. This concept look more or less like the Space@Sea solution, however the first pier was operational more then a month after the disaster. Partly because of the travel time and partly because of the need for debris removal (Think Defence, 2015). On the 7th day after the disaster the barges started with their travel from Texas to Port-au-Prince, a journey of around 3000km, 21 days after the disaster the barges arrived and still 10 days of installation was needed before it was operational (Think Defence, 2015). The barges which created the second pier arrived and was installed even later (Think Defence, 2015). This barges were being used till the moment the new terminals and piers were build, June 2016 (ECLAC, 2016). In the aftermath of the earthquake the barges handled annually more TEU then the original port before the earthquake. Especially in 2010-2011, right after the disaster, a lot of TEU was handled as can be seen in Figure B.5.

B.3. Insights

There are some insights which can be gained based on the Falklands war and the Haiti disaster response. In both cases a lot of militaries from different countries were already in the area which speeded

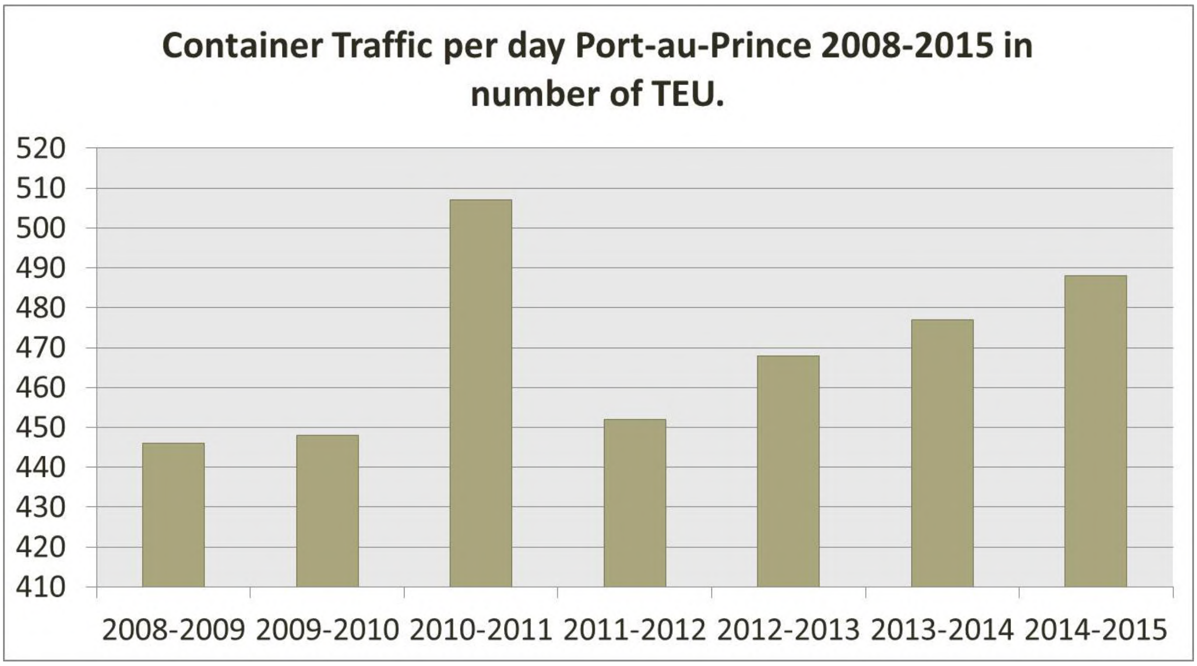


Figure B.5: Container Traffic per day Port-au-Prince 2008-2015 in number of TEU. Based on CSA (2014); ECLAC (2015).

the initial response. Next to that this militaries are off course highly trained to deal with this kind of situations. However the amount of different (military) organizations involved created many command and control problems (Think Defence, 2015). In Haiti for example the US military was given full permission on airspace control, which created tension mostly with civilian respond organizations. This was especially a problem since the lack of infrastructure forced the delivery of goods by airdrops (Think Defence, 2015).

Another factor that speeded the Haiti response was that the geography and time of year ensured that sea conditions were most perfect for this kind of operations. Another place or/and another time could have completely changed the ability of the military to get so much ashore so quickly (Think Defence, 2015). Military material is better equipped to transfer wheel based material from ship to shore then standardised containers. This means that the military material had the potential to transfer 700 TEU in Haiti but in the end they were only capable of handling 355 TEU per day (Think Defence, 2015). This means that going over the beach with help from the military is a solution for the short term when not that much handling capacity is needed but it simply cannot meet high volume demand. A single barge with one mobile crane could more than double the military capacity (Think Defence, 2015).

Lastly, the above showed the need for a FFM seaport which can be used during disaster relief organisations. In the end this seaport was created by barges, but this process was very time consuming. The Haiti earthquake and Falklands war showed the need for such a seaport because there was no alternative way of transferring goods from ships to the affected area, even not by other ports on the island (Think Defence, 2015).

As concluded by the evaluation of Cecchine et al. (2013) a serious problem emerged because of the informal top down process of pushing resources so quickly. By rushing high volumes of people, equipment, and supplies to the disaster area, the relief effort was likely flooded with more of some resources than were needed and less than were needed of others. The evaluation concluded that is difficult to suggest a more systematic method to plan such operation. This research maybe can give a starting point by investigating the effect of using a FFM seaport on this problem. This material convergence problem is described in more detail in chapter 4.

For military operations it would also be handy to have a FFM seaport. Nowadays must military operations make use of existing port. These ports are easy to defend by the enemy, for example with mines, and normally it cost a lot of time to take over and secure a port (Think Defence, 2015). Until today the military has not a facility to create an efficient port structure in order to transfer a huge amount of goods efficiently from the ship to the shore (Think Defence, 2015). They only have options to transfer goods from ships over the beach to the shore. They can make an elevated causeway which is a portable modular structure that can be built out from the beach to a distance of 900m into water of maximum 6 metres deep (Think Defence, 2015). This limited depth only allowed small vessels to come alongside and discharge their cargo. The main goal is to bridge the surf zone and decouple the loading/unloading equipment from waves and tide. This option can only be used by small logistic support vessels and pontoons/barges (Think Defence, 2015). This makes that a port created for military operations never could reach the throughput of an established port.

In the overview of Think Defence (2015) a small investigation is performed in order to check if it is possible to design a flexible seaport which the military can use in order to get supplies, equipment and personnel on the shore at logistically challenged locations. Requirements are that the port must be operating after 48 hours of the start of the construction and must be operable for a minimum of 90 days. The seaport, consisting of floating barges, must be operated in minimal 9 metres deep water. Since water depth vary across the world, the pier must be capable of spanning maximum 2000 metres between the shore and the floating barges. There are a couple of options however it will be a challenge to create a pier this long within 48 hours. According to the research it is possible and they argue to use the WaveWalker in order to create the pier. This is a walking leg jack-up platform used for construction and geotechnical investigation in rough seas, surf zones and beaches. The WaveWalker has 2 sets of 4 legs and since only 1 set is necessary in the seabed at a time, bi directional movement whilst elevated is possible and thus the jackup can move and relocate without floating after they have constructed a part of the pier. Also, in order to allow safe and efficient offloading at the barges the motion between the ships and barges must be minimised. This can be done by using commonly used floating breakwaters.

In order to ship all necessary material to the targeted location it is argued to use a semi-submersible heavy lift vessel, often called a float on flow off (FLO/FLO) vessel. At the target location these ships are ballasted down and the cargo can float off, something which is commonly used for extreme cargo and offshore constructions. This kind of vessels can reach speeds between 15 and 18 knots (27,8 and 33,3 km/h). This transport option is chosen because self-propelled barges are expensive and towlines parting are not uncommon. In the end the investigation concluded that such a flexible seaport is something which can be constructed and would massively increase the logistical options within military operations.

It can be concluded that the military can handle a very impressive amount of roll on roll of cargo, but it is not able to handle efficiently large amount of quantities of break bulk or ISO containers. Container handling is very slow in comparison with the established port handling equipment. Next to that the military is also interested in FFM seaports since this creates the opportunity to push amphibious operations further away from the enemies infrastructure.

C

Additional information disaster relief operation analysis

C.1. Calculation to define the islands of interest for the analysis

As described in appendix B it is known that 10,700 tonnes of food is the same as 560 containers (Think Defence, 2015). Nowadays the most containers are 40 feet containers which is the same as 2 TEU (C-port, 2020). Meaning that it is possible to transport 1 ton of food in 0,1 TEU. Next to that, during the Haiti disaster relief effort, a total of 140,000 tonnes of food was necessary to help all 3,700,000 affected people (Guha-Sapir et al., 2020; Think Defence, 2015). Meaning that one affected person needs 0,004 TEU of food during a disaster relief effort. UN News (2010) conclude that 89 tonnes of food contains 500,000 emergency meals, and thus a person needed 220 emergency meals during the Haiti earthquake. Next to that a 40 feet container, 2 TEU, can contain shelter, clean water tablets and other emergency goods for 200 people (Canadian Red Cross, 2010; UNDP, 2010).

When calculating further with the numbers above it can be calculated that, in the case that all people of an island with 100.000 inhabitants would be affected, in total 400 TEU is necessary to aid those people with food and 1000 TEU with shelter, clean water tablets and other emergency goods. This means that in total the whole relief operations needs 1400 TEU and this amount of TEU could be handled by the military equipment within 4 days. The military personnel and equipment can handle all the necessary shelter goods and 3.5 million meals within 72 hours after they are on the site. Since the military has the equipment to deliver those handling capacity the FFM seaport is not necessary to be used in situations where a small island is hit by a disaster. Within the disaster relief effort analysis only disaster are taken into account if an island is affected with at least 100,000 inhabitants.

C.2. Selecting large scale disaster in EM-DAT database

In the EM-DAT database the total damage is given for the total disaster and no distinction is made in the amount of damage per country. No amount of damage for the disasters per country is found, thus the total damage is used in the calculation. This means that for disasters which hit multiple countries, the amount of damage which is used to calculate the percentage of GDP is higher than the amount of damage that this island actually encountered. As a consequence this means that for some disaster the total damage for that island is higher in the calculations than what was actual the case in the real world and thus that in the selection of disasters some disasters are selected which would not have been selected if the actual amount of damage was known.

Next to that, since only islands are investigated, it can happen that the total amount of damage was for all affected countries and that for example an island country was affected but also a country on the mainland. The total amount of damage is than seen as the amount of damage on the island, given the same problems as described above. Next to that, it can also happen that only an island is hit which is part of a bigger country. The GDP of that total country is then taken in order to calculate the percentage, which is off course higher then the GDP of only the island. In that case sometimes a disaster is not selected due to a low damage percentage while this in reality would have been a higher percentage. Above limitations must not be forgotten when drawing conclusions from the disaster relief effort analysis.

If a disaster in the EM-DAT database does not contain information over the total damage, only the partial damage is used or if that is also not known this disaster is not taken into account. The GDP of the country per year in American Dollar is taken from the Worldbank Data (World Bank Data, 2020a). However this data set does not contain every necessary data point. The missing data is gathered from the Unctad Stad database (UNCTADSTAT, 2020), Jornal Económico (Flag, 2020), Macrotrends (Macrotrends, 2020), EDOM (EDOM, 2012), Countryeconomy (Countryeconomy, 2020a), Indexmundi (Indexmundi, 2006a,b, 2020), Theodora (Theodora, 2020), Nationmaster (NationMaster, 2014a) and the government of Tokelau (Hughes, 2017). However not every necessary missing data point could be found. In order to fill in the missing gaps the already available data is extrapolated with the mean GDP growth rate of the world found in the Worldbank Data (World Bank Data, 2020b). Next to that the GDP of 2020 was not known at the moment of the disaster relief effort analysis because at that moment the year was not finished. Therefore the same GDP as 2019 is used for 2020.

C.3. Amount of FFM seaport handling capacity necessary

The amount of necessary goods can be based on information about the amount of damage and the necessary goods to repair those damage. Not a lot of information was found in the disaster relief effort analysis about this, but some interesting results can be of support. First of all it is found that 22, 40-foot containers can contain the infrastructure repair needs for 100 families. On average a family contain 5 persons (Kramer, 2020) thus this means that 1 person needs 0.088 TEU of infrastructure repair goods.

With respect to temporary shelter less information was available. Only some dollar figures where given but not the amount of containers or volume necessary per person. The information about shelters is thus directly copied from the quick calculation which was made to narrow down the amount of data for the disaster relief effort analysis as described in appendix C.1. This was 0.01 TEU per person.

For food relief more data was available among the result of the disaster relief effort analysis. It is found that on average a person needs 500 gram per day of food relief. This is more or less in line with the calculations in appendix C.1 where it was concluded that a person needs 430 gram of food per day. When looking at the amount of food which can be transported in one container it is found within the disaster relief effort analysis that 1,728 m^3 contains 409MT of food. Since 1 TEU is 38.51 m^3 (Workshop Insider, 2021), this means that 9MT of food will fit in 1 TEU. When the 500 gram per person per day is taken as a guideline, this means that a person during a disaster relief effort needs 0.000055 TEU of food per day. A little bit more then the 0.000044 TEU of food per person per day as is calculated in the quick calculation to narrow down the amount of data for the disaster relief effort analysis as described in appendix C.1.

With the above it is possible to determine the amount of necessary TEU which the seaport must be able to handle. The infrastructure repair goods and the shelter goods are goods which needs to be delivered once. In total these two represents 0.098 TEU per person. The food relief goods must be delivered every day. This is 0.000055 TEU. As above described the FFM seaport is not necessary anymore after 90 days. Also the seaport needs 14 days to get to the location and get installed. This means that in total the seaport must handle for 76 days of food to the affected people which corresponds to 0.0042 TEU of food per person. When expressing this in monetary values it could be seen from the disaster relief effort analysis that this represents 14 USD per person for food help of 76 days. Next to that a total of 0.088 TEU of infrastructure repair goods and 0.01 TEU of shelter goods is necessary per person. In total this means that 0.102 TEU per person is necessary.

C.4. Timeline of disaster relief efforts of interest

Table C.1: All disasters sort on basis of the end date of the disaster. The sea or ocean where the affected islands are located is included. A color scheme is used in order to show which disasters are simultaneously in need of a disaster relief operation

Name	Affected island, in bold the countries affected large scale by the disaster	Sea or ocean, in bold the sea or ocean of the countries affected large scale by the disaster	Start date	End date	104 days after end date	Help necessary at the same time		
Tropical Cyclone Benedic, Electre, Frida, Justine	**Madagascar**	**West Indian Ocean/Mozambique Chanel**	28-1-1982	25-3-1982	7-7-1982		🟦	
Fiji: Drought 1983	**Fiji**	**South Pacific Ocean**	1-1-1983	1-1-1983	15-4-1983		🟨	
Tropical Cyclone Elinah	**Comoros**	**West Indian Ocean/Mozambique Chanel**	10-1-1983	10-1-1983	24-4-1983		🟨	
Tropical Cyclone Oscar	**Fiji**	**South Pacific Ocean**	1-3-1983	1-3-1983	13-6-1983		🟨	
Samoa: Storm 1983	**Samoa**	**South Pacific Ocean**	1-7-1983	1-7-1983	13-10-1983		🟦	
Tropical Cyclone Kamisy	**Madagascar**	**West Indian Ocean/Mozambique Chanel**	9-4-1984	9-4-1984	22-7-1984		🟨	
Tropical Cyclone Eric, Nigel, Odette	**Fiji**	**South Pacific Ocean**	17-1-1985	19-1-1985	3-5-1985		🟦	
Comoros Islands: Tropical Storm 1985	**Comoros**	**West Indian Ocean/Mozambique Chanel**	14-2-1985	14-2-1985	29-5-1985		🟦	
Tropical Cyclone Honorinina	**Madagascar**	**West Indian Ocean/Mozambique Chanel**	15-3-1986	15-3-1986	27-6-1986		🟨	
Tropical Cyclone Namu	**Solomon Islands**	**Solomon Sea**	19-5-1986	19-5-1986	31-8-1986		🟨	
Tropical Cyclone Rajah	**Fiji**	**South Pacific Ocean**	28-12-1986	28-12-1986	11-4-1987		🟦	
Fiji: Storm 1987	**Fiji**	**South Pacific Ocean**	1-1-1987	1-1-1987	15-4-1987		🟦	
Tropical Cyclone Jan	**Comoros**	**West Indian Ocean/Mozambique Chanel**	3-1-1987	3-1-1987	17-4-1987		🟦	
Bangladesh: Cyclonic Storm/Tidal Surge/Floods 1987	**Bangladesh islands**	**Bay of Bengal**	8-1-1987	8-1-1987	22-4-1987		🟦	
Saint Vincent and the Grenadines: Floods 1987	**Saint Vincent and the Grenadines**	**Caribbean Sea**	9-1-1987	9-1-1987	23-4-1987		🟦	
Maldives: Tidal Waves 1987	**Maldives**	**Laccadive Sea**	11-4-1987	11-4-1987	24-7-1987		🟦	
Tropical Cyclone Emily	**Barbados, Saint Vincent and the Grenadines**	**Caribbean Sea**	21-9-1987	21-9-1987	3-1-1988		🟨	
Bangladesh: Floods 1988	**Bangladesh islands**	**Bay of Bengal**	1-6-1988	1-9-1988	14-12-1988		🟦	
Tropical Cyclone Gilbert	**Jamaica, Haiti**	**Caribbean Sea**	11-9-1988	12-9-1988	25-12-1988		🟦	
Tropical Cyclone Fili & Gina	**Samoa**	**South Pacific Ocean**	6-1-1989	6-1-1989	20-4-1989		🟨	
Tropical Cyclone Firinga	**Réunion, Mauritus, Comoros**	**West Indian Ocean/Mozambique Chanel**	24-1-1989	29-1-1989	13-5-1989		🟨	
Tropical Cyclone Hugo	**Netherlands Antilles, Guadeloupe**	**Caribbean Sea**	17-9-1989	17-9-1989	30-12-1989		🟦	
Tropical Cyclone Ofa	**Samoa**	**South Pacific Ocean**	1-2-1990	4-2-1990	19-5-1990		🟨	
Grenada: Fire 1990	**Grenada**	**Caribbean Sea**	27-4-1990	27-4-1990	9-8-1990		🟨	
Maldives: Storms/Surges 1991	**Maldives**	**Laccadive Sea**	27-5-1991	9-6-1991	21-9-1991		🟦	
Tropical Cyclone Gorky	**Bangladesh islands**	**Bay of Bengal**	29-4-1991	5-10-1991	17-1-1992		🟨	
Sri Lanka: Floods 1992	**Sri Lanka**	**Laccadive Sea**	5-6-1992	8-6-1992	20-9-1992		🟦	
Tropical Cyclone Omar	**Guam**	**North Pacific Ocean/Philippines Sea**	28-8-1992	28-8-1992	10-12-1992		🟦	
Tropical Cyclone Kina	**Fiji**	**South Pacific Ocean**	2-1-1993	2-1-1993	16-4-1993		🟨	
Cuba: Tropical Storm and Floods 1993	**Cuba**	**Caribbean Sea**	13-3-1993	13-3-1993	25-6-1993		🟨	
Tropical Cyclone Hollanda, Ivy	**Mauritius**	**West Indian Ocean**	9-2-1994	11-2-1994	26-5-1994		🟦	
Volcano Rabaul	**Papua New Guinea**	**Coral Sea, Solomon Sea, Bismarck Sea, Arafura Sea**	19-9-1994	19-9-1994	1-1-1995	🟨		
Tropical Cyclone Gordon	**Haiti**	**Caribbean Sea**	5-11-1994	15-11-1994	27-2-1995	🟨		🟦
China: Drought 1994	**China islands**	**Yellow Sea, East China Sea, Taiwan Strait, South China Sea, Gulf of Tonkin**	1-1-1994	1-12-1994	15-3-1995	🟨		🟦
Japan: Earthquake 1995	**Japan**	**Japan Sea**	17-1-1995	17-1-1995	1-5-1995			🟦
Bangladesh: Rainstorm 1995	**Bangladesh islands**	**Bay of Bengal**	15-5-1995	15-5-1995	27-8-1995		🟨	
Tropical Cyclone Luis	Dominica, Antigua and Barbuda, Netherlands Antilles, Saint Kitts and Nevis, **Guadeloupe**	**Caribbean Sea**	3-9-1995	7-9-1995	20-12-1995		🟦	
Tropical Cyclone Marilyn	**Martinique**	**Caribbean Sea**	14-9-1995	19-9-1995	1-1-1996		🟦	
Azores Islands: Storm 1996	**Azores Islands**	**North Atlantic Ocean**	25-12-1996	25-12-1996	8-4-1997		🟨	
Indonesia: Wildfire 1997	**Indonesia,** Malaysia	**Malacca Strait, South China Sea, East Indian Ocean, Java Sea**	1-9-1997	1-9-1997	14-12-1997		🟨	
Tropical Cyclone Gavin	**Fiji**	**South Pacific Ocean**	10-3-1997	10-3-1997	22-6-1997		🟨	
Tropical Cyclone Paka	**Guam**	**North Pacific Ocean/Philippines Sea**	17-12-1997	17-12-1997	31-3-1998		🟦	
Bangladesh: Floods 1998	**Bangladesh islands**	**Bay of Bengal**	5-7-1998	22-7-1998	3-11-1998	🟨		
Tropical Cyclone Georges	Antigua and Berbuda, Belize islands, British Virgin Islands, Cayman Islands, **Cuba, Dominican Republic,** El Salvador islands, Grenada, **Haiti,** Honduras islands, Jamaica, Nicaragua islands, **Puerto Rico,** Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, United States Virgin Islands	**Caribbean Sea**	20-9-1998	30-9-1998	12-1-1999	🟨		🟦
Mauritus: Drought 1999	**Mauritius**	**West Indian Ocean**	1-1-1999	4-1-1999	18-4-1999			🟦
Canary Islands: Storm 1999	**Canary Islands**	**North Atlantic Ocean**	8-1-1999	10-1-1999	24-4-1999			🟦
Venezuela: Floods 1999	**Venezuela islands**	**Caribbean Sea**	15-12-1999	20-12-1999	2-4-2000		🟨	
Iran: Drought 1999 -2001	**Iran islands**	**Persian Gulf**	1-4-1999	1-1-2001	15-4-2001		🟦	
Tropical Cyclone Michelle	**Bahamas,** Bermuda, Cayman Islands, Cuba, Honduras islands, Jamaica, Mexico islands, Nicaragua islands	Caribbean Sea/**Sargasso Sea**/Gulf of Mexico	9-11-2001	9-11-2001	21-2-2002		🟨	

Table C.1 continued

Name	Affected island, in bold the countries affected large scale by the disaster	Sea or ocean, in bold the sea or ocean of the countries affected large scale by the disaster	Start date	End date	104 days after end date	Help necessary at the same time		
Tropical Cyclone Dina	Mauritius, **Reunion**	**West Indian Ocean**	1-1-2002	1-1-2002	15-4-2002		🟨	
Tropical Storm Chata'an	**Guam,** Micronesia, Philippines	**North Pacific Ocean/Philippines Sea**	5-7-2002	5-7-2002	17-10-2002	🟦		
Tropical Cyclone Lili	Barbados, Cayman Islands, Cuba, Dominican Republic, Guatemala, Haiti, Jamaica, Mexico islands, Saint Lucia, **Saint Vincent and the Grenadines**	**Caribbean Sea**/Gulf of Mexico	24-9-2002	24-9-2002	6-1-2003	🟦		🟨
Tropical Cyclone Pongsona	**Guam**	**North Pacific Ocean/Philippines Sea**	8-12-2002	8-12-2002	22-3-2003	🟨		🟨
Tropical Cyclone Ami	**Fiji**	**South Pacific Ocean**	14-1-2003	14-1-2003	28-4-2003	🟨		
Madagascar: Floods 2003	**Madagascar**	**West Indian Ocean/Mozambique Chanel**	18-1-2003	31-1-2003	15-5-2003	🟨		
Tropical Cyclone Erica	**New Caledonia**	**Coral Sea**	13-3-2003	13-3-2003	25-6-2003	🟨		
Tropical Cyclone Gafilo	**Madagascar**	**West Indian Ocean/Mozambique Chanel**	7-3-2004	12-3-2004	24-6-2004		🟦	
Hurricane Charley	Cayman Islands, **Cuba, Jamaica,** United States of America	**Caribbean Sea**/Gulf of Mexico	13-8-2004	14-8-2004	26-11-2004	🟨		
Tropical Cyclone Frances	Anguilla, Antigua and Barbuda, **Bahamas,** British Virgin Islands, Dominican Republic, Guadeloupe, Puetro Rico, Saint Kitts and Nevis, Turks and Caicos Islands, United States of America, United States Virgin Islands	Caribbean Sea/**Sargasso Sea**	2-9-2004	3-9-2004	16-12-2004	🟨		
Tropical Cyclone Ivan	**Grenada, Jamaica**	**Caribbean Sea**	8-9-2004	11-9-2004	24-12-2004	🟨		
Tropical Cyclone Jeanne	Anguilla, **Bahamas,** British Virgin Islands, Dominican Republic, Haiti, Puerto Rico, Saint Kitts and Nevis, Turks and Caicos Islands, United States of America, United States Virgin Islands	Caribbean Sea/**Sargasso Sea**	25-9-2004	25-9-2004	7-1-2005	🟨		🟦
South Asia: Earthquake and Tsunami 2004	**Maldives, Sri Lanka**	**Laccadive Sea**	26-12-2004	26-12-2004	9-4-2005			🟦
Hurricane Dennis	**Cuba**	**Caribbean Sea**	8-7-2005	9-7-2005	21-10-2005		🟨	
Hurricane Wilma	**Cuba**	**Caribbean Sea**	19-10-2005	24-10-2005	5-2-2006		🟦	
Fiji: Floods 2007	**Fiji**	**South Pacific Ocean**	3-2-2007	20-2-2007	4-6-2007		🟨	
Tropical Cyclone Indlala	**Madagascar**	**West Indian Ocean/Mozambique Chanel**	15-3-2007	17-3-2007	29-6-2007		🟨	
Tropical Cyclone Dean	Barbados, Belize, Cayman Islands, Cuba, Dominca, Dominican Republic, El Salvador, **Guadeloupe,** Haiti, **Jamaica, Martinique,** Mexico, **Saint Lucia**	**Caribbean Sea**/Gulf of Mexico	16-8-2007	29-8-2007	11-12-2007			🟦
Tropical Cyclone Guba	**Papua New Guinea**	**Coral Sea, Solomon Sea, Bismarck Sea, Arafura Sea**	12-11-2007	16-11-2007	28-2-2008	🟨		🟦
Tropical Cyclone Sidr	**Bangladesh**	**Bay of Bengal**	15-11-2007	19-11-2007	2-3-2008	🟨		🟦
Tropical Cyclone Gene	**Fiji**	**South Pacific Ocean**	28-1-2008	29-1-2008	12-5-2008	🟨		
Hurricane Gustav	**Cuba**	**Caribbean Sea**	29-8-2008	1-9-2008	14-12-2008		🟦	
Hurricane Ike	**Cuba**	**Caribbean Sea**	8-9-2008	9-9-2008	22-12-2008		🟦	
Fiji: Floods 2009	**Fiji**	**South Pacific Ocean**	8-1-2009	19-1-2009	3-5-2009		🟨	
South Pacific: Tsunami 2009	**Samoa**	**South Pacific Ocean**	29-9-2009	29-9-2009	11-1-2010		🟦	
Earthquake 2010	**Haiti**	**Caribbean Sea**	12-1-2010	12-1-2010	26-4-2010		🟨	
Tropical Cyclone Tomas	**Fiji**	**South Pacific Ocean**	14-3-2010	16-3-2010	28-6-2010		🟦	
New Zealand: Earthquake 2010	**New Zealand**	**Tasman Sea**	4-9-2010	4-9-2010	17-12-2010		🟨	
Tropical Cyclone Nicole	Costa Rica, El Salvador, **Jamaica**	**Caribbean Sea**	29-9-2010	30-9-2010	12-1-2011		🟨	
Hurricane Tomas	**Saint Vincent and the Grenadines**	**Caribbean Sea**	29-10-2010	29-10-2010	10-2-2011		🟨	
New Zealand: Earthquake 2011	**New Zealand**	**Tasman Sea**	22-2-2011	22-2-2011	6-6-2011	🟦		
Japan: Earthquake and Tsunami 2011	**Japan**	**Japan Sea**	11-3-2011	11-3-2011	23-6-2011	🟦		🟨
New Zealand: Earthquake 2011	**New Zealand**	**Tasman Sea**	13-6-2011	13-6-2011	25-9-2011			🟨
Tropical Cyclone Giovanna	**Madagascar**	**West Indian Ocean/Mozambique Chanel**	14-2-2012	15-2-2012	29-5-2012		🟦	
Fiji: Floods 2012	**Fiji**	**South Pacific Ocean**	29-3-2012	30-3-2012	12-7-2012		🟦	
Hurricane Sandy	**Haiti**	**Caribbean Sea**	24-10-2012	26-10-2012	7-2-2013		🟨	
Tropical Cyclone Evan	**Samoa**	**South Pacific Ocean**	12-12-2012	13-12-2012	27-3-2013		🟨	
Tropical Cyclone Haiyan	**Philippines**	**Philippine Sea**	8-11-2013	8-11-2013	20-2-2014	🟦		
Eastern Caribbean: Floods and Landslides 2013	**Saint Vincent and the Grenadines**	**Caribbean Sea**	23-12-2013	25-12-2013	8-4-2014	🟦		🟨
Tropical Cyclone Beisja	**Réunion**	**West Indian Ocean**	2-1-2014	2-1-2014	16-4-2014	🟦		🟨
Solomon Islands: Flash Floods 2014	**Solomon Islands**	**Solomon Sea**	1-4-2014	8-4-2014	21-7-2014			🟨
Tropical Cyclone Winston	**Fiji**	**South Pacific Ocean**	20-2-2016	21-2-2016	4-6-2016		🟦	
Sri Lanka: Floods and Landslides 2016	**Sri Lanka**	**Laccadive Sea**	14-5-2016	15-5-2016	27-8-2016		🟦	
Hurricane Matthew	**Haiti, Bahamas, Cuba**	**Caribbean Sea**	28-9-2016	10-10-2016	22-1-2017	🟨		
New Zealand: Earthquake and Tsunami 2016	**New Zealand**	**Tasman Sea**	14-11-2016	14-11-2016	26-2-2017	🟨		🟦
Caribbean: Drought - 2016-2017	**Haiti**	**Caribbean Sea**	1-1-2016	1-2-2017	16-5-2017			🟦
Hurricane Maria	Anguilla, Antigua and Barbuda, Barbados, Bonaire, Saint Eustatius, Saba, British Virgin Islands, Cuba, Dominca, Dominican Republic, Guadeloupe, Haiti, **Martinique,** Montserrat, **Puerto Rico,** Saint Barthélemy, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Sint Maarten, Turks and Caicos Islands, United States Virgin Islands	**Caribbean Sea**/Sargasso Sea	18-9-2017	20-9-2017	2-1-2018		🟨	
Tropical Cyclone Keni	**Fiji**	**South Pacific Ocean**	9-4-2018	11-4-2018	24-7-2018		🟦	
Timor-Leste: Floods 2020	**Timor-Leste**	**Timor Sea**	13-3-2020	13-3-2020	25-6-2020		🟨	

D

Communication factors to incorporate in the detailed design - literature overview

Based on the causal loop diagram described in chapter 5.1 there are three areas of interest: social learning (collaboration), disasters and sensemaking. By combining these three fields the sweet spot for the communication part of this research is defined. This appendix find literature within this sweet spot in order to find important keywords for the systematic literature analysis. On top of this the literature find in this appendix find additional factors which will help to let a disaster relief tool be a communication intervention. These factors are not used in this research since it is not possible to incorporate them in the conceptual design. However they can be incorporated in the detailed design. They can also be incorporated in other disaster relief tools which want to act as a communication intervention. To create an overview of the field a search towards (literature) reviews and overviews of the literature in this field is performed. Thi Figure D.1 illustrates the sweetspot.

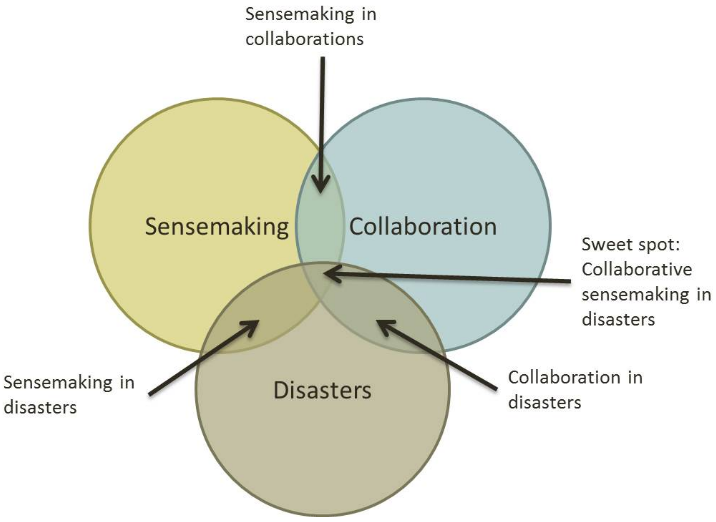


Figure D.1: The three areas of interest which need to combined in this research

D.1. procedure

A first search in Scopus and Web of Science, with the following key words was performed:

- ((”social learn*” OR ”social learning theory” OR ”social system”))
- ((sensemaking OR ”situation aware*” OR ”sense mak*”))

- ((disaster OR emergency OR chao* OR crisis OR stress OR (dynamic* W/5 uncertain* W/5 urgen*)))

The first term relates to the social learning and social learning theory,the second term searched for sensemaking and variants of sensemaking. The last term search for disasters and characteristics of disaster situations. These three search terms are combined in one search. All these three terms must appear in the title, abstract or keywords of the article. The result does not contain an article which present a (literature) review or overview of the field. Also a search where the social learning part is integrated in the sensemaking part by searching with social sensemaking or collaborative sensemaking did not contain such an article.

Because of this the choice is made to perform a search for the three smaller overlapping fields and do not focus that much on social learning theory but on the social/collaborative setting. This leads to searching for a (literature) review or overview of the sensemaking and collaboration, disaster and sensemaking and disaster and collaboration field.

When searched for the words collaboration and sensemaking and review in the title, abstract or keywords in Scopus and Web of Science there was found one article: Jørgensen et al. (2012). When searched with the same strategy but now with the words sensemaking and disaster and review there were found two articles: Comes (2016b) and Son et al. (2020b). When searched for collaboration and disasters and review there were found many hits. By restricting the search to obligate that review must appear in the title and not in the keywords or abstract it is possible to reduce the amount of hits. This strategy is justified by the fact that a (literature) review or overview article most of the time contains the word review in the title. This search yields three articles: Olszewski and Siebeneck (2021), Peng et al. (2013) and Simona et al. (2021). Only Simona et al. (2021) contains an article which is free to access with an university account and thus only this review is taken into account in this section. Furthermore based on this article another article was found by checking the reference of Simona et al. (2021). This article, Toner et al. (2015), did not contain the word review in the title but the abstract told that a section of the paper contain a literature review.

D.2. findings

By investigating these literature overviews some extra characteristics for a disaster relief tool to be a communication intervention are defined. These characteristics can be incorporated in any tool used in a disaster relief effort in order to foster the collaborative sensemaking during disasters. Jørgensen et al. (2012) has created a review of the work about sensemaking during collaborations, more detailed in inter-organizational context. Also discourse analyses are described in this research. They describe the sensegiving process. This is a particular form of sensemaking that deals with the creation of meaning for a target audience. Something which is important when dealing with sensemaking in a collaborative way. They describe this process as the communicative construction of meaning. This process can be performed unconsciously in a more routinized way or in a more conscious search for meaning in case of unusual and/or uncertain events. It is thus important that the usage of a disaster relief tool within collaborations deals with the sensegiving process and will construct meaning for the target audience (all different actors involved in the humanitarian relief operation) by using communication. This can be communication between the actors or communication between the actors and a technology or information display.

Jørgensen et al. (2012) also conclude that the role of representation technologies (such as PowerPoint, Project Time Lines, Standards) and mediating instruments (such as figures and graphs) as sensemaking and sensegiving devices has been neglected so far in research. Son et al. (2020b) researched an ad hoc mapping strategy and it was concluded that this indeed helped making sense of the situation and changing conditions. However only a few studies focused on specific tools to foster the collective sensemaking in disasters Jørgensen et al. (2012) states that collective symbols must be introduced. This are symbols which are ‘understood’ without the need for reflecting about their meaning, for example a traffic light indicator system. Collective symbols allow the linking of seemingly contradictory elements to a meaningful whole. Collective symbols are characterized by a transfer of meaning and always refer to a certain collective. When the disaster relief tool can use like such a collective symbols, it is able to transfer meaning. Possibilities arises in representation technologies or mediating instruments, such as ad hoc mapping strategies.

Son et al. (2020b) has created an overview of resilience in emergency management and concluded that collective sensemaking, which incorporate among other things the cognition of risks, is a crucial element of emergency response. A section of the literature research contains the literature about collective sensemaking during disasters. Note that this is about collective sensemaking in disasters and thus the literature discussed here is close related to the sweet spot. They describe sensemaking as creating a common operating picture which serves as collective awareness of incident status shared among emergency responders. They describe four ways of improving collective sensemaking during disasters: improvisation (creative reconfiguration of the current situation), virtual role systems (imagining what others would do), attitude of wisdom (avoiding overconfidence and overcautiousness) and respectful interaction (respecting others report). In the most ideal situation the design of a disaster relief tool incorporates all these four ways to improve collective sensemaking, but it can be argued that combining these four ways would be difficult.

Comes (2016b) has made a literature review about cognitive biases in humanitarian sensemaking and decision making. She noticed that NGOs contribute large shares of information processing and data collection but they are not embedded within the structures of the United Nations. This is also partly observed by (Son et al., 2020b). They conclude that more frequent face-to-face communication, briefings and debriefings foster collective situation awareness. Simona et al. (2021) have made a review about collaboration in emergencies. They see communication as the most important part in collaborations and describe that the coordination of action and the motivation to cooperate together is enabled by clear communication. It is thus important that usage of a disaster relief tool will reach all different actors involved in the humanitarian relief operation and that it will lead to face-to-face communication and/or briefings and debriefings.

As noted by Son et al. (2020b) and Comes (2016b) it is also important to be aware that collective sensemaking can lead to a cognitive overload due to excess influx of incident data. Awareness of the fact that information overload can give problems is necessary. This means that clear organizational information communication management processes must be designed and usage of the disaster relief tool must not lead to information overflow.

Comes (2016b) states that the role and nature of information is an important enabler for sensemaking and sensemaking provides a framework to structure chaotic information data into meaningful information which is the basis for decision making. It is concluded that responders making sense of a situation by relating the disaster to their past experiences. This introduces biases but also gives opportunities by building on symbols and/or systems in which people have past experiences. Next to this she also concludes that a humanitarian response efforts is characterized by a group effort and that groupthink is a real threat. It gives a illusion of invulnerability, stereotyping of out groups and illusions of unanimity. This means that an opportunity arises in using the past experience of humanitarian relief effort actors and that it is important to be aware of the groupthink bias when designing the conceptual design of a disaster relief tool with the collaborative function in mind.

Son et al. (2020b) points out that individual emergency responders need two skills: self-awareness (creating a situation overview) and self-regulating (prioritizing decisions and/or data over another to improve decision making tempo) in order to get individual overview of the situation. It present an opportunity if a disaster relief tool can foster these individual skills.

Collective sensemaking can be facilitated by four types of capabilities: preemptive (extending organizational boundaries), protective (diversifying information resources), exploitative (forecasting information needs), and corrective (dealing with new pieces of information) (Son et al., 2020b). These capabilities must be taken into mind when designing a disaster relief tool.

Toner et al. (2015) also have researched collaboration in emergencies. They conclude that there are

4 characteristics which can differ between emergency collaborations: diverse origins and structures, variety in scope and focus of different collaborations, all have different key functions and they differ about the engagement of other stakeholders. This means that they conclude that if you have seen one collaboration, you have seen one collaboration. Many collaboration participants also spoke about the difference cultural working norms (behaviours, terminology, work speed etc.) among the various involved persons in collaborations. This lead to misunderstanding, frustration and a lack of trust. They state that sensemaking or creation of a common vision and mission can help reducing these barriers. Toner et al. (2015) and Simona et al. (2021) both conclude there are only a few studies which are researching collaborative systems in emergency situations. The above means that it is important to take the differences between collaborations in emergencies into account.
All the above lead to the following things which can be incorporated in the design of a disaster relief tool in order to improve the collaborative sensemaking:

- Construct meaning for the target audience (all different actors involved in the humanitarian relief operation) by using communication.
- The usage of the seaport must lead to the usage of collective symbols in order to transfer meaning. Possibilities arises in representation technologies or mediating instruments, such as ad hoc mapping strategies as a bases to transfer these collective symbols.
- Usage of the seaport improves one ore more of the four ways of collective sensemaking during disasters: improvisation (creative reconfiguration of the current situation), virtual role systems (imagining what others would do), attitude of wisdom (avoiding overconfidence and overcautiousness) and respectful interaction (respecting others report).
- The usage of the seaport will involve all different relevant actors in the humanitarian relief operation and it will lead to face-to-face communication and/or briefings and debriefings.
- Be aware of the information overflow problem.
- Using the past experience of humanitarian relief effort actors to recognize different situations.
- Be aware of the groupthink bias.
- Foster the individual self-awareness and self-regulating skills.
- Collective sensemaking can be facilitated by four types of capabilities: preemptive (extending organizational boundaries), protective (diversifying information resources), exploitative (forecasting information needs), and corrective (dealing with new pieces of information).
- Take the differences between different collaborations in emergencies into account.

Note that this factors are not further used within this research. It is not possible to apply this factors on the conceptual design. These factors are more related and plays a role when the detailed design of such a seaport and the modules is made. Then also communication processes and different related software programs will be developed and these factors are better to incorporate in that stage.

E

Found and selected papers - systematic literature review

The systematic literature review found 45 results of interest. The title, abstracts and keywords of these papers are read and based on that, 21 results remain. These 21 papers are included in the review and with the help of open and axial coding a theoretical framework is created. Table E.1 gives an overview of all found 45 papers and the reason why some papers are examined further and others not.

Table E.1: Overview of the found papers after the systematic literature search and reasons why some papers are examined further and others not

Authors	Year	Title	Full paper examined	Reason to exclude or include
S. A. Alharthi, W. A. Hamilton, I. Dolgov and Z. O. Toups	2018	Mapping in the wild: Toward designing to train search & rescue planning	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
S. A. Alharthi, N. J. LaLone and H. N. Sharma	2021	An activity theory analysis of search and rescue collective sensemaking and planning practices	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
S. Appleby-Arnold, N. Brockdorff, L. Fallou and R. Bossu	2019	Truth, trust, and civic duty: Cultural factors in citizens' perceptions of mobile phone apps and social media in disasters	No	Examine social media and how the public perceive the usage of it during disasters. Not the collaborative sensemaking process of decision makers during disasters.
B. E. Baran and C. W. Scott	2010	Organizing ambiguity: A grounded theory of leadership and sensemaking within dangerous contexts	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
S. H. Berg, K. Rortveit, F. A. Walby and K. Aase	2020	Adaptive capacities for safe clinical practice for patients hospitalised during a suicidal crisis: a qualitative study	No	Not about a disaster but a personal suicidial crisis.
J. Blum, G. Kefalidou, R. Houghton, M. Flintham, U. Arunachalam and M. Goulden	2014	Majority report: Citizen empowerment through collaborative sensemaking	No	Tells about a social media platform in order to foster collaborative sensemkaing. But is not going into depth about factors which foster collaborative sensemaking. Not about how actors are making sense.
T. Comes	2016	Cognitive biases in humanitarian sensemaking and decision-making lessons from field research	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
A. Costanza, A. Amerio, A. Odone, M. Baertschi, H. Richard-Lepouriel, K. Weber, S. Di Marco, M. Prelati, A. Aguglia, A. Escelsior, G. Serafini, M. Amore, M. Pompili and A. Canuto	2020	Suicide prevention from a public health perspective. What makes life meaningful? The opinion of some suicidal patients	No	Not about a disaster but a personal suicidial crisis.
J. C. Fackler, C. Watts, A. Grome, T. Miller, B. Crandall and P. Pronovost	2009	Critical care physician cognitive task analysis: an exploratory study	No	Not about a disaster but an experiment about assessing cognitive activities in critical care medicine.
D. Fischer-Pressler, C. Schwemmer and K. Fischbach	2019	Collective sense-making in times of crisis: Connecting terror management theory with Twitter user reactions to the Berlin terrorist attack	No	About why people using twitter in disaster situation. Not related to actors making decisions
J. Fromm, K. Eyilmez, M. Bassfeld, T. A. Majchrzak and S. Stieglitz	2021	Social Media Data in an Augmented Reality System for Situation Awareness Support in Emergency Control Rooms	No	Does not describe a collective sensemaking process.
X. Y. Gao, C. Fan, Y. Yang, S. Lee, Q. C. Li, M. Maron and A. Mostafavi	2021	Early Indicators of Human Activity During COVID-19 Period Using Digital Trace Data of Population Activities	No	Does not describe a collective sensemaking process.
M. K. Gatzweiler and M. Ronzani	2019	Prospective sensemaking and thinking infrastructures in a large-scale humanitarian crisis	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
L. Gilson, E. Barasa, L. Brady, N. Kagwanja, N. Nxumalo, J. Nzinga, S. Molyneux and B. Tsofa	2021	Collective sensemaking for action: researchers and decision makers working collaboratively to strengthen health systems	No	Not related to a disaster or emergency situation.

Table E.1 continued

Authors	Year	Title	Full paper examined	Reason to exclude or include
C. A. Gilstrap, C. M. Gilstrap, K. N. Holderby and K. M. Valera	2016	Sensegiving, Leadership, and Nonprofit Crises: How Nonprofit Leaders Make and Give Sense to Organizational Crisis	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
Y. Kim	2018	Enhancing employee communication behaviors for sensemaking and sensegiving in crisis situations: Strategic management approach for effective internal crisis communication	No	Not related to a disaster or emergency situation but a internal/company crisis.
P. Krafft, K. Zhou, I. Edwards, K. Starbird and E. S. Spiro	2017	Centralized, parallel, and distributed information processing during collective sensemaking	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters. It is an examination about social media, but it describes how collaborative sensemaking for decision makers happens or how this is hindered by social media
Q. C. Li, L. Bessell, X. Xiao, C. Fan, X. Y. Gao and A. Mostafavi	2021	Disparate patterns of movements and visits to points of interest located in urban hotspots across US metropolitan cities during COVID-19	No	Does not describe a collective sensemaking process.
Q. C. Li, Z. Y. Tang, N. Coleman and A. Mostafavi	2021	Detecting Early-Warning Signals in Time Series of Visits to Points of Interest to Examine Population Response to COVID-19 Pandemic	No	Does not describe a collective sensemaking process.
R. B. MacKay and R. W. Parks	2013	The temporal dynamics of sensemaking: A hindsight-foresight analysis of public commission reporting into the past and future of the "new terrorism"	No	It describes the sensemaking of public commission reports. Not related to sensemaking during a disaster or emergency.
S. Maitlis	2005	The social processes of organizational sensemaking	No	Not related to a disaster or emergency situation.
P. Mansson, M. Abrahamsson, H. Hassel and H. Tehler	2015	On common terms with shared risks - Studying the communication of risk between local, regional and national authorities in Sweden	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
R. McMaster, C. Baber and T. Duffy	2012	The role of artefacts in Police emergency response sensemaking	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
M. Mirbabaie, D. Bunker, S. Stieglitz, J. Marx and C. Ehnis	2020	Social media in times of crisis: Learning from Hurricane Harvey for the coronavirus disease 2019 pandemic response	No	Examine social media and how the public making sense of situations. Not the collaborative sensemaking process of decision makers during disasters.
M. Mirbabaie and J. Marx	2020	'Breaking' news: uncovering sense-breaking patterns in social media crisis communication during the 2017 Manchester bombing	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
J. Moon, F. Sasangohar, C. Son and S. C. Peres	2020	Cognition in crisis management teams: an integrative analysis of definitions	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
A. Muller and R. Kraussl	2011	The Value of Corporate Philanthropy During Times of Crisis: The Sensegiving Effect of Employee Involvement	No	Sensegiving for financial donors not for creating situation overview.
L. Nardon, H. Zhang, B. Szkudlarek and D. Gulanowski	2020	Identity work in refugee workforce integration: The role of newcomer support organizations	No	Not related to a disaster or emergency situation.
M. Ogasahara, H. Kawashima and H. Fujishiro	2019	How Did Rumors on Twitter Diffuse and Change in Expression? An Investigation of the Process of Spreading Rumors on Twitter during the 2011 Great East Japan Earthquake	No	Examine social media and how the public making sense of situations. Not the collaborative sensemaking process of decision makers during disasters.

Table E.1 continued

Authors	Year	Title	Full paper examined	Reason to exclude or include
M. Olsson and A. Lloyd	2017	Being in place: embodied information practices	No	Not related to a disaster or emergency situation.
S. A. Paul and M. C. Reddy	2010	Understanding together: Sensemaking in collaborative information seeking	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
S. A. Paul, M. C. Reddy and C. J. DeFlitch	2008	Information and communication tools as aids to collaborative sensemaking	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
R. Ramanath	2016	Defying NGO-ization?: Lessons in Livelihood Resilience Observed Among Involuntarily Displaced Women in Mumbai, India	No	Not related to a disaster relief situation, but to the situation when NGO's leaves the counrty.
S. Reinhold, C. Laesser and P. Beritelli	2018	The 2016 St. Gallen Consensus on Advances in Destination Management	No	Not related to a disaster or emergency situation.
M. Sanfuentes, F. Valenzuela and A. Castillo	2021	What lies beneath resilience: Analyzing the affective-relational basis of shared leadership in the Chilean miners' catastrophe	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
A. W. Siegel and J. M. Schraagen	2017	Team reflection makes resilience-related knowledge explicit through collaborative sensemaking: observation study at a rail post	No	Not related to a disaster or emergency situation.
C. Son, F. Sasangohar, T. Neville, S. C. Peres and J. Moon	2020	Investigating resilience in emergency management: An integrative review of literature	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
K. K. Stephens, J. L. S. Jahn, S. Fox, P. Charoensap-Kelly, R. Mitra, J. Sutton, E. D. Waters, B. Xie and R. J. Meisenbach	2020	Collective Sensemaking Around COVID-19: Experiences, Concerns, and Agendas for our Rapidly Changing Organizational Lives	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
K. Y. Tham, Q. H. Lu and W. Teo	2020	Infodemic: what physician leaders learned during the COVID-19 outbreak: a qualitative study	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
D. Tisch and J. Galbreath	2018	Building organizational resilience through sensemaking: The case of climate change and extreme weather events	No	Not related to a disaster or emergency situation.
Z. O. Toups, A. Kerne and W. A. Hamilton	2011	The team coordination game: Zero-fidelity simulation abstracted from fire emergency response practice	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
J. Wolbers and K. Boersma	2013	The Common Operational Picture as Collective Sensemaking	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
A. Wu and X. Zhang	2009	Supporting collaborative sensemaking in map-based emergency management and planning	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
A. N. Wu, G. Convertino, C. Ganoe, J. M. Carroll and X. L. Zhang	2013	Supporting collaborative sense-making in emergency management through geo-visualization	Yes	Describe important factors of the collaborative sensemaking process of decision makers during disasters.
L. Yeomans and S. Bowman	2021	Internal crisis communication and the social construction of emotion: university leaders' sensegiving discourse during the COVID-19 pandemic	No	Sensemaking process not related to the disater relief decision makers.

F

Basics of mathematical optimization

The goal of the logistics part of this research is to make a model. Normally a model will be build in order to explore the features and characteristics of a real world system or object (Williams, 2013). Normally this model represents only some features and characteristics in order to create a structured representation which facilitates the analysis of the resulting model (Hart et al., 2017; Williams, 2013). A model can be used in order to explain phenomena, make predictions, assess key factors, identify extreme states and analyze trade-offs (Hart et al., 2017)

As described by Williams (2013) the term model in the context of operational research, and for this research, refers to an abstract model which uses mathematical relationships in order to mirror the internal real world relationship of the object being modelled. This models are called mathematical optimization models. Four mathematical concepts are central to mathematical optimization modeling activities (Hart et al., 2017; Williams, 2013):

- Objectives: represents the goal of the model. Since it is about optimization, the goal is to maximize or minimize a certain quantity.
- Variables: represents the unknown and/or changing parts of a model. It represents the decisions to take.
- Parameters: symbolic represents the real-world data. This can vary for different problem statements or scenarios.
- Constraints: the equations, inequalities or other mathematical relationships that relates the different parts of the model to each other.

The common feature of mathematical optimization is that all models involve optimization: the wish to maximize or minimize something (Williams, 2013). The quantity to be optimized is described in the objective function (Williams, 2013). In order to maximize or minimise some quantity, decisions must be made. Solving the mathematical optimization model gives the optimal values of these so called decision variables which represent this decision and result in the best possible value of the objective function (Hart et al., 2017). Next to an objective function and decision variables a mathematical optimization model consist of constraints. Constraints are restricting the possible values that decision variables can take (Williams, 2013). Constraints and objective functions are mathematical formula consisting of decision variables and parameters, where parameters represents the real-world situation which want to be modeled for example the costs of a given scenario (Hart et al., 2017).
Mathematical optimization models can be linear or non-linear (Hart et al., 2017; Williams, 2013). A linear model consist of an objective function and constraints which are composed only of sums of decision variables and/or decision variables multiplied by parameters. This means that a linear model only consist of non-constant, linear functions of the decision variables (Hart et al., 2017). It is not always possible to create a linear model of a practical problem. When one or more non-linear terms of the decision variable are present in the objective function of the constraints of the model the model is described as a non-linear model (Williams, 2013). Linear models are computationally much more

easier to solve and thus modelers make an effort to only use linear expressions or as less non-linear expressions as possible (Hart et al., 2017; Williams, 2013). Due to this many modelers are making use of linear approximations to non-linear models in the hope to find good approximate solutions to the original non-linear model (Hart et al., 2017).

Next to the above, mathematical optimization models also can be stochastic or deterministic (Hart et al., 2017; Williams, 2013). Stochastic models can be used when not all parameters are known and when this parameters can be represent by random variables or a probability distribution (Renard et al., 2013; Williams, 2013). When parameters are fully known or represented by only one expected value the model is called deterministic (Renard et al., 2013). Deterministic models perform the same way for a given set of parameters and thus they always create one unique solution (Renard et al., 2013). However deterministic models are sometimes unstable. This means that it is possible to obtain a totally different outcome by slightly changing one or more of the parameters (Renard et al., 2013).

Fractal values are not always desirable (Williams, 2013). By using constraints it is possible to only allow that some or all variables must take integers (Williams, 2013). This is called integer programming and this models are much more difficult to solve then conventional models (Williams, 2013). Three different forms of integer programming exists (Williams, 2013):

- Pure Integer Programming model: A model which purely consist of integer variables.
- Mixed Integer Programming model: A model which consist of both conventional continuous (decision) variables and integer (decision) variables.
- Binary Integer Programming model: A model in which some or all (decision) variables only can take up 1 or 0. Which represents the decision to perform any action (build a warehouse, take that route for example) or not.

Mathematical Optimization modelling can be used to model a wide variety of real world situations (Williams, 2013). Among other things the models are applied to solve problems within the petroleum industry, chemical industry, manufacturing industry, finance sector, health sector, supply chain and the transport and network sector (Williams, 2013). Mathematical Optimization models are also used in Humanitarian Logistics (Caunhye et al., 2012).

G

Mathematical optimization in Humanitarian Logistics

The first optimization models for humanitarian logistics were developed in the 1980s (Caunhye et al., 2012). Altay and Green (2006) were among on of the first which created a review of the at that time existing scientific papers which contain mathematical optimization models in humanitarian logistics (Anaya-Arenas et al., 2014). This review classified the humanitarian logistics mathematical optimization models into different aspects such as the disaster type, methodology and the four different phases of the disaster operations life cycle: mitigation, preparedness, response and rehabilitation (Altay and Green, 2006).

After this first review, multiple others followed. Caunhye et al. (2012) made an overview focusing on mathematical optimization models used in pre-disaster and short-term post-disaster context. They classified the research papers into two main categories: (1) Facility location and (2) Relief distribution and casualty transportation. Anaya-Arenas et al. (2014) reviewed articles which contain mathematical optimization models used in order to design and/or make decisions about the relief distribution network . They divide the research into three categories: (1) location and network design, (2) transportation problems and (3) a combination of location and transportation problems. Özdamar and Ertem (2015) reviewed the literature only focusing on the response and rehabilitation phase. In the response phase they define two categories: (1) relief delivery/casualty transport models and (2) mass evacuation models. In the rehabilitation phase they also define two categories: (1) road and other infrastructure restoration and (2) the removal, disposal, and recycling of debris. Hoyos et al. (2015) reviewed the existing body of literature in the field that uses mathematical optimization models which have a stochastic part. They classified the research into five categories: (1) facility location, (2) resource allocation, (3) relief distribution, (4) casualty transportation and (5) search and rescue.

The studies above all focuses on a certain phase of the disaster or a certain type of modelling. There are two systematical literature reviews which have a holistic approach.Habib et al. (2016) have create a systematical literature review. In this systematical literature review papers between 2005 and 2015 are selected. They divided the research papers into three major categories: (1) facility location, (2) network design and relief distribution and (3) mass evacuation. Hezam and Nayeem (2021) have create a systematical literature review of papers between 2000 and 2020 which contain Mathematical Optimization models within humanitarian logistics. They also categorise the existing literature into three different categories: (1) facility location, (2) relief distribution and (3) mass evacuation. The difference with the previous systematical literature review is however the fact that in this paper every category is divided in a section with deterministic models and a section with stochastic models. This creates a clear overview of the state of the art with respect to deterministic and stochastic modelling.

By combining the different categories from all the different literature reviews it is possible to create a comprehensive categorisation of mathematical optimization models for humanitarian logistics. In Figure

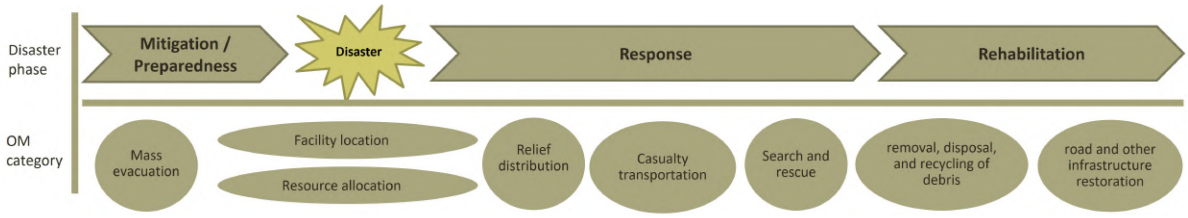


Figure G.1: The different Mathematical Optimization model categories placed in the different phases of the disaster management cycle.

G.1 this categorisation is presented and the different categories are placed in the different phases of the disaster management cycle. The following 7 categories can be distinguished:

- Facility location. This involves the positioning of facilities in the most suitable and effective locations in order to provide assistance during disasters (Hoyos et al., 2015). These models have the goal to determine the location of humanitarian aid distribution centers and warehouses in such a way that the demand of the affected area is fulfilled with minimal delivering cost and minimizing the people's suffering (Anaya-Arenas et al., 2014; Habib et al., 2016; Hezam and Nayeem, 2021). Objective functions try to maximize the covered demands, minimizing the costs and/or minimizing the expected shipping distance (Hoyos et al., 2015). Some authors are incorporating the positioning of stock together with the facility location planning (Anaya-Arenas et al., 2014; Caunhye et al., 2012; Habib et al., 2016; Hoyos et al., 2015). These models are called location-allocation models (Habib et al., 2016). These type of models are formulated by the use of a maximal covering location model which has the aim to locate facilities such that the maximum demand is covered by a required amount of stock and to assign the stock to facilities such that demands can be satisfied (Anaya-Arenas et al., 2014; Caunhye et al., 2012; Habib et al., 2016).

- Resource allocation. It can be concluded, on basis of the researched literature (Altay and Green, 2006; Anaya-Arenas et al., 2014; Caunhye et al., 2012; Habib et al., 2016; Hezam and Nayeem, 2021; Hoyos et al., 2015; Özdamar and Ertem, 2015), that not a lot of research is performed in this category. The few resource allocation models have the goal to determine the amount of resources at every fixed location before or right after the occurrence of a disaster (Anaya-Arenas et al., 2014; Hoyos et al., 2015).

- Mass evacuation. This category can be divided into three sub categories: evacuation model for rural areas, evacuation model for urban areas and no-notice/short-notice evacuation(Habib et al., 2016). In rural areas the evacuation model can be focused on the public transport or at the private transport (Habib et al., 2016; Hezam and Nayeem, 2021; Özdamar and Ertem, 2015). Public transport models are pickup only vehicle routing problems, which optimizes routes consisting of a depot, several pickup stations and shelters (Habib et al., 2016; Hezam and Nayeem, 2021; Özdamar and Ertem, 2015). The objective functions in these models are mostly time related, evacuee number related and/or cost and flow related (Özdamar and Ertem, 2015). Most private transport models have objective functions which maximize the traffic flow, minimize travel time and/or minimize traffic risks (Habib et al., 2016; Hezam and Nayeem, 2021; Özdamar and Ertem, 2015). Urban areas have a high population density, which means that in urban areas the mathematical models tries to optimize the traffic congestion, route/street capacity, flow conversation, inflow capacity and lane consistency (Habib et al., 2016; Hezam and Nayeem, 2021). In no-notice/short-notice evacuation models the time for evacuation and the predictability of the disaster is a big factor (Habib et al., 2016). The objective functions of these mathematical optimization models are maximizing the number of evacuees and flow rate while minimizing the cost for transportation and time for evacuation (Habib et al., 2016).

- Relief distribution. The goal of this models is to find the best way to bring relief (medical supplies, shelters, manpower, sanitation, and other related resources) to the affected people (Caunhye et al., 2012; Hoyos et al., 2015). Models are involved with determining the amount of relief goods which a vehicle must take and bring to different points of interest, the vehicle fleet composition and with the route this vehicles must take in order to not congest some roads and deliver the goods as fast as possible Caunhye et al. (2012). This kind of models, which consider capacitated vehicles, have constraints related to the vehicle capacity, fleet composition, road capacity, road reliability, supply/vehicle availability, depot/shelter/pickup location capacity, demand satisfaction, delivery time windows, re-fueling time, split or non-split deliveries/pickups, response time deadlines, vehicle fleet size, and vehicle working time windows (Anaya-Arenas et al., 2014; Hezam and Nayeem, 2021; Özdamar and Ertem, 2015). Objective functions are usually to minimize the cost/travel time, minimize the response time, minimize the road risk and/or maximize the satisfaction of all beneficiaries (Anaya-Arenas et al., 2014; Hezam and Nayeem, 2021; Özdamar and Ertem, 2015). Distinctions can be made with respect to the period (single period or multi-period) and the transported commodity (single commodity or multi-commodity) (Anaya-Arenas et al., 2014; Hezam and Nayeem, 2021).

- Casualty transportation. This models center their attention on finding the best possible routes to transport people from the disaster area to hospitals, medical centers or shelters (Caunhye et al., 2012; Hoyos et al., 2015). Most of the time this casualty transportation is an added concern in relief distribution models (Anaya-Arenas et al., 2014; Caunhye et al., 2012). This models are involved with determining the amount of casualties a vehicle need to pick up from different points of interest, the vehicle fleet composition and with the route this vehicles must take in order to not congest some roads and transporting as many people as fast as possible Caunhye et al. (2012). Since the goal of these models lies in the same line as with the relief distribution category, most papers put these two type of models into one category (Anaya-Arenas et al., 2014; Hoyos et al., 2015). This also leads that in this category more or less the same constraints and objective functions applies as in the relief distribution category (Anaya-Arenas et al., 2014; Hezam and Nayeem, 2021; Özdamar and Ertem, 2015).

- Search and Rescue. Within all the examined literature review papers this category was only present in the stochastic literature review of Hoyos et al. (2015). This points out the fact that these models are mostly stochastic. The mathematical optimization models in this category focuses on optimizing the search and rescue activities (the routes and deployment of search teams) in order to save the lives of as many people as possible, while there is high uncertainty about the location of the victims(Hoyos et al., 2015). Objective functions try to maximize the expected number of saved lives and/or minimize the search time (Hoyos et al., 2015).

- Removal, disposal and recycling of debris. This consist of two phases. During the first phase the goal is to clear debris from important paths and routes. The most be done as quick as possible to ensure the traffic flow to affected areas. In the second phase all other debris will be collected and all the debris will be reduced, transported, temporarily stored, recycled, and disposed. These operations could take months (Özdamar and Ertem, 2015). This category mostly contain decisions models which determine the location of temporary storage and recycling facilities around the affected area and the debris transportation routes (Özdamar and Ertem, 2015). The mathematical optimization models mostly try to minimize the costs of debris collection, recycling, transport and disposal. Some other models also try to minimize the psychological costs of delay of debris collection into account (Özdamar and Ertem, 2015).

- Road and other infrastructure restoration. Roads, but also power and fiber-optic networks must be restored in order to open up the evacuation routes or information sharing (Özdamar and Ertem, 2015). Any restoration operation can be conducted efficiently by identifying the optimal sequence of restoration work (Özdamar and Ertem, 2015). The main objective functions of this mathematical optimization models are trying to maximizing the network accessibility and flow, minimizing the network vulnerability, maximizing the length of restored links and/or minimizing the repair operation's completion time (Özdamar and Ertem, 2015).

H

Current mathematical optimization model and meeting necessary characteristics

Chapter 6.3 explains the different literature which is interesting for this research. The chapter indicates if the found literature contains the objective functions, decision variables and constraints which are necessary in the model for this research. Table H.1 explains in more detail why the found models contains these objective function, decision variables and constraints.

Table H.1: Overview of the found mathematical optimization models in literature. The table explains if these models contain one or multiple of the for this research necessary objectives, decision variables and constraints.

	Minimize the cost of storage facilities to open	Minimize the cost of the capacities stored at all facilities	Minimize the costs of transporting the handling capacity	Determine which facilities must be opened and which not in order to cover all demand points	Place the amount of goods necessary at the facilities in order to serve all demand points	Determine the amount of handling capacity sent from a certain facility point to a certain demand point in a specific situation	Have enough supply for every demand point	Contains a maximum service distance	Every demand point is assigned to at least one facility	Individual service distance limits for every demand point	Uncertainty has influence on the maximum service distance	Take the uncertainty about the exact striking area into account	Take into account the fact that multiple disasters can happen simultaneously	Demand points can be supplied by multiple facilities
Duran et al. (2011)	No (Minimize the travel time from facilities to demand points)	No (Every facility has a maximum capacity)	No (Minimize the travel time from facilities to demand points)	Yes (Based on a maximum total amount of facilities)	Yes	Yes	Yes	No	No	No	No	Yes (multiple scenario's and every scenario has a probability of occurring. Since the objective is to minimize the response time, it is more important to minimize the response time of scenario's which are more likely to occur then scenario's which have a very low occurring probability)	Yes (some scenario's consist of multiple disasters happening simultaneously)	Yes
Balcik and Beamon (2008)	No (Maximize the total demand covered by an upfront determined amount of distribution centres to open based on the available budget)	No (Every facility has a maximum capacity based on the available budget)	No (cost of transporting is included, but can not exceed a maximum value)	Yes (Based on the cost of opening facilities and a pre-determined budget, however not every demand point will be fully covered)	Yes	Yes	No (Maximize the total demand covered)	Yes	No (Maximize the total demand covered)	No	No	Yes (multiple scenario's and every scenario has a probability of occurring. Since the objective is to maximize the demand it is more important to maximize the demand of scenario's which are more likely to occur then scenario's which have very low occurring probability)	No (a scenario only represents one disaster and only one demand point)	Yes
Sheu et al. (2005)	No (Minimize the travel distance from facilities to demand points)	No (Every facility has a maximum capacity)	Yes (second stage)	Yes (Based on a maximum total amount of facilities)	Yes	Yes (a demand point can only be served by one facility)	No	No	Yes (also a demand point is maximum served by one facility)	No	No	No	Yes (The model optimizes for one situation, this situation can include multiple disaster happening at the same time)	No
Murali et al. (2012)	No (Maximize the total demand covered by the established distribution centres, pre determined maximum amount of facility centres to open)	No (Every facility has a maximum capacity)	Yes (third stage)	Yes (Based on a maximum total amount of facilities)	Yes	Yes	No (Maximize the total demand covered)	Yes	No (Maximize the total demand covered)	No (Every demand point has the same different coverage levels and for every demand point, maximum a certain fraction of the total needed demand can be served by facilities located in a certain coverage level)	No	No (Model takes the uncertainty about the amount of demand into account)	Yes (The model optimizes for one situation, this situation can include multiple disaster happening at the same time)	Yes
Rawls and Turnquist (2010)	Yes (It is a cost minimization function consisting of the cost to build facilities, the cost to store and buy goods, the cost to transport the goods, the cost for unmet demand and the cost for storing unused goods)	Yes (see left)		Yes	Yes	Yes	No (Minimize the cost. There is cost for the unmet demand)	No (Minimize the cost, the further travel time the more cost)	No (demand points can be not served at all)	No	No	Yes (multiple scenario's and every scenario has a probability of occurring. The scenario's does not affect the first stage, but it affects the second stage. Since the objective of the second stage is to minimize the unmet demand it is more important to minimize the unmet demand of scenario's which are more likely to occur then scenario's which have very low occurring probability)	Yes (some scenario's consist of multiple disasters happening simultaneously)	Yes

Table H.1 continued

	Minimize amount of facilities to open	Minimize the amount of goods stored at facilities		Determine which facilities must be opened and which not in order to cover all demand points	Place the amount of goods necessary at the facilities in order to serve all demand points		Have enough supply for every demand point	Contains a maximum service distance	Every demand point is assigned to at least one facility	Individual service distance limits for every demand point	Uncertainty has influence on the maximum service distance	Take the uncertainty about the exact striking area into account	Take into account the fact that multiple disasters can happen simultaneously	Demand points can be supplied by multiple facilities
Toregas et al. (1971)	Yes (standard set covering problem. Parameter with cost can be included)	No (standard set covering problem)	No	Yes (standard set covering problem)	No	No	No	Yes	Yes (standard set covering problem)	Yes (standard set covering problem)	No (standard set covering problem)	No (standard set covering problem)	No (standard set covering problem)	Yes (standard set covering problem)
Aly and White (1978)	Yes (standard set covering problem. Parameter with cost can be included)	No (probabilistic standard set covering problem)	No	Yes (probabilistic standard set covering problem)	No (probabilistic standard set covering problem)	No	No (standard set covering problem)	Yes (probabilistic standard set covering problem)	Yes (probabilistic standard set covering problem, however facilities can only cover demand points which have a high probability of being located within the cover distance)	Yes (probabilistic standard set covering problem, the threshold for the probability of a demand point being located within the cover distance can be adjusted for every individual demand point)	No (facilities can only cover demand points which have a high probability of being located within the cover distance)	Yes (facilities can only cover demand points which have a high probability of being located within the cover distance)	No (probabilistic standard set covering problem)	Yes (probabilistic standard set covering problem)
Daskin and Stern (1981)	Yes (standard set covering problem. Parameter with cost can be included)	No (based on a set covering problem)	No	Yes (based on a set covering problem)	No (based on a set covering problem)	No	No (standard set covering problem)	Yes (based on a set covering problem)	Yes (based on a set covering problem)	Yes (based on a set covering problem)	No (deterministic set covering problem)	No (deterministic set covering problem)	Partly (by incorporating to maximize the amount of demand points which can be served by multiple facilities)	Yes (based on a set covering problem)
Revelle and Hogan (1989)	Yes (standard set covering problem. Parameter with cost can be included)	No (a facility can help only one demand point and can thus only hold 1 ambulance)	No	Yes (based on a set covering problem)	No (a facility can help only one demand point and a demand point needs only one supply unit)	No	Partly (All the demand points must be covered with a specific reliability level related to the estimated busy fraction of a facility)	Yes (based on a set covering problem)	Partly (All the demand points must be covered with a specific reliability level related to the estimated busy fraction of a facility)	Yes (based on a set covering problem)	No	No	Yes (by estimating the busy fraction of a facility, which is the same in the whole system)	Yes (based on a set covering problem)

Table H.1 continued

	Minimize amount of facilities to open	Minimize the amount of goods stored at facilities		Determine which facilities must be opened and which not in order to cover all demand points	Place the amount of goods necessary at the facilities in order to serve all demand points		Have enough supply for every demand point	Contains a maximum service distance	Every demand point is assigned to at least one facility	Individual service distance limits for every demand point	Uncertainty has influence on the maximum service distance	Take the uncertainty about the exact striking area into account	Take into account the fact that multiple disasters can happen simultaneously	Demand points can be supplied by multiple facilities
Ball and Lin (1993)	Yes (standard set covering problem. Parameter with cost is included)	Yes (assumption that every demand point needs only one supply unit)	No	Yes (based on a set covering problem)	Yes (Assumption that every demand point needs only one supply unit)	No	Partly (Assumption that every demand point needs only one supply unit, and enough supply to reach the specific reliability level)	Yes (based on a set covering problem)	Partly (All the demand points must be covered with a specific reliability level based on the probability a facility fails to deliver demand)	Yes (based on a set covering problem)	No	No	Yes (by estimating the fact that a facility fails to deliver demand, which is the same in the whole system)	Yes (based on a set covering problem)
Marianov and Revelle (1994)	Yes (standard set covering problem. Parameter with cost can be included)	No (a facility can help only one demand point and can thus only hold 1 ambulance)	No	Yes (based on a set covering problem)	No (a facility can help only one demand point and a demand point needs only one supply unit)	No	Partly (All the demand points must be covered with a specific reliability level related to the estimated busy fraction of a facility)	Yes (based on a set covering problem)	Partly (All the demand points must be covered with a specific reliability level related to the estimated busy fraction of a facility)	Yes (based on a set covering problem)	No	No	Yes (by estimating the busy fraction of a facility, which is neighbourhood dependent)	Yes (based on a set covering problem)
Shiah and Chen (2007)	Yes (standard set covering problem. Parameter with cost can be included)	No	No	Yes (based on a set covering problem)	Partly (it assumes that every demand point needs only one supply unit and the model creates demand points which also only need one supply unit)	No	Yes (it assumes that every demand point needs only one supply unit and the model creates demand points which also only need one supply unit)	Yes (based on a set covering problem)	Yes (based on a set covering problem)	Yes (based on a set covering problem)	No	No	No	No
Dekle et al. (2005)	Yes (standard set covering problem. Parameter with cost can be included)	No	No	Yes (based on a set covering problem)	No	No	No	Yes	Yes (based on a set covering problem)	No	No	No	No	Yes
Rath and Gutjahr (2014)	Yes (It is a cost minimization function consisting of the cost to build facilities, the cost to warehousing goods and the cost to transport goods)	Yes (see left)	Yes (see left)	Yes (based on a set covering problem)	Yes	Yes	No (Maximize the total demand covered, given a certain maximum capacity)	Yes	No (Maximize the total demand covered)	No (every facility has an individual covering distance)	No	No	No	No

Table H.1 continued

	Minimize amount of facilities to open	Minimize the amount of goods stored at facilities		Determine which facilities must be opened and which not in order to cover all demand points	Place the amount of goods necessary at the facilities in order to serve all demand points		Have enough supply for every demand point	Contains a maximum service distance	Every demand point is assigned to at least one facility	Individual service distance limits for every demand point	Uncertainty has influence on the maximum service distance	Take the uncertainty about the exact striking area into account	Take into account the fact that multiple disasters can happen simultaneously	Demand points can be supplied by multiple facilities
Hu et al. (2014)	Yes (standard set covering problem. Parameter with cost is included)	No	Yes (minimizes the distance but it is possible to add a cost factor to that distance)	Yes (based on a set covering problem)	No	Yes (a demand point can only be totally helped and served by one facility)	Yes (a demand point can only be totally helped and served by one facility)	No	Yes	No	No	No	No	No
Hale and Moberg (2005)	Yes (standard set covering problem. Parameter with cost can be included)	No	No	Yes (based on a set covering problem)	Yes (but assumption that a demand point can only be served by a facility which has enough capacity to totally help that demand point. And only one demand point need help at a time)	No	Yes (but assumption that a demand point can only be served by a facility which has enough capacity to totally help that demand point. And only one demand point need help at a time)	Yes	Yes (based on a set covering problem)	Yes	No	Partly (by not only setting a covering maximum distance but also a minimum distance in order to not place facilities inside potential disaster areas)	No	Yes
Jabbarzadeh et al. (2014)	Yes (standard set covering problem. Parameter with cost is included)	Yes	Yes	Yes (based on a set covering problem)	Yes	Yes	No	Yes	No	No	No	Yes (multiple scenario's and every scenario has a probability of occurring. Since the objective is to minimize the costs it is more important to minimize the cost of scenario's which are more likely to occur then scenario's which have very low occurring probability)	Yes (some scenario's consist of multiple disasters happening simultaneously)	Yes
Chang et al. (2007)	Yes (standard set covering problem. Parameter with cost is included)	Yes	Yes	Yes (based on a set covering problem)	Yes	Yes	No (Minimize the total unmet demand, facilities have maximum capacity)	Yes	No	No	No	Yes (multiple scenario's and every scenario has a probability of occurring. Since the objective is to minimize the costs it is more important to minimize the cost of scenario's which are more likely to occur then scenario's which have very low occurring probability)	Yes (some scenario's consist of multiple disasters happening simultaneously)	Yes
Oksuz and Satoglu (2020)	Yes (standard set covering problem. Parameter with cost is included)	No	Yes	Yes (based on a set covering problem)	No	Yes	No (Minimize the total unmet demand, facilities have maximum capacity)	Yes	No	No	No	Yes (multiple scenario's and every scenario has a probability of occurring. Since the objective is to minimize the costs it is more important to minimize the cost of scenario's which are more likely to occur then scenario's which have very low occurring probability)	Yes (some scenario's consist of multiple disasters happening simultaneously)	No
An et al. (2015)	Yes (standard set covering problem. Parameter with cost is included)	No	Yes	Yes (based on a set covering problem)	No	Yes	No (Minimize the total unmet demand, facilities have maximum capacity)	No	No	No	No	Yes (multiple scenario's and every scenario has a probability of occurring. Since the objective is to minimize the costs it is more important to minimize the cost of scenario's which are more likely to occur then scenario's which have very low occurring probability)	Yes (some scenario's consist of multiple disasters happening simultaneously)	No

I

Inputs mathematical optimization model

In order to run the model and thus determine the logistical design it is important to look at the different inputs which will be put in the preprocessing steps and the mathematical optimization model in order to define the results. As described in chapter 7 there are different inputs which must be determined in order to solve the mathematical optimization model. First the maximum distance for every individual demand point to be considered as covered must be determined. This maximum distance depends on the speed of transport of the FFM seaport. Second the different demand situations which can occur separately from each other and the amount of times this situation happens during the time frame has to be determined. Next to these two inputs also the set of possible facility locations with related costs, the distances between every demand point and possible facilities with related costs to transport handling capacity over this distance and the amount of handling capacity necessary to help a specific demand point is necessary in order to solve the mathematical optimization model. All these inputs will be discussed in this appendix.

I.1. Speed

Since speed is such an important characteristic, it is important to determine the way in which the FFM seaport will be transported to the affected area. For this research it is looked how oil rigs are transported to there destination. This is done by semi-submersible heavy lift vessels (Golson, 2014; Nguyen, 2012; Van Hoorn, 2008). For this research it is assumed that the FFM seaports also will be transported to the affected area by such heavy lift vessels. This because these kind of vessels are specifically designed to transport big infrastructures on the open sea. Next to that, as described in appendix B, also the military used heavy lift vessels to create the seaport during the Falkland War.

When looking at specific semi-submersible heavy lift vessels it can be seen that the Dockwise Vanguard is the world largest semi-submersible heavy lift vessel (gCaptain, 2016; Golson, 2014; Nguyen, 2012). It has a maximum carrying capacity of 110.000t and it consumes 5000t of fuel when it travels from the Far East to the Gulf of Mexico (Dockwise, 2012). Construction costs of the Dockwise Vanguard was $240m (ShipTechnology, 2013). The Dockwise Vanguard has an operational speed of 14 kts (Dockwise, 2012; ShipTechnology, 2013). However this speed will most certainly increase in the future. There are already heavy lift vessels with a lower carrying capacity which reaches a speed of 18 kts (ShipBuilding Industry, 2007) and even 20 kts (Van Hoorn, 2008). Also there are designs made of military heavy lift vessels which can reach 18 kts (Bloxom et al., 2007). This makes the expectation that also the newest largest heavy lift vessel will reach a higher speed as is endorsed by ShipBuilding Industry (2007). Since speed is important it is assumed that these semi-submersible heavy lift vessels will transport the FFM seaport. Since most certainly the seaport will be build in the future, and thus heavy lift vessels especially can be designed with speed in mind it is assumed that the vessels transporting the FFM seaport will reach a speed of 18 kts.

I.2. Maximum covering distance

As discussed in chapter 3 the results of the disaster relief effort analysis points out that the FFM seaport can be of help for islands with 265,000 or more inhabitants. So all these islands are identified on basis of the Noordhof Atlasproducties (2012). For all these islands several things are checked. First of all in which sea they are located (this for the situation making which will be explained in the next section). Second with the help of Google Maps (Google, nd) it is checked if there is a road connection with the mainland of the landmasses of Afro-Eurasia, Americas and Mainland Australia. If yes, then this island can be reached by trucks over the road and the FFM seaport is not a necessary component anymore for the disaster relief situation and thus that demand point is not taken into consideration.

After that a list remain of the demand points which will be taken into consideration. To determine the maximum coverage distance of these demand points two things will be evaluated for every demand point: the probability that a disaster will happen at that demand point and the consequences if a demand point is affected by a disaster. The first one: the probability that a disaster will happen is based on the geographic vulnerability of the location of the island and the amount of previous big disasters. The first one is taken from the World Risk Index Report 2020 (Behlert et al., 2020). They describe the location's vulnerability as the exposure of the population of a country to disasters. They give all countries in the world a number related to this amount of exposure of the population to disasters. The more amount of exposure, the higher the number. This number is directly copied to the islands. Note however that sometimes an island consist of more different countries. In that case the highest number of that involving countries is chosen as a worst case scenario. It is also possible that a country consist of multiple islands and/or an island and mainland. In that case just the number of that corresponding country is taken. The amount of previous big disasters is based on the disaster relief effort analysis. Within the disaster relief effort analysis it can be seen which islands with more then 100,000 inhabitants are affected hard the past previous 38 years. It is counted how many times an islands is affected hard the previous 38 years and this number is written down.

For the consequences for a demand point after a disaster hit that demand point three different things are taken into account: the likelihood of generally suffering damage, the amount and size of airports on the island and the amount and size of seaports on the island. With the last two also the amount of inhabitants on the islands is taken into account. The likelihood of generally suffering damage is again taken from the World Risk Report 2020 (Behlert et al., 2020). They describe it as the current status of a country and it is a measure about how badly a country can be hit after a disaster and thus how fast and how many disaster aid is necessary. It consist of the current state of the public infrastructure, housing conditions, nutrition conditions, poverty conditions and the economic capacity (the GPA of the country) and income distribution (Behlert et al., 2020). Again this is information is bundled in a number and the higher the number the higher the likelihood of damage. This number is directly copied to the islands. Note however again that, the same as described above, that sometimes an island consist of multiple different countries or a country consist of multiple islands and/or an island and mainland. In that case again the same choices are made as above. With respect to the amount of airports there is checked how many small, regional and major airports there are located on the island based on information from OurAirports (2021). For every small airport on the island 1 point is given, every regional airport 2 points are given and every major airport 3 points. By summing up this points and dividing by the amount of inhabitants on that island the amount of points per inhabitant is given for every demand point. For the seaport this same tactic is used. There is checked how many very small, small, medium, large and very large seaports are located on the island based on information from Waters (2021). Again the scores are summed and divided by the amount of inhabitant on that island.

With this information the demand points are classified for every category. So for the geographic vulnerability there is looked at the classification from the World Risk Report 2020. They classified the numbers for every country of the world with the quintile method (Behlert et al., 2020). Meaning that the top 20% countries within that category of the World Risk Index get a dark green classification, the 20% till 40% countries a green classification, the 40% till 60% a yellow classification, the 60% till 80% a red classification and the 80% till 100% countries a dark red classification. This classification is also copied to this research. When a countries geographic vulnerability was in the highest quintile in the World Risk Index the classification for this factor which is part of determining the maximum coverage distance was a 1. When it was in the second quintile the classification was a 0.75, in the third quintile the classification was a 0.5, in the fourth quintile a 0.25 and in the fifth quintile a 0. This classification method for this research is also used for determining the classification for the susceptibility factor.

For the airports and seaports more or less the same method is used. However right now it is not looked to every country in the world, but the amount points per inhabitant is compared for every demand point. Again when this score was in the highest quintile the classification for this factor which is part of determining the maximum coverage distance was a 1. When it was in the second quintile the classification was a 0.75, in the third quintile the classification was a 0.5, in the fourth quintile a 0.25 and in the fifth quintile a 0. This method is performed for the seaports as well as for the airports.

For the big previous disasters it is a little bit harder to use the same method as is done for the airport and seaport. This because more then 20% of the demand points is not affected by any big previous disaster. Next to that the difference between the demand point the most times hit by a big previous disaster (15 times) is a lot more then the demand point the second most times hit by a big previous disaster (8 times). So a self made classification is used. When the demand point is not hit by any big disaster in the previous 38 years the demand point is given a 1. When it is hit once or twice a 0.75, when it is hit three or four times a 0.5, when it is hit five, six or seven times a 0.25 and 8 times or higher a 0.

On basis of this information with the help of a formula an overall factor is determined. If a demand point scored in the highest quintile over every category it is assumed that the time for the FFM seaport to be operational for that demand point is two times as much as a demand point which scored in the lowest quintitle over every category. Formula I.1 is used to determine the multiplication factor for the maximum service distance.

$$MF = 1 + (0.5 * (0.5 * GV_c + 0.5 * PD_c) + 0.5 * (0.33 * S_c + 0.33 * Air_c + 0.33 * Sea_c)) \tag{I.1}$$

Where MF stands for the multiplication factor, GV_c for the geographic vulnerability classification, PD_c for the previous disaster classification, S_c for the susceptibility classification, Air_c for the airports classification and Sea_c for the seaport classification.

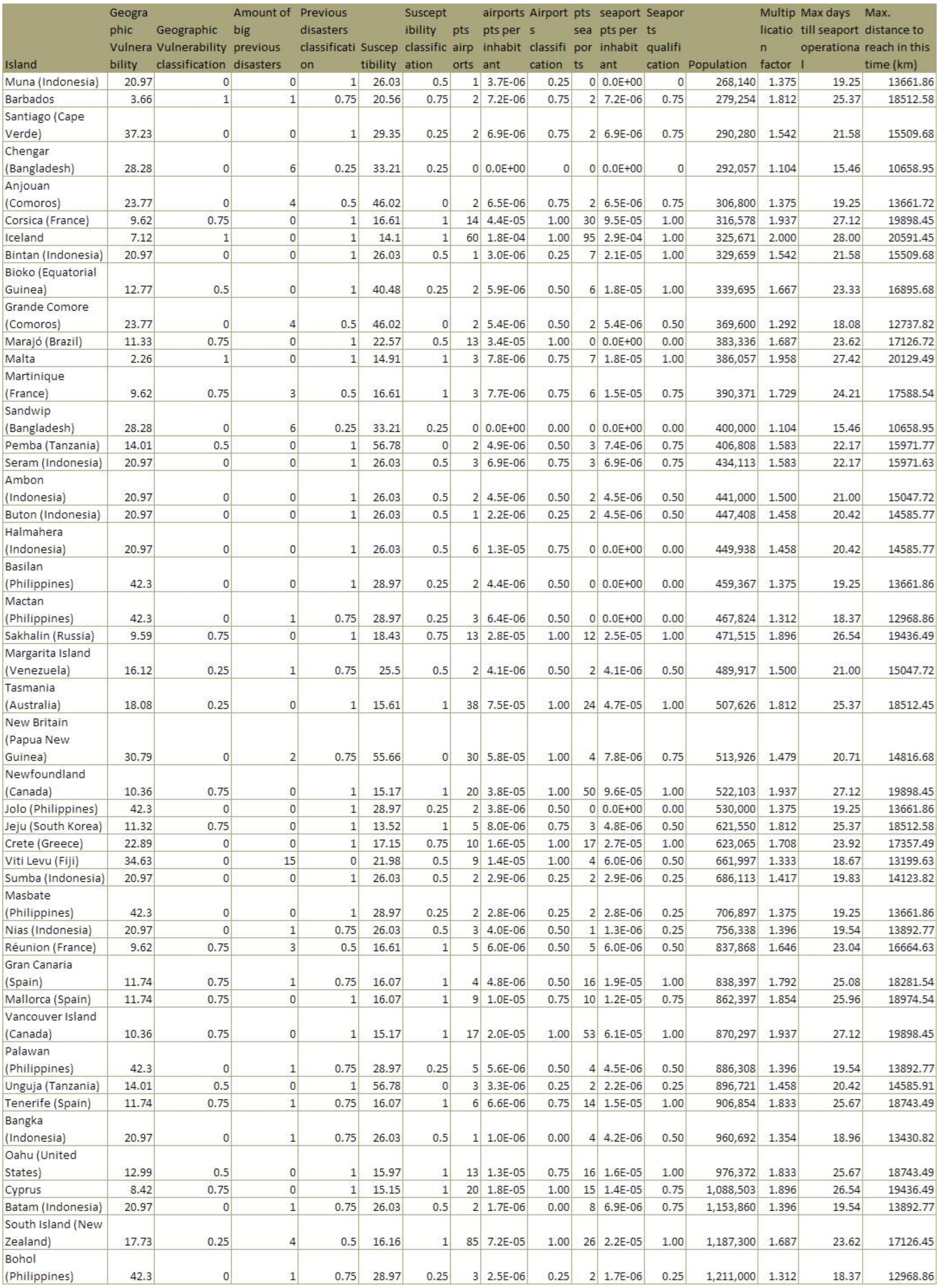
In the end this formula gives for every demand point the multiplication factor which is a number between 1 and 2. As discussed in chapter 2.3 every disaster relief effort takes at least 14 days before ships are bringing the relief goods. This means that the multiplication factor is multiplied by 14 days and this figure gives the maximum days after the seaport must be operational at that demand point. It is assumed that it take two days to install the FFM seaport. This assumption is based on the possibilities from the military which also must theoretical be able to create an operational seaport within 2 days as discussed in appendix B. By subtracting 2 days from the maximum amount of days till the seaport must be operational and multiplying this number with 24 hours and 33 km/h (the speed of the semi-submersible heavy lift vessels, see subsection I.1) the maximum distance which can be reached within the time frame is calculated. This maximum distance is the maximum coverage distance for that particular demand point and that demand point can only be served by facilities which are within this maximum coverage distance. The results can be seen in table I.1.

I.3. Demand situations

Another input for the mathematical optimization model are the different demand situations. Every situation occurs separate from each other and consist of the the demand points which needs service within the same time frame during that situation. Next to that, as will be explained later, also possible facility locations can be located at an island and in some situations this island can be affected and thus this possible facility location can not be of help during that situation and thus this facility location will not be taken into account in that situation. Also the amount of times this disaster situation will happen will be taken into consideration.

Since this amount of times that a disaster situation will happen is important to know, also the total time frame in which the FFM seaport design will be of help must taken into consideration. Within this time

Table I.1: The maximum coverage distance of every demand point and the information necessary to calculate that distance



Island	Geographic Vulnerability	Geographic Vulnerability classification	Amount of big previous disasters	Previous disasters classification	Susceptibility	Susceptibility classification	pts airports	airports pts per inhabitant	Airports classification	pts seaports	seaport pts per inhabitant	Seaports qualification	Population	Multiplication factor	Max days till seaport operational	Max. distance to reach in this time (km)
Muna (Indonesia)	20.97	0	0	1	26.03	0.5	1	3.7E-06	0.25	0	0.0E+00	0	268,140	1.375	19.25	13661.86
Barbados	3.66	1	1	0.75	20.56	0.75	2	7.2E-06	0.75	2	7.2E-06	0.75	279,254	1.812	25.37	18512.58
Santiago (Cape Verde)	37.23	0	0	1	29.35	0.25	2	6.9E-06	0.75	2	6.9E-06	0.75	290,280	1.542	21.58	15509.68
Chengar (Bangladesh)	28.28	0	6	0.25	33.21	0.25	0	0.0E+00	0	0	0.0E+00	0	292,057	1.104	15.46	10658.95
Anjouan (Comoros)	23.77	0	4	0.5	46.02	0	2	6.5E-06	0.75	2	6.5E-06	0.75	306,800	1.375	19.25	13661.72
Corsica (France)	9.62	0.75	0	1	16.61	1	14	4.4E-05	1.00	30	9.5E-05	1.00	316,578	1.937	27.12	19898.45
Iceland	7.12	1	0	1	14.1	1	60	1.8E-04	1.00	95	2.9E-04	1.00	325,671	2.000	28.00	20591.45
Bintan (Indonesia)	20.97	0	0	1	26.03	0.5	1	3.0E-06	0.25	7	2.1E-05	1.00	329,659	1.542	21.58	15509.68
Bioko (Equatorial Guinea)	12.77	0.5	0	1	40.48	0.25	2	5.9E-06	0.50	6	1.8E-05	1.00	339,695	1.667	23.33	16895.68
Grande Comore (Comoros)	23.77	0	4	0.5	46.02	0	2	5.4E-06	0.50	2	5.4E-06	0.50	369,600	1.292	18.08	12737.82
Marajó (Brazil)	11.33	0.75	0	1	22.57	0.5	13	3.4E-05	1.00	0	0.0E+00	0.00	383,336	1.687	23.62	17126.72
Malta	2.26	1	0	1	14.91	1	3	7.8E-06	0.75	7	1.8E-05	1.00	386,057	1.958	27.42	20129.49
Martinique (France)	9.62	0.75	3	0.5	16.61	1	3	7.7E-06	0.75	6	1.5E-05	0.75	390,371	1.729	24.21	17588.54
Sandwip (Bangladesh)	28.28	0	6	0.25	33.21	0.25	0	0.0E+00	0.00	0	0.0E+00	0.00	400,000	1.104	15.46	10658.95
Pemba (Tanzania)	14.01	0.5	0	1	56.78	0	2	4.9E-06	0.50	3	7.4E-06	0.75	406,808	1.583	22.17	15971.77
Seram (Indonesia)	20.97	0	0	1	26.03	0.5	3	6.9E-06	0.75	3	6.9E-06	0.75	434,113	1.583	22.17	15971.63
Ambon (Indonesia)	20.97	0	0	1	26.03	0.5	2	4.5E-06	0.50	2	4.5E-06	0.50	441,000	1.500	21.00	15047.72
Buton (Indonesia)	20.97	0	0	1	26.03	0.5	1	2.2E-06	0.25	2	4.5E-06	0.50	447,408	1.458	20.42	14585.77
Halmahera (Indonesia)	20.97	0	0	1	26.03	0.5	6	1.3E-05	0.75	0	0.0E+00	0.00	449,938	1.458	20.42	14585.77
Basilan (Philippines)	42.3	0	0	1	28.97	0.25	2	4.4E-06	0.50	0	0.0E+00	0.00	459,367	1.375	19.25	13661.86
Mactan (Philippines)	42.3	0	1	0.75	28.97	0.25	3	6.4E-06	0.50	0	0.0E+00	0.00	467,824	1.312	18.37	12968.86
Sakhalin (Russia)	9.59	0.75	0	1	18.43	0.75	13	2.8E-05	1.00	12	2.5E-05	1.00	471,515	1.896	26.54	19436.49
Margarita Island (Venezuela)	16.12	0.25	1	0.75	25.5	0.5	2	4.1E-06	0.50	2	4.1E-06	0.50	489,917	1.500	21.00	15047.72
Tasmania (Australia)	18.08	0.25	0	1	15.61	1	38	7.5E-05	1.00	24	4.7E-05	1.00	507,626	1.812	25.37	18512.45
New Britain (Papua New Guinea)	30.79	0	2	0.75	55.66	0	30	5.8E-05	1.00	4	7.8E-06	0.75	513,926	1.479	20.71	14816.68
Newfoundland (Canada)	10.36	0.75	0	1	15.17	1	20	3.8E-05	1.00	50	9.6E-05	1.00	522,103	1.937	27.12	19898.45
Jolo (Philippines)	42.3	0	0	1	28.97	0.25	2	3.8E-06	0.50	0	0.0E+00	0.00	530,000	1.375	19.25	13661.86
Jeju (South Korea)	11.32	0.75	0	1	13.52	1	5	8.0E-06	0.75	3	4.8E-06	0.50	621,550	1.812	25.37	18512.58
Crete (Greece)	22.89	0	0	1	17.15	0.75	10	1.6E-05	1.00	17	2.7E-05	1.00	623,065	1.708	23.92	17357.49
Viti Levu (Fiji)	34.63	0	15	0	21.98	0.5	9	1.4E-05	1.00	4	6.0E-06	0.50	661,997	1.333	18.67	13199.63
Sumba (Indonesia)	20.97	0	0	1	26.03	0.5	2	2.9E-06	0.25	2	2.9E-06	0.25	686,113	1.417	19.83	14123.82
Masbate (Philippines)	42.3	0	0	1	28.97	0.25	2	2.8E-06	0.25	2	2.8E-06	0.25	706,897	1.375	19.25	13661.86
Nias (Indonesia)	20.97	0	1	0.75	26.03	0.5	3	4.0E-06	0.50	1	1.3E-06	0.25	756,338	1.396	19.54	13892.77
Réunion (France)	9.62	0.75	3	0.5	16.61	1	5	6.0E-06	0.50	5	6.0E-06	0.50	837,868	1.646	23.04	16664.63
Gran Canaria (Spain)	11.74	0.75	1	0.75	16.07	1	4	4.8E-06	0.50	16	1.9E-05	1.00	838,397	1.792	25.08	18281.54
Mallorca (Spain)	11.74	0.75	0	1	16.07	1	9	1.0E-05	0.75	10	1.2E-05	0.75	862,397	1.854	25.96	18974.54
Vancouver Island (Canada)	10.36	0.75	0	1	15.17	1	17	2.0E-05	1.00	53	6.1E-05	1.00	870,297	1.937	27.12	19898.45
Palawan (Philippines)	42.3	0	1	0.75	28.97	0.25	5	5.6E-06	0.50	4	4.5E-06	0.50	886,308	1.396	19.54	13892.77
Unguja (Tanzania)	14.01	0.5	0	1	56.78	0	3	3.3E-06	0.25	2	2.2E-06	0.25	896,721	1.458	20.42	14585.91
Tenerife (Spain)	11.74	0.75	1	0.75	16.07	1	6	6.6E-06	0.75	14	1.5E-05	1.00	906,854	1.833	25.67	18743.49
Bangka (Indonesia)	20.97	0	1	0.75	26.03	0.5	1	1.0E-06	0.00	4	4.2E-06	0.50	960,692	1.354	18.96	13430.82
Oahu (United States)	12.99	0.5	0	1	15.97	1	13	1.3E-05	0.75	16	1.6E-05	1.00	976,372	1.833	25.67	18743.49
Cyprus	8.42	0.75	0	1	15.15	1	20	1.8E-05	1.00	15	1.4E-05	0.75	1,088,503	1.896	26.54	19436.49
Batam (Indonesia)	20.97	0	1	0.75	26.03	0.5	2	1.7E-06	0.00	8	6.9E-06	0.75	1,153,860	1.396	19.54	13892.77
South Island (New Zealand)	17.73	0.25	4	0.5	16.16	1	85	7.2E-05	1.00	26	2.2E-05	1.00	1,187,300	1.687	23.62	17126.45
Bohol (Philippines)	42.3	0	1	0.75	28.97	0.25	3	2.5E-06	0.25	2	1.7E-06	0.25	1,211,000	1.312	18.37	12968.86

Table I.1 continued

Island	Geographic Vulnerability	Geographic Vulnerability classification	Amount of big previous disasters	Previous disasters classification	Susceptibility	Susceptibility classification	pts airports	airports pts per inhabitant	Airports classification	pts seaports	seaport pts per inhabitant	Seaports qualification	Population	Multiplication factor	Max days till seaport operational	Max. distance to reach in this time (km)
Mauritius	23.84	0	3	0.5	17.46	0.75	4	3.3E-06	0.25	3	2.5E-06	0.25	1,219,265	1.333	18.67	13199.77
Trinidad (Trinidad and Tobago)	23.39	0	0	1	24.17	0.5	3	2.4E-06	0.25	15	1.2E-05	0.75	1,267,145	1.500	21.00	15047.72
Okinawa Island (Japan)	38.67	0	0	1	17.76	0.75	8	6.1E-06	0.50	6	4.6E-06	0.50	1,301,000	1.542	21.58	15509.68
Mindoro (Philippines)	42.3	0	0	1	28.97	0.25	8	6.0E-06	0.50	2	1.5E-06	0.25	1,331,473	1.417	19.83	14123.82
Sumbawa (Indonesia)	20.97	0	0	1	26.03	0.5	4	2.9E-06	0.25	3	2.2E-06	0.25	1,391,340	1.417	19.83	14123.82
Sardinia (Italy)	15.17	0.25	0	1	17.25	0.75	40	2.4E-05	1.00	69	4.2E-05	1.00	1,659,000	1.771	24.79	18050.49
Samar (Philippines)	42.3	0	1	0.75	28.97	0.25	8	4.6E-06	0.50	6	3.4E-06	0.50	1,751,267	1.396	19.54	13892.77
Bhola Island (Bangladesh)	28.28	0	6	0.25	33.21	0.25	0	0.0E+00	0.00	0	0.0E+00	0.00	1,758,000	1.104	15.46	10658.95
Flores (Indonesia)	20.97	0	0	1	26.03	0.5	7	3.8E-06	0.50	6	3.3E-06	0.50	1,831,000	1.500	21.00	15047.72
Leyte (Philippines)	42.3	0	1	0.75	28.97	0.25	7	2.7E-06	0.25	8	3.0E-06	0.50	2,626,970	1.354	18.96	13430.82
Jamaica	26.05	0	5	0.25	25.14	0.5	26	8.8E-06	0.75	23	7.8E-06	0.75	2,950,210	1.396	19.54	13892.63
Timor (Indonesia & Timor-Leste)	25.85	0	1	0.75	42.33	0.25	17	5.3E-06	0.50	4	1.3E-06	0.25	3,182,693	1.354	18.96	13430.82
Lombok (Indonesia)	20.97	0	0	1	26.03	0.5	3	9.1E-07	0.00	3	9.1E-07	0.00	3,311,044	1.333	18.67	13199.91
Puerto Rico (United States)	12.99	0.5	2	0.75	15.97	1	24	6.9E-06	0.75	34	9.8E-06	0.75	3,474,182	1.729	24.21	17588.54
Shikoku (Japan)	38.67	0	0	1	17.76	0.75	8	2.1E-06	0.25	67	1.8E-05	1.00	3,815,000	1.583	22.17	15971.63
North Island (New Zealand)	17.73	0.25	1	0.75	16.16	1	84	2.2E-05	1.00	30	7.7E-06	0.75	3,896,200	1.708	23.92	17357.49
Madura (Indonesia)	20.97	0	0	1	26.03	0.5	2	5.0E-07	0.00	4	1.0E-06	0.25	4,004,564	1.375	19.25	13661.86
Cebu (Philippines)	42.3	0	1	0.75	28.97	0.25	1	2.3E-07	0.00	3	7.0E-07	0.00	4,311,040	1.229	17.21	12044.95
Bali (Indonesia)	20.97	0	0	1	26.03	0.5	4	9.3E-07	0.00	4	9.3E-07	0.00	4,317,404	1.333	18.67	13199.91
Panay (Philippines)	42.3	0	1	0.75	28.97	0.25	10	2.2E-06	0.25	8	1.8E-06	0.25	4,542,926	1.312	18.37	12968.86
Negros (Philippines)	42.3	0	1	0.75	28.97	0.25	6	1.3E-06	0.00	14	3.0E-06	0.25	4,656,945	1.271	17.79	12506.91
Sicily (Italy)	15.17	0.25	0	1	17.25	0.75	47	9.4E-06	0.75	50	1.0E-05	0.75	5,017,000	1.687	23.62	17126.58
Hokkaidō (Japan)	38.67	0	1	0.75	17.76	0.75	55	1.0E-05	0.75	35	6.5E-06	0.50	5,383,579	1.521	21.29	15278.63
Ireland (Ireland and United Kingdom)	16.68	0.25	0	1	15.74	1	133	1.9E-05	1.00	121	1.8E-05	1.00	6,894,291	1.812	25.37	18512.45
Hainan (China)	14.3	0.5	1	0.75	20.98	0.75	14	1.4E-06	0.00	9	8.9E-07	0.00	10,081,232	1.437	20.12	14354.86
Cuba	16.53	0.25	8	0	19.48	0.75	148	1.3E-05	0.75	56	4.9E-06	0.50	11,318,747	1.396	19.54	13892.63
Kyūshū (Japan)	38.67	0	0	1	17.76	0.75	36	2.7E-06	0.25	126	9.5E-06	0.75	13,200,000	1.542	21.58	15509.68
New Guinea (Papua New Guinea and Indonesia)	30.79	0	2	0.75	55.66	0	607	4.1E-05	1.00	36	2.4E-06	0.25	14,800,000	1.396	19.54	13892.77
Celebes (Indonesia)	20.97	0	0	1	26.03	0.5	30	1.5E-06	0.00	20	9.9E-07	0.25	20,160,000	1.375	19.25	13661.86
Sri Lanka	15.99	0.25	3	0.5	22.82	0.5	30	1.4E-06	0.00	10	4.6E-07	0.00	21,919,000	1.271	17.79	12506.91
Hispaniola (Dominican Republic and Haiti)	24.85	0	8	0	51.15	0	66	3.0E-06	0.25	43	1.9E-06	0.25	22,278,000	1.083	15.17	10427.91
Borneo (Indonesia, Brunei, Malaysia)	57.61	0	1	0.75	26.03	0.5	159	6.7E-06	0.75	78	3.3E-06	0.50	23,720,000	1.479	20.71	14816.68
Taiwan (Republic of China)	14.3	0.5	0	1	20.98	0.75	49	2.1E-06	0.00	18	7.5E-07	0.00	23,865,820	1.500	21.00	15047.86
Mindanao (Philippines)	42.3	0	0	1	28.97	0.25	70	2.6E-06	0.25	37	1.4E-06	0.25	27,021,036	1.375	19.25	13661.86
Madagascar	15.12	0.25	7	0.25	65.68	0	104	3.7E-06	0.25	17	6.0E-07	0.00	28,479,665	1.167	16.33	11351.95
Sumatra (Indonesia)	20.97	0	1	0.75	26.03	0.5	64	1.1E-06	0.00	56	9.5E-07	0.25	58,880,000	1.312	18.37	12968.86
Luzon (Philippines)	42.3	0	0	1	28.97	0.25	83	1.3E-06	0.00	26	4.0E-07	0.00	64,260,312	1.292	18.08	12737.95
Great Britain (United Kingdom)	12.58	0.5	0	1	16.42	1	1053	1.6E-05	1.00	543	8.2E-06	0.75	66,397,821	1.833	25.67	18743.49
Honshū (Japan)	38.67	0	2	0.75	17.76	0.75	184	1.8E-06	0.00	438	4.2E-06	0.50	104,000,000	1.396	19.54	13892.77
Java	20.97	0	0	1	26.03	0.5	40	2.7E-07	0.00	56	3.8E-07	0.00	147,795,436	1.333	18.67	13199.91

frame it can be analysed how many times a certain situation occur. One of the results of the disaster relief effort analysis is a time analysis of all different disasters which happened the past 38 years. This result can be find in appendix C.4. From this results it can be distract how many years the FFM seaport was necessary during the past years when taking into consideration that the seaport must travel 14 days towards the affected area and travel 14 days back towards the storage facility. It can be seen that more or less half of the time the seaport would be travelling or operational and half of the time the seaport would be stored. Meaning that in total the seaport would be 19 years operational or travelling within the past 38 years.

As described in the business case of the Transport and Logistics hub for Space@Sea by Dafnomilis (2020), the expected lifetime of the FFM seaport is 25 years by fulltime usage. However since the seaport will not be in use every day this lifetime can be extended. An option would be to double this expected lifetime since the seaport would not be necessary for about 50% of the time. However, when in storage, the FFM seaport will also lose a little bit of his lifetime, dependant on the way how these modules are stored. Therefore, for this research, it is assumed that the lifetime can be extended by 50% resulting in a lifetime of 38 years.

This means that almost all disaster situations are also analysed over 38 years. The disaster relief effort analysis over the last 38 years, see chapter 3, forms the inspiration for these disaster situations. However only making decisions based on past disasters forms a risk since the past does not give any guarantee for the future. However that disasters will occur simultaneously in the future is almost guaranteed. Different hurricane and raining seasons are within the same time span all around the globe (Man Institute, 2019; NOAA's Atlantic Oceanographic and Meteorological Laboratory, 2021; Ryan, 2018). Next to that other disasters, like earthquakes, droughts and flooding, can happen all year around at the world (Emergency Essentials, 2016; Smith, 2021). Also hurricanes can happen within the off season (NOAA's Atlantic Oceanographic and Meteorological Laboratory, 2021).

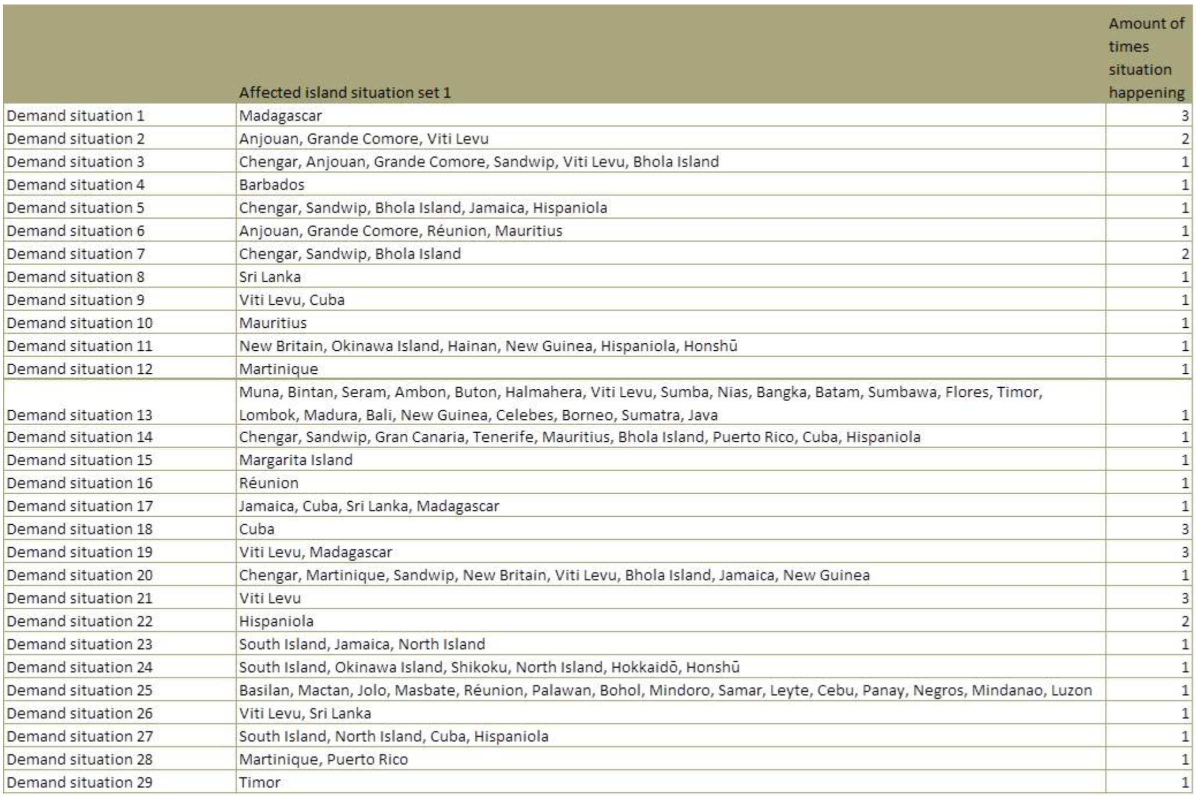
Therefore four different sets of disaster situations are made. These sets will be analysed and compared to each other and this comparison can give the information necessary to make final decisions about the conceptual design of the FFM seaport.

The first set consist of the affected islands with more then 265,000 inhabitants that were hard affected the past 38 years. A time frame of the past 38 years in which one or multiple islands needed help present a demand situation in this research. The information is based on the results from the disaster relief effort analysis and tells that there are 29 different demand situations within this set. It is also possible that a certain island or multiple islands are multiple times affected in different time frames. This means that also the amount of times that this demand situation happen is taken into account. The resulting demand situations can be seen in table I.2.

The third set consist of the islands with more then 265,000 inhabitants which are located in the affected seas or ocean that were hard affected the past 38 years. From the disaster relief effort analysis it is analysed in which seas the hard affected islands are located and all the islands with more then 265,000 inhabitants which are in these seas are taken into account. Off course it is possible that in a certain time frame in the past 38 years, multiple different seas are affected. In that case all the islands in these multiple different seas are taken into account during that time frame. It is also possible that a certain island or multiple islands are multiple times affected in different time frames. This means that also the amount of times that this demand situation happen is taken into account. The oceans and seas are taken from Wang (1992) and this results in 28 different demand situations. Note that this is some kind of a worst case scenario, since it expect that all islands within all affected seas are in need of help. This is also the reason why, in the disaster relief effort analysis, all islands and thus all the corresponding seas are taken into account and not only the islands and their corresponding seas of the islands which are hard affected. The resulting demand situations can be seen in table I.3.

However, this is really a very black worst case scenario. As can be seen in the results from the disaster relief effort analysis in chapter 3 the most amount of islands which are affected in a large way during a time frame is 6 different islands. So the second set consist of the same demand situations as in the third set, however when during a set more then 6 different islands are located in the affected seas,

Table I.2: The first demand situation set



	Affected island situation set 1	Amount of times situation happening
Demand situation 1	Madagascar	3
Demand situation 2	Anjouan, Grande Comore, Viti Levu	2
Demand situation 3	Chengar, Anjouan, Grande Comore, Sandwip, Viti Levu, Bhola Island	1
Demand situation 4	Barbados	1
Demand situation 5	Chengar, Sandwip, Bhola Island, Jamaica, Hispaniola	1
Demand situation 6	Anjouan, Grande Comore, Réunion, Mauritius	1
Demand situation 7	Chengar, Sandwip, Bhola Island	2
Demand situation 8	Sri Lanka	1
Demand situation 9	Viti Levu, Cuba	1
Demand situation 10	Mauritius	1
Demand situation 11	New Britain, Okinawa Island, Hainan, New Guinea, Hispaniola, Honshū	1
Demand situation 12	Martinique	1
Demand situation 13	Muna, Bintan, Seram, Ambon, Buton, Halmahera, Viti Levu, Sumba, Nias, Bangka, Batam, Sumbawa, Flores, Timor, Lombok, Madura, Bali, New Guinea, Celebes, Borneo, Sumatra, Java	1
Demand situation 14	Chengar, Sandwip, Gran Canaria, Tenerife, Mauritius, Bhola Island, Puerto Rico, Cuba, Hispaniola	1
Demand situation 15	Margarita Island	1
Demand situation 16	Réunion	1
Demand situation 17	Jamaica, Cuba, Sri Lanka, Madagascar	1
Demand situation 18	Cuba	3
Demand situation 19	Viti Levu, Madagascar	3
Demand situation 20	Chengar, Martinique, Sandwip, New Britain, Viti Levu, Bhola Island, Jamaica, New Guinea	1
Demand situation 21	Viti Levu	3
Demand situation 22	Hispaniola	2
Demand situation 23	South Island, Jamaica, North Island	1
Demand situation 24	South Island, Okinawa Island, Shikoku, North Island, Hokkaidō, Honshū	1
Demand situation 25	Basilan, Mactan, Jolo, Masbate, Réunion, Palawan, Bohol, Mindoro, Samar, Leyte, Cebu, Panay, Negros, Mindanao, Luzon	1
Demand situation 26	Viti Levu, Sri Lanka	1
Demand situation 27	South Island, North Island, Cuba, Hispaniola	1
Demand situation 28	Martinique, Puerto Rico	1
Demand situation 29	Timor	1

only the 6 islands with most inhabitants are taken into account. The resulting demand situations can be seen in table I.4. One thing which stand out is the fact that there is one situation less then in this set then in the third set. This because when looking at the 6 biggest affected islands, two demand situations of the third set are the same. The amount of time that this situation happens in this set is thus the sum of the amount of times in the third set. Note that this appendix first describes the third set and later the second set. This names are chosen to present the results of the different set in a logical order as can be seen in the results in the main report.

All these three sets are based on the disaster relief effort analysis and thus about history. Since history does not always give guarantee for the future also a fourth set will be analysed. This set consist of all islands, which are affected independent from each other once. This set is maybe not the most realistic one, but it give a good comparison with history.

A last note must be made with respect to the fact that sometimes during the same time frame a certain island can be affected multiple times by another disaster. So that during a disaster relief effort another disaster happen at that same island. One of the advantages of the FFM seaport is the fact that it can be easily transported to another location when necessary. Most of the time, when an island is hit by multiple different disaster during the same time frame this is by cyclones, hurricanes or tsunami’s. These three disasters can be predicted upfront and thus the seaport can be transported to a safe area when necessary. Only once in the past 38 years an affected islands was hit by an earthquake, something which is unpredictable. However on sea and floating structures an earthquake has much less destructive influence (Hasan et al., 2010; Tsai et al., 2012). This means that one of the advantages of the FFM seaport is the fact that it is also much more resistant to natural disasters.

Table I.3: The third demand situation set

Affected sea	Affected island situation set 2	Amount of times situation happening
West Indian Ocean	Anjouan, Grande Comore, Pemba, Réunion, Unguja, Mauritius, Madagascar	4
Philippine Sea	Mactan, Masbate, Bohol, Okinawa Island, Mindoro, Samar, Leyte, Shikoku, Cebu, Panay, Negros, Taiwan, Mindanao, Luzon, Honshū	1
Bay of Bengal	Chengar, Sandwip, Bhola Island, Sri Lanka	2
Caribbean Sea	Barbados, Martinique, Margarita Island, Trinidad, Jamaica, Puerto Rico, Cuba, Hispaniola	10
South Pacific Ocean	Viti Levu, South Island, North Island, New Guinea	5
Laccadive Sea	Sri Lanka	1
Timor Sea	Timor	1
Bay of Bengal & Caribbean Sea	Barbados, Chengar, Martinique, Sandwip, Margarita Island, Trinidad, Bhola Island, Jamaica, Puerto Rico, Cuba, Sri Lanka, Hispaniola	2
South Pacific Ocean & Caribbean Sea	Barbados, Martinique, Margarita Island, Viti Levu, South Island, Trinidad, Jamaica, Puerto Rico, North Island, Cuba, New Guinea, Hispaniola	3
South Pacific Ocean & Laccadive Sea	Viti Levu, South Island, North Island, New Guinea, Sri Lanka	1
Carribean Sea & Tasman Sea	Barbados, Martinique, Margarita Island, Tasmania, South Island, Trinidad, Jamaica, Puerto Rico, North Island, Cuba, Hispaniola	3
West Indian Ocean & South Pacific Ocean & Mozambique chanel	Anjouan, Grande Comore, Pemba, Viti Levu, Réunion, Unguja, South Island, Mauritius, North Island, New Guinea, Madagascar	5
West Indian Ocean & Mozambique Chanel & Solomon Sea	Anjouan, Grande Comore, Pemba, New Britain, Réunion, Unguja, Mauritius, New Guinea, Madagascar	1
Philippine Sea & Caribbean Sea & West Indian Ocean	Barbados, Anjouan, Grande Comore, Martinique, Pemba, Mactan, Margarita Island, Masbate, Réunion, Unguja, Bohol, Mauritius, Trinidad, Okinawa Island, Mindoro, Sumbawa, Samar, Leyte, Jamaica, Puerto Rico, Shikoku, Cebu, Panay, Negros, Cuba, Hispaniola, Taiwan, Mindanao, Madagascar, Luzon, Honshū	1
Tasman Sea & Japan Sea	Sakhalin, Tasmania, South Island, North Island, Hokkaidō, Kyūshū, Honshū	2
Caribbean Sea & West Indian Ocean & Solomon Sea	Barbados, Anjouan, Grande Comore, Martinique, Pemba, Margarita Island, New Britain, Réunion, Unguja, Mauritius, Trinidad, Jamaica, Puerto Rico, Cuba, New Guinea, Hispaniola, Madagascar	1
South Pacific Ocean & West Indian Ocean & Mozambique Chanel & Bay of Bengal & Caribbean Sea & Laccadive Sea	Barbados, Chengar, Anjouan, Grande Comore, Martinique, Sandwip, Pemba, Margarita Island, Viti Levu, Réunion, Unguja, South Island, Mauritius, Trinidad, Bhola Island, Jamaica, Puerto Rico, North Island, Cuba, New Guinea, Sri Lanka, Hispaniola, Madagascar	1
Laccadive Sea & North Pacific Ocean & Philippines Sea	Mactan, Masbate, Oahu, Bohol, Okinawa Island, Mindoro, Samar, Leyte, Shikoku, Cebu, Panay, Negros, Hokkaidō, Sri Lanka, Taiwan, Mindanao, Luzon, Honshū	1
Caribbean Sea & West Indian Ocean & North Atlantic Ocean	Barbados, Santiago, Anjouan, Iceland, Grande Comore, Martinique, Pemba, Margarita Island, Réunion, Gran Canaria, Unguja, Tenerife, Mauritius, Trinidad, Jamaica, Puerto Rico, Cuba, Hispaniola, Madagascar	1
North Pacific Ocean & Philippines Sea & South Pacific Ocean & West Indian Ocean & Mozambique Chanel & Coral Sea	Anjouan, Grande Comore, Pemba, Mactan, Viti Levu, Masbate, Réunion, Unguja, Oahu, South Island, Bohol, Mauritius, Okinawa Island, Mindoro, Samar, Leyte, Shikoku, North Island, Cebu, Panay, Negros, Hokkaidō, New Guinea, Taiwan, Mindanao, Madagascar, Luzon, Honshū	1
Coral Sea & Solomon Sea & Bismarck Sea & Arafura Sea & Bay of Bengal & South Pacific Ocean	Chengar, Sandwip, New Britain, Viti Levu, South Island, Bhola Island, North Island, New Guinea, Sri Lanka	1
Coral Sea & Solomon Sea & Bismarck Sea & Arafura Sea & Caribbean Sea & Yellow Sea & East China Sea & Taiwan Strait & South China Sea & Gulf of Tonkin	Barbados, Bintan, Martinique, Margarita Island, New Britain, Jeju, Palawan, Bangka, Batam, Trinidad, Okinawa Island, Mindoro, Jamaica Puerto Rico, Hainan, Cuba, Kyūshū, New Guinea, Hispaniola, Borneo, Taiwan, Sumatra, Luzon	1
Caribbean Sea & Yellow Sea & East China Sea & Taiwan Strait & South China Sea & Gulf of Tonkin & Japan Sea	Barbados, Bintan, Martinique, Sakhalin, Margarita Island, Jeju, Palawan, Bangka, Batam, Trinidad, Okinawa Island, Mindoro, Jamaica, Puerto Rico, Hokkaidō, Hainan, Cuba, Kyūshū, Hispaniola, Borneo, Taiwan, Sumatra, Luzon, Honshū	1
North Atlantic Ocean & Malacca Strait & South China Sea & East Indian Ocean & Java Sea & South Pacific Ocean	Santiago, Iceland, Bintan, Viti Levu, Nia, Gran Canaria, Palawan, Tenerife, Bangka, Batam, South Island, Mindoro, Sumbawa, North Island, Madura, Bali, Hainan, New Guinea, Celebes, Borneo, Taiwan, Sumatra, Luzon, Java	1
Caribbean Sea & Sargasso Sea & Gulf of Mexico & West Indian Ocean	Barbados, Anjouan, Grande Comore, Martinique, Pemba, Margarita Island, Réunion, Unguja, Mauritius, Trinidad, Jamaica, Puerto Rico, Cuba, Hispaniola, Madagascar	1
North Pacific Ocean & Philippines Sea & Caribbean Sea	Barbados, Martinique, Mactan, Margarita Island, Masbate, Oahu, Bohol, Trinidad, Okinawa Island, Mindoro, Samar, Leyte, Jamaica, Puerto Rico, Shikoku, Cebu, Panay, Negros, Hokkaidō, Cuba, Hispaniola, Taiwan, Mindanao, Luzon, Honshū	2
Caribbean Sea & Sargasso Sea & Laccadive Sea	Barbados, Martinique, Margarite Island, Trinidad, Jamaica, Puerto Rico, Cuba, Sri Lanka, Hispaniola	1
Caribbean Sea & Coral Sea & Solomon Sea & Bismarck Sea & Arafura Sea & Bay of Bengal	Barbados, Chengar, Martinique, Sandwip, Margarita Island, New Britain, Trinidad, Bhola Island, Jamaica, Puerto Rico, Cuba, New Guinea, Sri Lanka, Hispaniola	1

I.4. Amount of handling capacity

Another important input for the mathematical optimization model is the amount of handling capacity necessary for a demand point to be helped. One of the results from the disaster relief effort analysis is the amount of TEU average needed per person in order to be helped during a disaster relief effort. This was 0.102 TEU. When taking a worst case scenario in mind one can argue that the total population of an island can be affected and that thus the total amount of TEU necessary for an island is 0.102 times the amount of inhabitants.

For smaller islands this is a plausible assumption, but for bigger islands this can lead to handling more then 10 million of TEU in a small time frame of less then 3 months. This is almost as much as the total port of Antwerp handles in 1 year (World Shipping Council, 2021). This amount of handling capacity does not seem reachable for a FFM seaport and thus another assumption must be made.

Table I.4: The second demand situation set

Affected sea	Affected island situation set 3	Amount of times situation happening
West Indian Ocean	Comore, Pemba, Réunion, Unguja, Mauritius, Madagascar	4
Philippine Sea	Panay, Negros, Taiwan, Mindanao, Luzon, Honshū	1
Bay of Bengal	Chengar, Sandwip, Bhola Island, Sri Lanka	2
Caribbean Sea	Margarita Island, Trinidad, Jamaica, Puerto Rico, Cuba, Hispaniola	10
South Pacific Ocean	Viti Levu, South Island, North Island, New Guinea	5
Laccadive Sea	Sri Lanka	1
Timor Sea	Timor	1
Bay of Bengal & Caribbean Sea	Bhola Island, Jamaica, Puerto Rico, Cuba, Sri Lanka, Hispaniola	2
South Pacific Ocean & Caribbean Sea	Jamaica, Puerto Rico, North Island, Cuba, New Guinea, Hispaniola	3
South Pacific Ocean & Laccadive Sea	Viti Levu, South Island, North Island, New Guinea, Sri Lanka	1
Carribean Sea & Tasman Sea	Trinidad, Jamaica, Puerto Rico, North Island, Cuba, Hispaniola	3
West Indian Ocean & South Pacific Ocean & Mozambique chanel	Unguja, South Island, Mauritius, North Island, New Guinea, Madagascar	5
West Indian Ocean & Mozambique Chanel & Solomon Sea	New Britain, Réunion, Unguja, Mauritius, New Guinea, Madagascar	1
Philippine Sea & Caribbean Sea & West Indian Ocean	Hispaniola, Taiwan, Mindanao, Madagascar, Luzon, Honshū	1
Tasman Sea & Japan Sea	Tasmania, South Island, North Island, Hokkaidō, Kyūshū, Honshū	2
Caribbean Sea & West Indian Ocean & Solomon Sea	Jamaica, Puerto Rico, Cuba, New Guinea, Hispaniola, Madagascar	1
South Pacific Ocean & West Indian Ocean & Mozambique Chanel & Bay of Bengal & Caribbean Sea & Laccadive Sea	North Island, Cuba, New Guinea, Sri Lanka, Hispaniola, Madagascar	1
Laccadive Sea & North Pacific Ocean & Philippines Sea	Hokkaidō, Sri Lanka, Taiwan, Mindanao, Luzon, Honshū	1
Caribbean Sea & West Indian Ocean & North Atlantic Ocean & Sargasso Sea & Gulf of Mexico	Trinidad, Jamaica, Puerto Rico, Cuba, Hispaniola, Madagascar	2
North Pacific Ocean & Philippines Sea & South Pacific Ocean & West Indian Ocean & Mozambique Chanel & Coral Sea	New Guinea, Taiwan, Mindanao, Madagascar, Luzon, Honshū	1
Coral Sea & Solomon Sea & Bismarck Sea & Arafura Sea & Bay of Bengal & South Pacific Ocean	Viti Levu, South Island, Bhola Island, North Island, New Guinea, Sri Lanka	1
Coral Sea & Solomon Sea & Bismarck Sea & Arafura Sea & Caribbean Sea & Yellow Sea & East China Sea & Taiwan Strait & South China Sea & Gulf of Tonkin	New Guinea, Hispaniola, Borneo, Taiwan, Sumatra, Luzon	1
Caribbean Sea & Yellow Sea & East China Sea & Taiwan Strait & South China Sea & Gulf of Tonkin & Japan Sea	Hispaniola, Borneo, Taiwan, Sumatra, Luzon, Honshū	1
North Atlantic Ocean & Malacca Strait & South China Sea & East Indian Ocean & Java Sea & South Pacific Ocean	Celebes, Borneo, Taiwan, Sumatra, Luzon, Java	1
North Pacific Ocean & Philippines Sea & Caribbean Sea	Cuba, Hispaniola, Taiwan, Mindanao, Luzon, Honshū	2
Caribbean Sea & Sargasso Sea & Laccadive Sea	Trinidad, Jamaica, Puerto Rico, Cuba, Sri Lanka, Hispaniola	1
Caribbean Sea & Coral Sea & Solomon Sea & Bismarck Sea & Arafura Sea & Bay of Bengal	Jamaica, Puerto Rico, Cuba, New Guinea, Sri Lanka, Hispaniola	1

When looking at the disaster relief effort analysis two things stand out. First the biggest amount of affected people in the past 38 years on an island was 7.5 million, during the wildfire in Indonesia. Second the highest percentage, in the past 38 years, of affected people on an island was 37.8% of the inhabitants of that island.

The above lead to three different tactics related to the making of assumptions. Within this research this three different tactics are all used and thus the mathematical optimization model will be solved different times with this three different tactics. The first tactic is a combination of tactic 2 and 3. So to reduce the amount of people which need help to 37.8% of the total population of an island and for the bigger island to limit this to 7.5 million people, even if 37.8% of the inhabitants is more then this 7.5 million. The second tactic is to maximize the amount of inhabitants which need help to 7.5 million, even although the island has more inhabitants. The third tactic is to reduce the amount of people which need help to 37.8% of the total population of an island.

So together with the 4 different demand situations set this lead to twelve different input instances with which the model will be run. The first tactic with respect to the amount of TEU necessary with the 4 different demand situations set, the second tactic with the 4 different demand situations set and the third tactic with the 4 different demand situations set. Analysing and comparing this results with an amount of handling capacity point of view leads to insights about how the facility locations to open differentiate when more or less handling capacity must be transported from a facility to a demand location.

From this total needed handling capacity the handling capacity in TEU per hour can be calculated. This specification in hours is necessary since the different demand points has a different maximum covering distance. However for every demand point the FFM seaport will be uninstalled after 90 days. Since for one demand point the seaport can take a longer travel time and thus a longer time till it arrived and is installed at an affected island then for another island it means that the operational time for the seaport is different for every demand point. To calculate the necessary handling capacity in TEU per hour the total demand is divided by 24 and by the total days it is operational. The total days of operation can be calculated by subtracting the maximum amount of days till the seaport must be arrived and installed from 90 days. The result of the necessary throughput capacity in TEU per hour for every tactic can be found in table I.5. Note that an assumption is made that the FFM seaport will operate 24 hours 7 days a week during the disaster relief period.

I.5. Facility locations

Another input for the mathematical optimization model is the set of possible facility locations. The total option of all facility locations is based upon 5 different sets. The first set are the locations of the United Nations Humanitarian Response Depots (UNHRD). This are 6 depots located around the world near major ports and airports and the goal is to pre position relief items and humanitarian support equipment. The locations are: Panama City (Panama), Accra (Ghana), Brindisi (Italy), Dubai (United Arab Emirates), Kuala Lumpur (Malaysia) and Las Palmas de Gran Canaria (Spain) (UNHRD, nd).

The second set is based on the work of Duran et al. (2011). They did research towards the best facilities to pre position emergency items for CARE International. They define a set of interesting facility locations near big seaports and airports where CARE was considering opening a depot. This possible facility locations are also used in this research.

The third set are Amazon fulfillment centres. From all Amazon warehouses as indicated by Seller Essentials (2021), there is checked if this warehouses is located close by a seaport. If so it is taken into consideration. This could be an interesting option since Amazon already had opened a warehouse for disaster relief supplies (Inside Logistics, 2021).

The fourth set is the Logistic Emergency Team locations. As discussed in chapter 2.4 the Logistic Cluster has a strategic partnership with four of the largest global logistics and transportation companies. These companies also have warehouses, in the case of Agility and UPS, or even have entire seaports or terminals at their disposal, in the case of A.P. Moller - Maersk and DP World. This are interesting options since it will be most certainly lest costly to open a facility on this locations. So warehouses from UPS which are close to seaports, based on the map of UPS Global Logistics (2019), are taken into consideration. The same is done with warehouses from Agility which are close to a seaport, based on information from Agility (nd). Also the seaports from DP world (DP World, nd) and the terminals from Maersk (Maersk, nd) are taken into consideration.

The last set of possible facility locations is based on the work of Stienen et al. (2021). They determine the optimal depot locations to store relief goods, based on the idea of minimize the response time. As possible depot locations they identify cities which has a major seaport and airport located close to each other. The airports are checked with the site from OurAirports (2021) and the major seaports are taken out the list from Nightingale (2020).

Taking all facility locations into consideration this lead to 256 possible facility locations. However multiple locations are duplicate because for example DP World and Amazon has a possible facility location in the same city. This duplicates are removed, but not simply by removing duplicates. A next input step for the mathematical model is the amount of costs related to opening a facility at a certain location. And one can imagine that opening a facility location on a new ground or site is, for the WFP, more expensive then opening a facility location in a DP World seaport. So this means that duplicates are removed but there is an order from which particular facility location provider this duplicate is removed. First the duplicates out the interesting location from CARE and the tactic of opening facilities in cities with a big seaport and airport are removed. Facilities must be build up from scratch from these two

Table I.5: The amount of necessary throughput capacity per hour for every demand point and the three demand tactics

Island	Population	Demand in TEU	Max days till seaport arrive	Demand in TEU per hour tactic 1	Demand in TEU per hour tactic 2	Demand in TEU per hour tactic 3
Muna (Indonesia)	268,140	27,350	19.25	16	6	6
Barbados	279,254	28,484	25.37	18	7	7
Santiago (Cape Verde)	290,280	29,609	21.58	18	7	7
Chengar (Bangladesh)	292,057	29,790	15.46	17	6	6
Anjouan (Comoros)	306,800	31,294	19.25	18	7	7
Corsica (France)	316,578	32,291	27.12	21	8	8
Iceland	325,671	33,218	28.00	22	8	8
Bintan (Indonesia)	329,659	33,625	21.58	20	8	8
Bioko (Equatorial Guinea)	339,695	34,649	23.33	22	8	8
Grande Comore (Comoros)	369,600	37,699	18.08	22	8	8
Marajó (Brazil)	383,336	39,100	23.62	25	9	9
Malta	386,057	39,378	27.42	26	10	10
Martinique (France)	390,371	39,818	24.21	25	9	9
Sandwip (Bangladesh)	400,000	40,800	15.46	23	9	9
Pemba (Tanzania)	406,808	41,494	22.17	25	10	10
Seram (Indonesia)	434,113	44,280	22.17	27	10	10
Ambon (Indonesia)	441,000	44,982	21.00	27	10	10
Buton (Indonesia)	447,408	45,636	20.42	27	10	10
Halmahera (Indonesia)	449,938	45,894	20.42	27	10	10
Basilan (Philippines)	459,367	46,855	19.25	28	10	10
Mactan (Philippines)	467,824	47,718	18.37	28	10	10
Sakhalin (Russia)	471,515	48,095	26.54	32	12	12
Margarita Island (Venezuela)	489,917	49,972	21.00	30	11	11
Tasmania (Australia)	507,626	51,778	25.37	33	13	13
New Britain (Papua New Guinea)	513,926	52,420	20.71	32	12	12
Newfoundland (Canada)	522,103	53,255	27.12	35	13	13
Jolo (Philippines)	530,000	54,060	19.25	32	12	12
Jeju (South Korea)	621,550	63,398	25.37	41	15	15
Crete (Greece)	623,065	63,553	23.92	40	15	15
Viti Levu (Fiji)	661,997	67,524	18.67	39	15	15
Sumba (Indonesia)	686,113	69,984	19.83	42	16	16
Masbate (Philippines)	706,897	72,103	19.25	42	16	16
Nias (Indonesia)	756,338	77,146	19.54	46	17	17
Réunion (France)	837,868	85,463	23.04	53	20	20
Gran Canaria (Spain)	838,397	85,516	25.08	55	21	21
Mallorca (Spain)	862,397	87,964	25.96	57	21	21
Vancouver Island (Canada)	870,297	88,770	27.12	59	22	22
Palawan (Philippines)	886,308	90,403	19.54	53	20	20
Unguja (Tanzania)	896,721	91,466	20.42	55	21	21
Tenerife (Spain)	906,854	92,499	25.67	60	22	22
Bangka (Indonesia)	960,692	97,991	18.96	57	22	22
Oahu (United States)	976,372	99,590	25.67	65	24	24
Cyprus	1,088,503	111,027	26.54	73	27	27
Batam (Indonesia)	1,153,860	117,694	19.54	70	26	26
South Island (New Zealand)	1,187,300	121,105	23.62	76	29	29
Bohol (Philippines)	1,211,000	123,522	18.37	72	27	27
Mauritius	1,219,265	124,365	18.67	73	27	27
Trinidad (Trinidad and Tobago)	1,267,145	129,249	21.00	78	29	29
Okinawa Island (Japan)	1,301,000	132,702	21.58	81	30	30
Mindoro (Philippines)	1,331,473	135,810	19.83	81	30	30
Sumbawa (Indonesia)	1,391,340	141,917	19.83	84	32	32
Sardinia (Italy)	1,659,000	169,218	24.79	108	41	41
Samar (Philippines)	1,751,267	178,629	19.54	106	40	40
Bhola Island (Bangladesh)	1,758,000	179,316	15.46	100	38	38
Flores (Indonesia)	1,831,000	186,762	21.00	113	42	42
Leyte (Philippines)	2,626,970	267,951	18.96	157	59	59
Jamaica	2,950,210	300,921	19.54	178	67	67
Timor (Indonesia & Timor-Leste)	3,182,693	324,635	18.96	190	71	71
Lombok (Indonesia)	3,311,044	337,726	18.67	197	74	74
Puerto Rico (United States)	3,474,182	354,367	24.21	224	84	84
Shikoku (Japan)	3,815,000	389,130	22.17	239	90	90
North Island (New Zealand)	3,896,200	397,412	23.92	251	94	94
Madura (Indonesia)	4,004,564	408,466	19.25	241	90	90
Cebu (Philippines)	4,311,040	439,726	17.21	252	94	94
Bali (Indonesia)	4,317,404	440,375	18.67	257	96	96
Panay (Philippines)	4,542,926	463,378	18.37	270	101	101
Negros (Philippines)	4,656,945	475,008	17.79	274	103	103
Sicily (Italy)	5,017,000	511,734	23.62	321	120	120
Hokkaidō (Japan)	5,383,579	549,125	21.29	333	125	125
Ireland (Ireland and United Kingdom)	6,894,291	703,218	25.37	453	170	170
Hainan (China)	10,081,232	1,028,286	20.12	456	230	230
Cuba	11,318,747	1,154,512	19.54	452	256	256
Kyūshū (Japan)	13,200,000	1,346,400	21.58	466	307	307
New Guinea (Papua New Guinea and Indonesia)	14,800,000	1,509,600	19.54	452	335	335
Celebes (Indonesia)	20,160,000	2,056,320	19.25	451	454	451
Sri Lanka	21,919,000	2,235,738	17.79	441	484	441
Hispaniola (Dominican Republic and Haiti)	22,278,000	2,272,356	15.17	426	474	426
Borneo (Indonesia, Brunei, Malaysia)	23,720,000	2,419,440	20.71	460	546	460
Taiwan (Republic of China)	23,865,820	2,434,314	21.00	462	551	462
Mindanao (Philippines)	27,021,036	2,756,146	19.25	451	609	451
Madagascar	28,479,665	2,904,926	16.33	433	616	433
Sumatra (Indonesia)	58,880,000	6,005,760	18.37	445	1,310	445
Luzon (Philippines)	64,260,312	6,554,552	18.08	443	1,424	443
Great Britain (United Kingdom)	66,397,821	6,772,578	25.67	495	1,645	495
Honshū (Japan)	104,000,000	10,608,000	19.54	452	2,352	452
Java	147,795,436	15,075,134	18.67	447	3,302	447

locations. Second that out of the Amazon fulfillment centres, since they have not a direct partnership with the Logistic Cluster. Third the duplicate locations from UPS are removed, since from the Logistics Emergency Teams they have the smallest warehouses. Fourth the duplicate locations from Agility are removed, because they have after UPS the smallest warehouses. Fifth the duplicate locations from Maersk are removed since they have after DP World the biggest warehouses and thus sixth the location from DP World are removed. This means that the locations from UNHRD are never removed, which makes sense since this are the best options for opening a facility from a relationship standpoint. The above removing of duplicates leaves 157 available facility locations, which can be seen in figure I.1.

Figure I.1: Possible facility locations after duplicates are removed

However as can be seen in figure I.1 there are a couple of locations which are very close to each other, as for example around China, the east cost of the USA and around Dubai. Putting them into the mathematical optimization model is still possible, but it will lead to unnecessary extra computation effort by taking them into consideration. In order to minimize the amount of options close to each other facility options are analysed. When two locations are close to each other, around 1000 km next to each other, there is checked how many different facility location providers have a possibility for a facility at that certain location. The facility location option with the most different providers having an option at that city is chosen in favour of the other. If the two facility options has the same amount of different providers the provider is chosen in the same order as is described above when duplicates where removed. And if the different facility options does have exactly the same different providers, there is checked which of the facility options is the closest to the equator. This distinctive step is possible since most of the islands of the world are centred around the equator (Pabon, 2018). This results in the end to 62 possible facility locations which can be seen in figure I.2.

I.6. Costs related to storage facilities and initial investment

Two other inputs for the mathematical optimization model are the related costs to open a certain facility and the related cost to store 1 TEU of handling capacity at a certain facility. The related costs to open a certain facility are costs which are not affected by the amount of handling capacity that would be stored at that location, while the other costs are affected by the amount of handling capacity that is stored. Within this research the following costs are taken into account:

- The investments costs of the modules for the seaport and the necessary seaport equipment which eventually will be stored at the warehouses.
- Costs of the semi-submersible heavy lift vessels.
- The costs to realise storage facilities.
- The operational costs of operating the storage facilities and having a crew ready to depart when necessary.

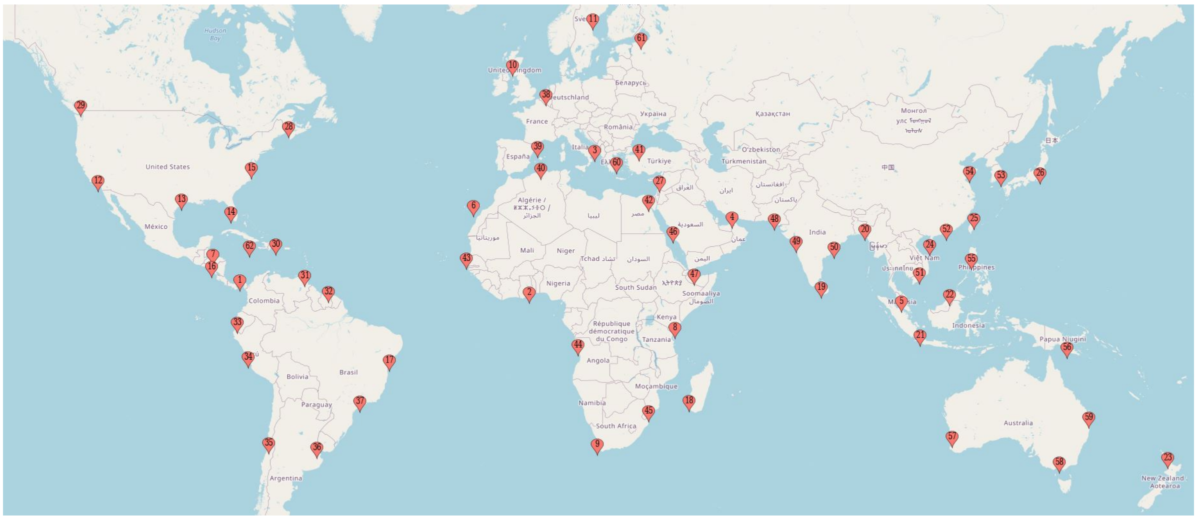


Figure I.2: The final possible facility locations

From all these costs only the last one, the operational costs of operation of a storage facility, is not related towards the amount of TEU stored at a certain location.

Investment costs modules and seaport equipment

As is calculated in the business case for the Transport and Logistics hub within the Space@Sea project by Dafnomilis (2020) the initial investment costs of a seaport at sea with a handling capacity of 756 TEU/hour consisting of 96 modules of 45x45x11 is €1,357,109,825.-. With the exchange rate of this time of writing this is $1,533,669,813.- (European Central Bank, 2021). Within this costs every initial investment is taking into account, such as the module construction, electric infrastructure, ship-to-shore cranes, gantry crane, automated guided vehicles and all personnel buildings. But also costs like transporting all the equipment to the point of interest (in this case from the building side to the warehouses) and the costs of labor to construct the modules (Dafnomilis, 2020).

When there is assumed that there is a linear relation between the investment costs and the handling capacity per hour, it can be calculated that the investment costs of a FFM seaport with 1 TEU/hour handling capacity is $2,028,664.-. This number is used within this research.

Costs of the semi-submersible heavy lift vessels

As explained in chapter I.1 the construction costs of the Dockwise Vanguard was $240m while it has a maximum carrying capacity of 110,000t. The construction costs of another semi-submersible heavy lift vessel like the White Marlin was $150m (Offshore, 2012) while it has a maximum carry capacity of 72,000t (Boskalis, 2018). So the Dockwise Vanguard costed $2181.82 per ton carrying capacity and the White Marlin costed $2083.33 per ton carrying capacity. In this research it is assumed that there is a linear relation between the amount of construction costs for a semi-submersible heavy lift vessel and the amount of carrying capacity and that this is the average of the calculated costs meaning $2132.58 per ton carrying capacity.

As explained above 96 modules together represent a handling capacity of 756 TEU/hour. As written down by Otto and Hüsken (2017) one module of 45x45x11 weighs 3520.80t. When a linear relation is assumed this means that a module with enough space to accommodate 1 TEU/hour weighs 447t. Next to the weight of the modules also the weight of the seaport equipment which must be transported together with the modules is important. A modern ship-to-shore crane weighs 750t (LIEBHERR, nd). Such cranes can reach speeds up to 35 moves per hour (Achterkamp, 2019; TIL, nd). This means 35, 40ft containers can be moved within an hour and thus 70 TEU per hour per crane can be moved. Again assuming a linear relation this means that a crane which can move 1 TEU/hour weighs 10.7t. When it is assumed that the weight of the seaport equipment consist for 50% out of the cranes weight it tells that the total weight of the seaport equipment is 21.4t for equipment able to handle 1 TEU/hour.

When the equipment weight and module weight are add together this results in a weight for one TEU of handling capacity on a FFM seaport of 468.4t, this relates to a costs of $998,900.47 per TEU handling capacity.

Realizing storage facilities

The warehouses where the modules of the FFM seaport will be stored together with all the seaport equipment, are assumed to be build on land at a seaport nearby the water. The semi-submersible heavy lift vessel will be stored at that seaport and in that case it is possible to transport the seaport quickly to the semi-submersible heavy lift vessel and to quickly hit the open seas when necessary. Note that this transport time of transporting the modules to the semi-submersible heavy lift vessel is assumed to be negligible small and thus is not taken into account within this research.

Another assumption is made with respect to storage the modules on land. It is also possible to store the seaport on sea during the times it is not necessary. In that case it even can serve as extra handling capacity for a seaport during normal operation. In that case the time between a call for help and transport of the modules and seaport equipment must taken into account since it will take more time between dismantle the seaport and load it on the semi-submersible heavy lift vessel. However the choice to store the modules and seaport equipment on land is made due to the lifetime of the seaport. In this research the lifetime of the port is assumed to be more then the 25 years which is assumed by Dafnomilis (2020). It is argued that this extension can be made since the seaport will be stored at a dry and weather protected location.

This means that storage facilities must be realised. Realisation consist of two parts. First the price to buy the land and second the construction costs of the storage facilities. To calculate the cost of land at the concerned seaport for a facility location, the price per square meter to buy apartment outside of city centre in USD for the related country is taken from NationMaster (2014b) and divided by 2. It is divided by 2 since an assumption can be made that the land value is 50% of the total property costs (Cheng, 2016; Collinson, 2017; DellaLoggia, 2016).

The costs to build a warehouse are taken from Compass (2017). They calculate the cost to design & build a warehouse around the world and give the average construction costs in dollar per square meter. Not every country is listed within this list. If a country is not listed, the closest country is taken and this related number is used. Since the biggest warehouse in the world has a height of 27.4 meters (Kiger, 2019) and the modules has a height of 11 meter (Otto and Hüsken, 2017) it is assumed that for this price per square meter it is possible to store maximum two modules on top of each other.

As stated above the business case for the transport and logistics hub seaport for the space@sea project investigate a seaport with a handling capacity of 756 TEU/hour consisting of 96 modules of 45x45x11m (Dafnomilis, 2020). This relates with an area of 194,400 m^2. When a linear assumption can be made about the amount of handling capacity and the area of the seaport, 1 TEU/hour relates with an area of 257m^2. Since the warehouse is able to store two modules on top of each other it can be argued that 1 TEU/hour relates to an are of 129m^2 of modules stored. Next to that also some storage place for the necessary seaport equipment must be stored. A ship-to-shore crane which can move 70 TEU/hour has an area of 237m^2 (LIEBHERR, nd) and when a linear relation is assumed a crane which can move 1 TEU/hour has an area of 3m^2. When assuming that the total area of the seaport equipment consist for 50% of the area of the ship-to-shore crane, the total area of seaport equipment is 6m^2 for a seaport which can handle 1 TEU/hour. This means that in total 1 TEU/hour handling capacity relates to a storage area of 135m^2 inside the storage facility.

When you add both costs together the investment costs of realizing the storage facilities of 1 TEU/hour of handling capacity at that facility are known. These costs could be directly put into the mathematical optimization model, however these costs are also dependant on the facility location provider. This can be the UNHRD, DP World, Maersk, Agility, UPS and/or Amazon or no facility provider could be available. Depending on the exact facility provider certain costs are reduced. When the UNHRD has a facility at that possible facility location it is assumed that the ground is already in possession of the United Nations and thus only the costs of building extra warehouse space must taken into account.

Since already an existing construction is build and maybe some space is already available in the existing warehouse it is assumed that the costs to build warehouses are half less then normal. When DP World already has a location at the proposed location facility, it is assumed that the costs to buy the land on that location is zero, since this land is already in possession of the seaport. Costs to build a warehouse are assumed to be normal since a warehouse still has to be build. When Maersk and/or Agility already has a warehouse at that location it is assumed that land had to be bought and that, since already an existing construction is build and maybe some space is already available in the existing warehouse, it is assumed that the costs to build warehouses are half less then normal. When UPS has an existing warehouse at the location it is assumed that extra land must be bought to open a warehouse at that location. Since maybe UPS has already some space at that location it is assumed that the land prices are normal and costs to build a facility are 50% less then normal. For Amazon the same but then it is assumed that the land prices are normal and costs to build a facility are 25% less the normal, since they are not part of the Logistic Emergency Team. When no facility provider has a warehouse or facilities yet at that location of course the full costs are taken into account. From all these options, the most advantageous choice is made if at a facility location multiple facility providers are available. In the end this gives for every facility the cost to realize a warehouse at that certain location.

Operation cost of storage facilities
Next to the cost to realize a facility, also the costs to operate a facility during the lifetime is essential. It is assumed that 50% of the operational costs are labour costs (Savills, 2021). In order to define the costs of labour the national monthly minimum wage of every related country is taken from Countryeconomy (2020b) and multiplied by 12 months and 38 years of lifetime. When a country has not a minimum wage, the minimum wage of the most nearby country is taken.

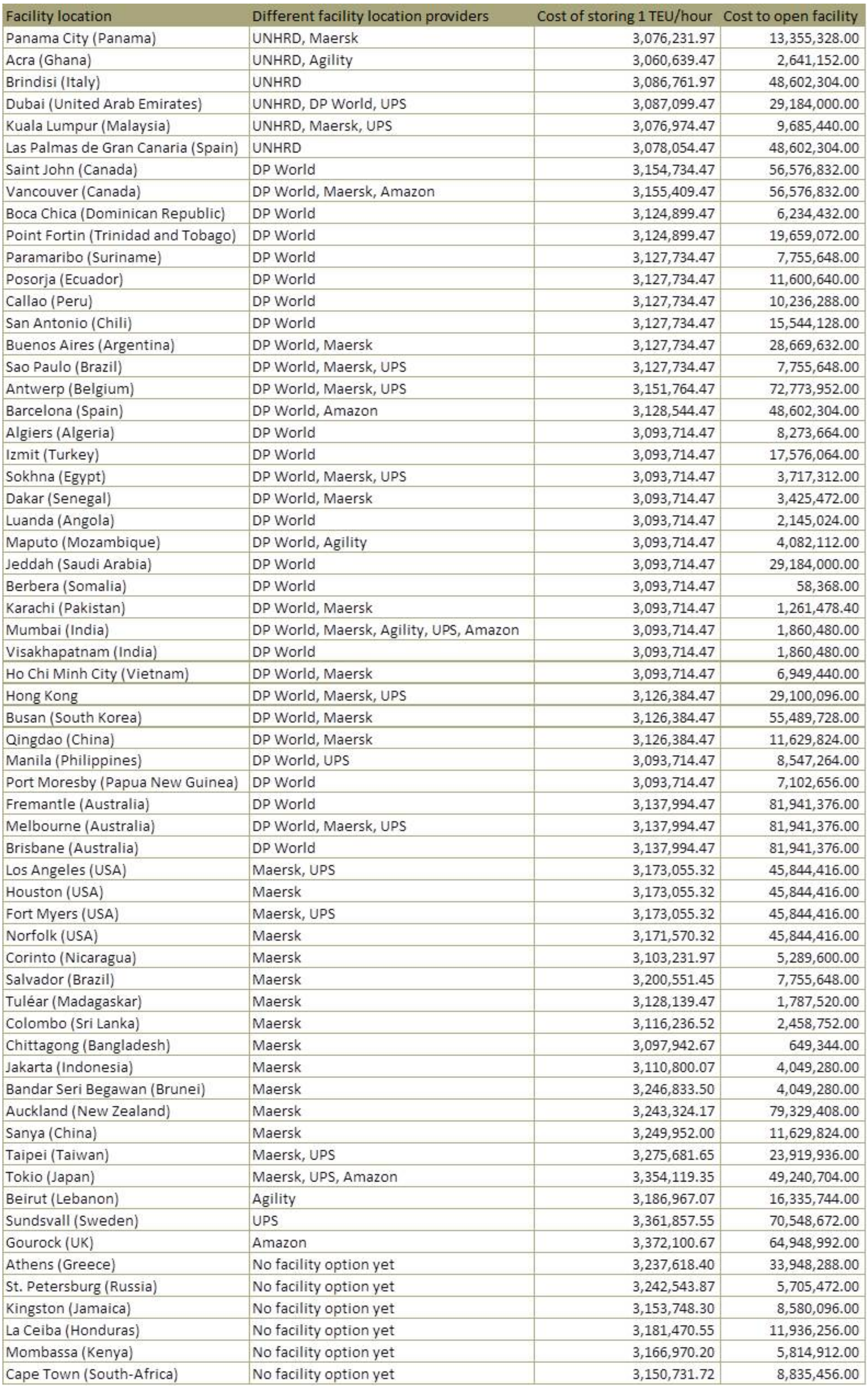
The last step in determining the operation costs is determining the amount of workers necessary at the warehouses. Since, when the FFM seaport is not necessary, only small and minor work is necessary in the warehouse, not a lot of personnel is necessary. Only some maintenance on the seaport equipment, on the modules, on the semi-submersible heavy lift vessel and security is necessary. Next to that the crew must also be ready and be stand by to directly depart to the affected area when necessary. The crew on board of such a semi-submersible heavy lift vessel consist of 20 crewmembers (Insight, 2015; Professional Mariner, 2019). However it is possible that only a part of the total handling capacity stored at a facility is necessary at a demand point at a certain time and thus that the other part is still stored and some personnel must thus still be available at the warehouse. Thus it is assumed that 40 crewmembers for the ships are necessary and that 20 crewmembers always must be stand by to depart when necessary. It is assumed that these 40 crewmembers also can manage the operations at the storage facility when the FFM seaport is in storage. This means that the cost of labour is multiplied by 40 and by multiplying the cost with labour with 2 the total operation costs are determined. Since these costs are not dependant on the total size of the storage facility, since these crewmembers are always necessary on the vessel and at every location a transport vessel must be stand by, this costs are always made when a facility will be opened.

Since the operational costs are known, for every possible facility point the cost to store 1 TEU/hour of handling capacity at that location (which consist of the price to buy a semi-submersible heavy lift vessel, the cost to buy the modules and seaport equipment and the cost to buy the land and build a storage facility on that land) and cost to open a certain facility (which consist of the labour cost of 40 crewmembers for 38 years and all other operational costs to store handling capacity at that particular location). This costs for every facility can be seen in table I.6.

I.7. Distance and cost

Since all facility points are known, also the distance between every facility point and demand point can be determined for every facility and demand point. All distances are determined with the use of Searoutes (nd). They build a web app which determines the distances point to point, port to point and port to port sea routes and sea distances. This app automatically determines the fastest sea route between two points and returns the amount of kilometers of that route. Important to note is the fact that it also consider routes which pass the Panama, Suez or Kiel canal. An assumption is thus made that

Table I.6: The options to open facility locations and the corresponding amount of costs at those locations



Facility location	Different facility location providers	Cost of storing 1 TEU/hour	Cost to open facility
Panama City (Panama)	UNHRD, Maersk	3,076,231.97	13,355,328.00
Acra (Ghana)	UNHRD, Agility	3,060,639.47	2,641,152.00
Brindisi (Italy)	UNHRD	3,086,761.97	48,602,304.00
Dubai (United Arab Emirates)	UNHRD, DP World, UPS	3,087,099.47	29,184,000.00
Kuala Lumpur (Malaysia)	UNHRD, Maersk, UPS	3,076,974.47	9,685,440.00
Las Palmas de Gran Canaria (Spain)	UNHRD	3,078,054.47	48,602,304.00
Saint John (Canada)	DP World	3,154,734.47	56,576,832.00
Vancouver (Canada)	DP World, Maersk, Amazon	3,155,409.47	56,576,832.00
Boca Chica (Dominican Republic)	DP World	3,124,899.47	6,234,432.00
Point Fortin (Trinidad and Tobago)	DP World	3,124,899.47	19,659,072.00
Paramaribo (Suriname)	DP World	3,127,734.47	7,755,648.00
Posorja (Ecuador)	DP World	3,127,734.47	11,600,640.00
Callao (Peru)	DP World	3,127,734.47	10,236,288.00
San Antonio (Chili)	DP World	3,127,734.47	15,544,128.00
Buenos Aires (Argentina)	DP World, Maersk	3,127,734.47	28,669,632.00
Sao Paulo (Brazil)	DP World, Maersk, UPS	3,127,734.47	7,755,648.00
Antwerp (Belgium)	DP World, Maersk, UPS	3,151,764.47	72,773,952.00
Barcelona (Spain)	DP World, Amazon	3,128,544.47	48,602,304.00
Algiers (Algeria)	DP World	3,093,714.47	8,273,664.00
Izmit (Turkey)	DP World	3,093,714.47	17,576,064.00
Sokhna (Egypt)	DP World, Maersk, UPS	3,093,714.47	3,717,312.00
Dakar (Senegal)	DP World, Maersk	3,093,714.47	3,425,472.00
Luanda (Angola)	DP World	3,093,714.47	2,145,024.00
Maputo (Mozambique)	DP World, Agility	3,093,714.47	4,082,112.00
Jeddah (Saudi Arabia)	DP World	3,093,714.47	29,184,000.00
Berbera (Somalia)	DP World	3,093,714.47	58,368.00
Karachi (Pakistan)	DP World, Maersk	3,093,714.47	1,261,478.40
Mumbai (India)	DP World, Maersk, Agility, UPS, Amazon	3,093,714.47	1,860,480.00
Visakhapatnam (India)	DP World	3,093,714.47	1,860,480.00
Ho Chi Minh City (Vietnam)	DP World, Maersk	3,093,714.47	6,949,440.00
Hong Kong	DP World, Maersk, UPS	3,126,384.47	29,100,096.00
Busan (South Korea)	DP World, Maersk	3,126,384.47	55,489,728.00
Qingdao (China)	DP World, Maersk	3,126,384.47	11,629,824.00
Manila (Philippines)	DP World, UPS	3,093,714.47	8,547,264.00
Port Moresby (Papua New Guinea)	DP World	3,093,714.47	7,102,656.00
Fremantle (Australia)	DP World	3,137,994.47	81,941,376.00
Melbourne (Australia)	DP World, Maersk, UPS	3,137,994.47	81,941,376.00
Brisbane (Australia)	DP World	3,137,994.47	81,941,376.00
Los Angeles (USA)	Maersk, UPS	3,173,055.32	45,844,416.00
Houston (USA)	Maersk	3,173,055.32	45,844,416.00
Fort Myers (USA)	Maersk, UPS	3,173,055.32	45,844,416.00
Norfolk (USA)	Maersk	3,171,570.32	45,844,416.00
Corinto (Nicaragua)	Maersk	3,103,231.97	5,289,600.00
Salvador (Brazil)	Maersk	3,200,551.45	7,755,648.00
Tuléar (Madagaskar)	Maersk	3,128,139.47	1,787,520.00
Colombo (Sri Lanka)	Maersk	3,116,236.52	2,458,752.00
Chittagong (Bangladesh)	Maersk	3,097,942.67	649,344.00
Jakarta (Indonesia)	Maersk	3,110,800.07	4,049,280.00
Bandar Seri Begawan (Brunei)	Maersk	3,246,833.50	4,049,280.00
Auckland (New Zealand)	Maersk	3,243,324.17	79,329,408.00
Sanya (China)	Maersk	3,249,952.00	11,629,824.00
Taipei (Taiwan)	Maersk, UPS	3,275,681.65	23,919,936.00
Tokio (Japan)	Maersk, UPS, Amazon	3,354,119.35	49,240,704.00
Beirut (Lebanon)	Agility	3,186,967.07	16,335,744.00
Sundsvall (Sweden)	UPS	3,361,857.55	70,548,672.00
Gourock (UK)	Amazon	3,372,100.67	64,948,992.00
Athens (Greece)	No facility option yet	3,237,618.40	33,948,288.00
St. Petersburg (Russia)	No facility option yet	3,242,543.87	5,705,472.00
Kingston (Jamaica)	No facility option yet	3,153,748.30	8,580,096.00
La Ceiba (Honduras)	No facility option yet	3,181,470.55	11,936,256.00
Mombassa (Kenya)	No facility option yet	3,166,970.20	5,814,912.00
Cape Town (South-Africa)	No facility option yet	3,150,731.72	8,835,456.00

the FFM seaport also can travel pass this canals. Since the calculations about the maximum distance which can be reached by the FFM seaport in a certain amount of travel time was performed based on the assumption that the seaport will be transported by semi-submersible heavy lift vessels sailing constantly with their maximum speed it is also assumed that these semi-submersible heavy lift vessels can sail this maximum speed at those canals.

Another issue is the fact that demand points are islands with more then 265,000 inhabitants. This can be islands which have a very large area and thus it is important to identify the exact point at the coastline of which the FFM seaport will be installed to determine the exact distance between this point and the facility location. This exact point is off course dependent on the disaster and the exact striking area of the disaster. Within this research the choice is made to set the exact installation point of the seaport to the largest city of that island (when this city is a city located at the coast). Choosing the biggest city makes sense since, if a disasters strikes on the island and this city is affected probably the most people wanting assistance lives in that city. When this city is not located at the coast the city at the coast closest to the biggest city of that island is chosen. This gives the list of cities for the demand points that can be found in table I.7.

Table I.7: The exact point of the island to which the FFM seaport will travel

Island	Coastal town	Island	Coastal town	Island	Coastal town
Muna	Mawasangka	Viti Levu	Suva	Lombok	Mataram
Barbados	Bridgetown	Sumba	Waingapu	Puerto Rico	San Juan
Santiago	Praia	Masbate	Masbate City	Shikoku	Matsuyama
Chengar	Tomoroddi	Nias	Gunung Sitoli	North Island	Auckland
Anjouan	Mutsamudu	Réunion	Saint-Denis	Madura	Bangkalan
Corsica	Ajaccio	Gran Canaria	Las Palmas de Gran Canaria	Cebu	Cebu City
Iceland	Reykjavik	Mallorca	Palma de Mallorca	Bali	Denpasar
Bintan	Tanjungpinang	Vancouver Island	Victoria	Panay	Iloilo City
Bioko	Malabo	Palawan	Puerto Princesa	Negros	Bacolod
Grande Comore	Moroni	Unguja	Zanzibar City	Sicily	Palermo
Marajó	Breves	Tenerife	Santa Cruz de Tenerife	Hokkaidō	Sapporo
Malta	Valletta	Bangka	Pangkal Pinang	Ireland	Dublin
Martinique	Fort-de-France	Oahu	Honolulu	Hainan	Haikou
Sandwip	Magdhara	Cyprus	Girne	Cuba	Havana
Pemba	Wete	Batam	Batam City	Kyūshū	Fukuoka
Seram	Amahai	South Island	Christchurch	New Guinea	Port Moresby
Ambon	Ambon	Bohol	Tagbilaran	Celebes	Makassar
Buton	Bau Bau	Mauritius	Port Louis	Sri Lanka	Colombo
Halmahera	Tobelo	Trinidad	Couva	Hispaniola	Santo Domingo
Basilan	Isabela	Okinawa Island	Naha	Borneo	Balikpapan
Mactan	Lapu Lapu	Mindoro	San Jose	Taiwan	Taipei
Sakhalin	Korsakov	Sumbawa	Bima	Mindanao	Davao City
Margarita Island	Porlamar	Sardinia	Cagliari	Madagascar	Vatomandry
Tasmania	Hobart	Samar	Calbayog	Sumatra	Belawan
New Britain	Kimbe	Bhola Island	Char Fasson	Luzon	Manilla
Newfoundland	Saint John's	Flores	Maumere	Great Britain	Tilbury
Jolo	Jolo	Leyte	Tacloban	Honshū	Tokyo
Jeju	Jeju City	Jamaica	Kingston	Java	Jakarta
Crete	Heraklion	Timor	Kupang		

This choice is off course another assumption. For smaller islands this assumption does not propose any problems, but for bigger islands one can imagine that, when a disaster strikes at the other side of the island this assumption can have an impact. For example traveling with boat from one side of New

Guinea, from all demand points the largest island with respect to area, to the other side can take up to 2390 km and travelling with car is even impossible. So when a disaster strikes at one side of the island, and the biggest city of that island is on the other side, the FFM seaport will travel to the affected side and not the biggest city. This means that the actual travel distance is different then the travel distance used in the mathematical optimization model and could for example lead to a situation in which a facility point is in the model taken as close enough to be in the covering distance of the demand point while in the real situation this was not the case, or the other way around.

Since the distances between the facility points and demand points are known and the maximum covering distance of every demand point, it is possible to determine if a facility can service a certain demand point or not. This forms a matrix consisting of ones (if a demand point can be served by that facility) and zeros (if a demand point can not be served by that facility). This matrix is a input for the mathematical optimization model.

Next to this input, also another input can be determined. Since the distances are known, it is possible to determine the cost to transport one TEU of handling capacity over that distance. This forms also a matrix and also this matrix is an input for the mathematical optimization model. This costs are based on the amount of fuel a semi-submersible heavy lift vessels uses. As explained in chapter I.1 a semi-submersible heavy lift vessel consumes 5000t of fuel when it travels from the Far East to the Gulf of Mexico. The distance between the Far East and the Gulf of Mexico is around 20,000 km (Searoutes, nd). Meaning that the semi-submersible heavy lift vessel consumes 250kg per km. As explained in the subsection above the weight for one TEU/hour of handling capacity on a FFM seaport is 468.4t and the Dockwise Vanguard has a maximum carrying capacity of 110,000t. This means that one semi-submersible heavy lift vessel can transport 235 TEU/hour of handling capacity and thus this relates to a fuel usage of 1.06kg per km per TEU. The kg price of Heavy Fuel Oil at this moment worldwide average is \$0.63 (Ship&Bunker, 2021) and thus this relates to a cost of \$0.67 per km per TEU. This amount will be multiplied by the distance between a demand point and a facility point, resulting in a transportation cost.

The final input is the operational costs of one TEU of handling capacity. It are the costs which are related to operating the FFM seaport. As concluded by Dafnomilis (2020) the operational costs of 25 years of operation with 6200 operation hours per year is €1,960,667,884.- for a FFM seaport with a handling capacity of 756 TEU/hour and consisting of 96 modules of 45x45x11m. With the exchange rate of this time of writing this is \$2,217,515,377.- (European Central Bank, 2021). When again assuming linear relations this results in an operation costs of \$19 per TEU per hour of operation. Since every demand point (island) has his own amount of time of which a seaport will be of help, see chapter I.4, this \$19 per TEU is for every demand point multiplied by the amount of hours the seaport is of help for that demand point. This results in the operational costs of using the seaport for that demand point.

This operational costs is added up by twice the transport costs. This transport costs is added up twice since it must deliver the seaport, but also bring it back again to the facility when it is not necessary anymore. This means that for every possible route an unique operation costs is given consisting of the transport costs which is different for every possible route and a operation costs which is different for every demand point. Together this gives the last input for the model: the cost to transport one TEU of handling capacity from a facility towards that demand point.

I.8. Assumptions

This means that we have all necessary inputs. Since a lot of assumptions are made in order to define the inputs, a summary of the assumptions will be given:

- With respect to the maximum distance which is allowed between a demand point and a facility point to be covered or not it is assumed that when a demand point does not have a high probability that a disaster will happen at that location and the consequences if a disaster happen are low, the maximum time at which the FFM seaport arrives may be twice as long as for a demand point which have a high probability and high consequences.

- It is assumed that installation time for the FFM seaport is 2 days.
- It is assumed that the semi-submersible heavy lift vessel travels with a constant speed of 33 km/h, also in canals like the Panama or Suez canal.
- When a disaster hit an island with a facility location at that island, that facility location can not assist in disaster relief efforts in the same time frame.
- It is assumed that the FFM seaport has a lifetime of 38 years, when the modules and seaport equipment is stored protected from wind and weather.
- It is assumed that the FFM seaport can survive when a disaster will hit the affected area another time and the seaport is in operation. Since a FFM seaport is more resistant to natural disasters.
- Assumptions are made about the total necessary amount of handling capacity for every demand point. Per person 0.102 TEU is necessary and maximum 7.5 million people or 37.8% of the total inhabitants on an island are affected.
- Assumptions are made about the possible facility location. It is assumed that some facility location providers are favoured over others. Next to that also locations close to each other are deleted to reduce the computing power necessary to solve the problem. Also the favouring of facility location providers is used to reduce the locations close to each other.
- With respect to the costs it is assumed that the operational costs of the storage facility does not changes when more or less handling capacity is stored at that location.
- The investment costs of realizing the FFM seaport consist of the investment of modules, seaport equipment, semi-submersible heavy lift vessels and storage facilities. This all depend on the amount of handling capacity which will be brought.
- The current time of writing exchange rate between dollars and euros is assumed.
- Within costs a linear relation is assumed between the investment costs and capacity per hour, between the amount of construction costs for a semi-submersible heavy lift vessel and the amount of carrying capacity, between the amount of handling capacity on a module and the area of a module, between the weights of a ship-to-shore container crane and its handling capacity, between the area of a ship-to-shore crane and its handling capacity and between the operational costs of the FFM seaport and the handling capacity of the seaport.
- It is assumed that the weight of the seaport equipment consist for 50% out of the weight of the ship-to-shore cranes.
- It is assumed that the total area which is taken by the needed seaport equipment for 50% out of the area of the ship-to-shore cranes.
- The transport time of transporting the modules to the semi-submersible heavy lift vessel is assumed to be negligible small.
- It is assumed that the warehouses are build on land at a port side and that the semi-submersible heavy lift vessel is laying in the water waiting for service. The cost to maintain this vessel and dock this vessel are neglected.
- It is assumed that realizing a warehouse consist of construction costs and land costs.
- It is assumed that the land value is 50% of the property cost.
- It is assumed that warehouses can store two modules on top of each other.
- It is assumed that the property value and construction costs of a warehouse are comparable with countries nearby.
- It is assumed that the costs to buy land or the costs to construct a warehouse differs over the multiple different facility location providers. The exact amount of price reduction are also assumed.

- It is assumed that 50% of the operational costs of the storage facilities is labour costs.
- It is assumed that there are 40 member working in every facility location and that a part of them are also the crewmembers of the vessels during the transport stage and that they help part of the seaport operations personnel when operating. It is assumed that they earn the minimum salary of the country in which the storage facility is located. The cost for the extra seaport personnel when the FFM seaport is operation is neglected.
- It is assumed that, when an island is affected, the FFM seaport would be installed close to the most populous city on the island.
- The heavy fuel price of the time of writing is used.

J

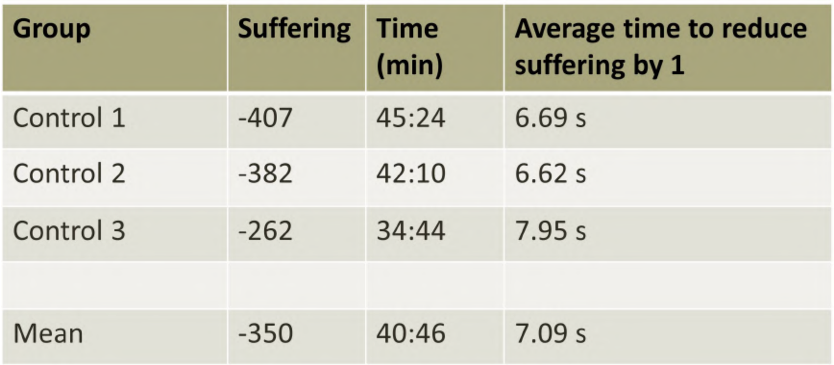
Remaining results emergency simulation role playing game

Chapter 13 only discuss the most important results of the emergency simulation role playing game. This appendix shows the results which are not shown in detail. First the overall results which are not presented yet are shown. This is followed by the not yet presented results of the shared information gathering concept and shared interpreting of information concept. Lastly the not yet presented results of the shared leadership concept are shown. Note that this appendix does not discuss the collective actions, conversation quality, conversation participation and shared feelings concepts. Also the integrating questions are not discussed in this appendix. All results of these concepts and questions are discussed in chapter 13.

J.1. Overall results

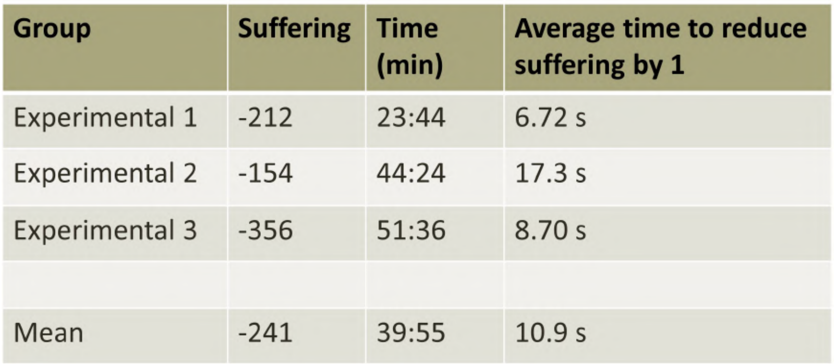
Chapter 13 only shows the mean. The overall results of the experimental and control groups are added together and divided by the amount of groups. This section presents all results. The scores of the three control groups for both the suffering and the time is stated in Table J.1 and for the three experimental groups is stated in Table J.2. The lower the suffering score, the better the plan since more people will be helped in that case. The time passed after the beginning of the experiment till the groups asked for help and the time passed till the groups filled in the fill in form to draw up their plan is shown in Table J.3 for the control groups in Table J.4 for the experimental groups. Note that in chapter 13 only the first entry of filling the plan of action is noted. These tables shows every entry. This can be multiple times, since most of the times the group filled in the form in different steps.

Table J.1: The amount of time the control group needed to define their plan of action and the amount of suffering reduced by that plan of action



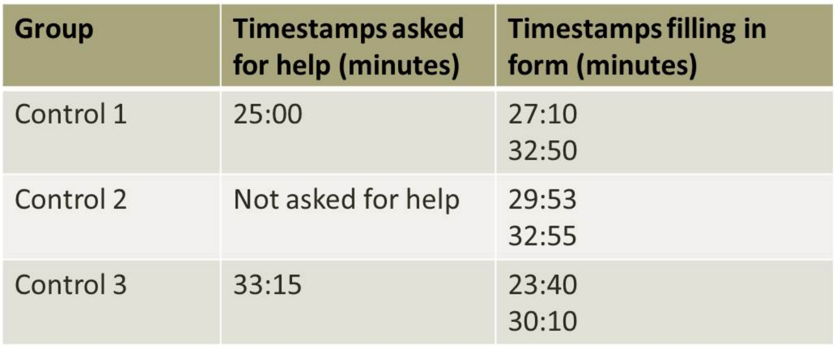
Group	Suffering	Time (min)	Average time to reduce suffering by 1
Control 1	-407	45:24	6.69 s
Control 2	-382	42:10	6.62 s
Control 3	-262	34:44	7.95 s
Mean	-350	40:46	7.09 s

Table J.2: The amount of time the experimental group needed to define their plan of action and the amount of suffering reduced by that plan of action



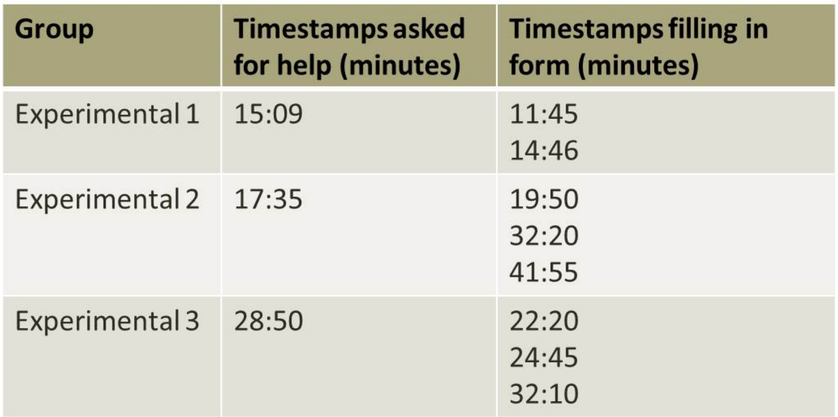
Group	Suffering	Time (min)	Average time to reduce suffering by 1
Experimental 1	-212	23:44	6.72 s
Experimental 2	-154	44:24	17.3 s
Experimental 3	-356	51:36	8.70 s
Mean	-241	39:55	10.9 s

Table J.3: The timestamps when the control groups asked for help and filled in the plan of action form



Group	Timestamps asked for help (minutes)	Timestamps filling in form (minutes)
Control 1	25:00	27:10 32:50
Control 2	Not asked for help	29:53 32:55
Control 3	33:15	23:40 30:10

Table J.4: The timestamps when the experimental groups asked for help and filled in the plan of action form



Group	Timestamps asked for help (minutes)	Timestamps filling in form (minutes)
Experimental 1	15:09	11:45 14:46
Experimental 2	17:35	19:50 32:20 41:55
Experimental 3	28:50	22:20 24:45 32:10

J.2. Shared information gathering

Chapter 13 shows how many times other participants indicate the right information which a participant had available. This section also shows how the participants answered on the question about which information the others had available. This answer is compared with the actual information that this player had available. This comparison for the control group can be seen in Table J.5 and for the experimental group in Table J.6. When this actual information does not lay in line with the filled in response of the others this text is underlined.

Table J.5: The different information that the participant had within the experiment according to the other participants for the control groups. In top they are stated which role this person actually had and which information is related to that role. When the information the person had is not in line with others stating, this text is underlined within the table

Group	Role of player 1: assessment expert	Role of player 2: supply expert	Role of player 3: Logistics expert
Control 1	- Suffering - Suffering	- Suppliers - Seaport and capacities	- Suppliers - Needed goods
Control 2	- Cities and suffering - Suppliers	- Suppliers - Cities and capacities	- Capacities of sea/air ports - Needed goods
Control 3	- Needed amount of goods - Needed amount of goods	- Suppliers - Suffering	- Cities on roads - Choice ships or airplane

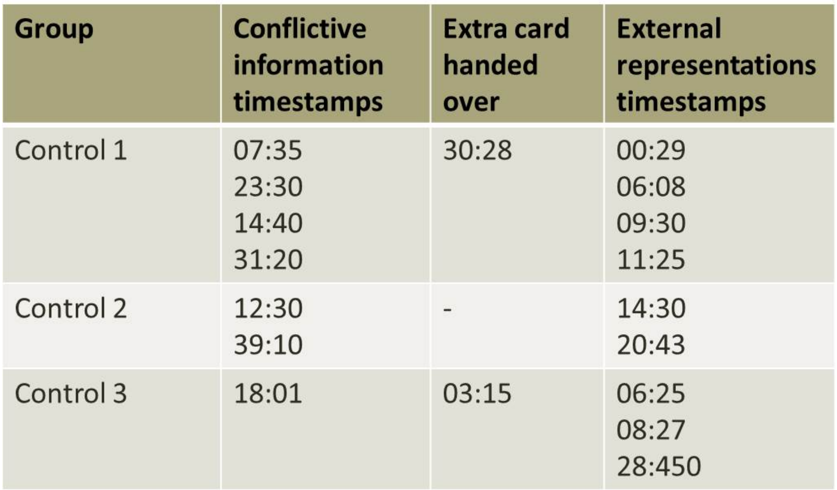
Table J.6: The different information that the participant had within the experiment according to the other participants for the experimental groups. In top they are stated which role this person actually had and which information is related to that role. When the information the person had is not in line with others stating, this text is underlined within the table

Group	Role of player 1: assessment expert	Role of player 2: supply expert	Role of player 3: Logistics expert
Experimental 1	- Countries and relations - Political relations	- Situation cities - Overview of suppliers	- Logistical tables - Capacity of air/sea ports
Experimental 2	- Score of suffering - Percentage of suffering	- Information about suppliers - Suppliers	- Capacity of air/sea ports - No idea
Experimental 3	- Amount of suffering which can be reduced - Condition of roads and amount of goods necessary	- Information about suppliers - Which suppliers could deliver goods	- Capacities of air/sea ports - Capacities of air/sea ports

J.3. Shared interpreting of information

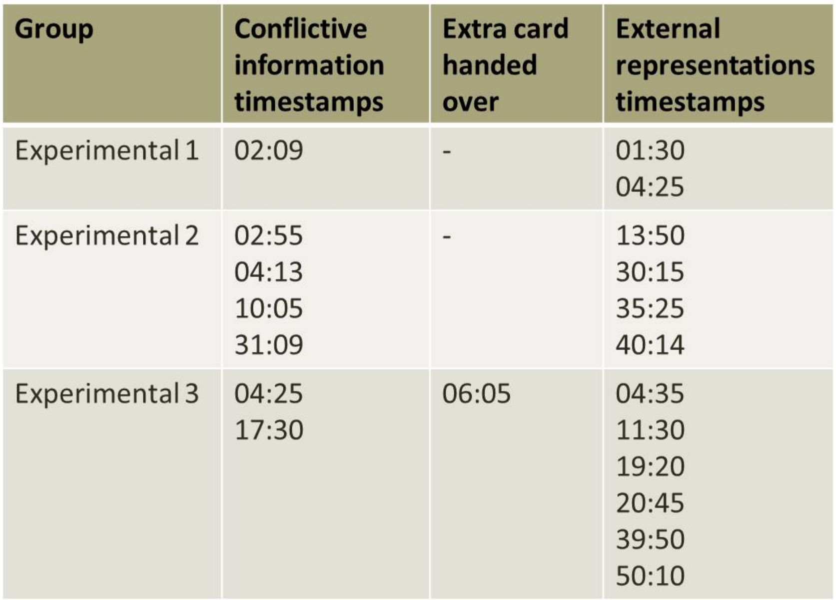
Chapter 13 shows that the there was no difference between the control group and experimental group with respect to conflictive information. This section shows the data behind this conclusion. The observer has detected when the group identified conflictive information and noted down the time passed after the beginning of the experiment when the participants identify that some information conflict each other. Next to that there is checked if the participants identify the conflicting information about the amount of goods necessary for a city and if so at what timestamp they identify this and thus at which timestamp the card with the right information is handed over. An overview of the different timestamps at which the control groups identify the conflictive information can be found in Table J.7. An overview of this for the experimental groups can be found in Table J.8. Next to that these tables shows the timestamps after external representations are made. Chapter 13 also presents this data.

Table J.7: The timestamps at which control groups identify conflictive information, the conflictive information about the amount of goods necessary at cities (and thus the time at which the extra card is handed over) and the timestamps at which external representations are made



Group	Conflictive information timestamps	Extra card handed over	External representations timestamps
Control 1	07:35 23:30 14:40 31:20	30:28	00:29 06:08 09:30 11:25
Control 2	12:30 39:10	-	14:30 20:43
Control 3	18:01	03:15	06:25 08:27 28:450

Table J.8: The timestamps at which experimental groups identify conflictive information, the conflictive information about the amount of goods necessary at cities (and thus the time at which the extra card is handed over) and the timestamps at which external representations are made



Group	Conflictive information timestamps	Extra card handed over	External representations timestamps
Experimental 1	02:09	-	01:30 04:25
Experimental 2	02:55 04:13 10:05 31:09	-	13:50 30:15 35:25 40:14
Experimental 3	04:25 17:30	06:05	04:35 11:30 19:20 20:45 39:50 50:10

J.4. Shared leadership

Chapter 13 shows how many times the other participants agreed about the role of the participants. This section also shows how the participants answered on the question about which role the others had according to them in the experiment. There was asked from all participant to describe the role of the other two participants. Their answers on this question are shown in Table J.9 for the control groups and in Table J.10 for the experimental groups. As can be seen, if the two participants are not agreeing on the role of the other participant, the text in this cell is underlined.

Table J.9: The different roles that the participant had within the experiment according to the other participants for the control groups. When the two players do not agree about the role of the other the text in that cell is underlined

Group	Role of player 1	Role of player 2	Role of player 3
Control 1	- Suffering - Suffering	- Suppliers - Seaport and capacities	- Suppliers - Needed goods
Control 2	- Cities and suffering - Suppliers	- Suppliers - Cities and capacities	- Capacities of sea/air ports - Needed goods
Control 3	- Needed amount of goods - Needed amount of goods	- Suppliers - Suffering	- Cities on roads - Choice ships or airplane

Table J.10: The different roles that the participant had within the experiment according to the other participants for the experimental groups. When the two players do not agree about the role of the other the text in that cell is underlined

Group	Role of player 1	Role of player 2	Role of player 3
Experimental 1	- Countries and relations - Political relations	- Situation cities - Overview of suppliers	- Logistical tables - Capacity of air/sea ports
Experimental 2	- Score of suffering - Percentage of suffering	- Information about suppliers - Suppliers	- Capacity of air/sea ports - No idea
Experimental 3	- Amount of suffering which can be reduced - Condition of roads and amount of goods necessary	- Information about suppliers - Which suppliers could deliver goods	- Capacities of air/sea ports - Capacities of air/sea ports