UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master Degree Project in Logistics and Transport Management

Building a Measurement Model for Port-Hinterland Container Transportation Network Resilience

Hong Chen

Supervisor: Kevin Cullinane
Master Degree Project No. 2015:58
Graduate School

Abstract

The ongoing development of world trade bolsters the demand for container transport that is safe and resistant to risks. Being important in international logistics and local economy development, container transportation between seaports and the associated hinterland is worth of being studied. In this thesis, we study a concept called resilience and apply it into the context of port-hinterland container transportation network. Resilience is one of the concepts dealing with safety and risk management issues academically, but with its own distinctive characteristics differentiating itself from others like stability and robustness. We firstly propose our definition of resilience in this context based on literature reviews. Next, a model is built to measure it quantitatively from shippers' perspective by adopting stochastic integer programming. This measurement model is then testified to demonstrate its feasibility by a numerical simulation taking the case of Port of Gothenburg and part of its hinterland. By studying thoroughly the resilience concept in general and analyzing the results from the numerical simulation, we discuss the validity and reliability of our contextual resilience definition and the measurement model. We find them to be not only theoretically meaningful but practically useful.

Key words: resilience, port-hinterland container transportation network, shippers' perspective, measurement model, stochastic integer programming

Acknowledgement

I want to give my grate thankfulness to several people who have kindly contributed with their knowledge, experience, and support to help me conducting this thesis. First of all, I would like to express my thankfulness to my supervisor at home university, Prof. Nan Liu. I couldn't have had this opportunity of studying here without his recommendation. Secondly, I would like to give my utmost gratitude to Prof. Kevin Cullinane, who is my supervisor here at University of Gothenburg. He has sacrificed much of his valuable time to arrange and have meetings with me from the very beginning of my thesis's work. I couldn't have completed this thesis without his highly valuable input, feedback and guidance. Thirdly, I would like to thank Prof. Rickard Bergqvist. The meeting with him makes me well informed with the background of the case in my thesis. Most importantly, he kindly recommended me three interviewees with whom I have conducted successful interviews. And I would like to show my appreciation to these three gentlemen as well. Finally, I would like to deeply thank my family and my boyfriend, who have supported me throughout the whole period studying and living abroad in Sweden.

Hong Chen

Content

List of figures

List of tables

List of Abbreviations and Definitions

GDP	Gross Domestic Product
ILWU	International Longshore and Warehouse Union
KRW	South Korean Won
OD	Origin-Destination
PMA	Pacific Maritime Association
PoG	Port of Gothenburg
PHCTN	Port-Hinterland Container Transportation Network
RQ	Research Question
SCRES	Supply Chain Resilience
SCV	Supply Chain Vulnerability
SCRM	Supply Chain Risk Management
SLC	Skaraborg Logistic Center
SLT	Supply Lead Time
TEU	Twenty-foot Equivalent Unit
UEE	Unconventional Emergency Event
USD	US Dollar

1. Introduction

In this chapter, we will firstly introduce the background of this study, including the brief introduction of the targeted concept—resilience. Then, two research questions and the research purpose are presented. Next, we will discuss two pieces of contributions from this study. Finally, the delimitation, limitation, and structure of the thesis are illustrated.

1.1 Background

The world trade has been steadily increasing since 21st century. Though affected by the economy crisis through 2007 to 2009, the exports and imports merchandise trade value in major economies across the world have been gradually recovering over the last six years (United Nations, 2013). For example, after hitting the bottom in 2009, the value of merchandise exports of the United States reached 1578.0 billion and the imports reached 2328.3 billion US dollars in 2013, recovering year by year since then (United Nations, 2013). The same pattern can be seen in other major economies like China and Europe (United Nations, 2013).

The ongoing development of world trade bolsters the demand for transport. As the transportation hub linking shipping and inland transport, seaports play an extremely important role in increasing the efficiency of international logistics and local economy development. It is not uncommon to see a small town develops into an international city because of the seaport it relies on. Moreover, among all, the container transportation and container port industries have received increasing attention in recent years, given its pivotal role in the globalization of the world economy (Cullinane et al., 2006). Besides, the shippers and carriers nowadays are considering more about reducing the whole transportation cost, not just that on the deep-sea shipping, in the context of global trade. Therefore, the efficiency of hinterland transportation becomes equally important as that of ports and seaborne shipping, and even more than ever before (Notteboom & Rodrigue, 2005; Rodrigue & Notteboom, 2006; Wilmsmeier et al., 2011). To achieve this, a safe and sound environment is a prerequisite.

Unfortunately, being so important in global trading and local economy development, ports and their hinterland are vulnerable to various disturbance that are often unexpected and severe, causing the breakdown of container transportation network between ports and the hinterland. Huge economic losses are usually generalized and social welfare is therefore harmed. For example, on 11th of March, 2011, a Magnitude 9.0 great earthquake hit Japan near northeast coast of Honshu, followed by horrible tsunamis. More seriously, that earthquake knocked the Fukushima Nuclear Power Plant, which was the largest one in the world at that time. Three of its reactors were caused to have hydrogen explosion. And at least 11 reactors were shut down. Radioactive material were leaking into the surrounding area and the ocean. 14,704 people died and 10,969 were injured in this disaster (Tencent News, 2011). GDP of the affected area made up 12.8% of Japan in terms of year 2010. Total economy loss was approximated up to 122 to 235 billion US dollars (Wang et al.,

2011). During this sever disaster, almost all the ports in north-east coast of Japan were shut down, including Port of Hachinoe, Port of Kashima, Port of Sendai, etc. Many other ports in the east were damaged to different degrees accordingly, such as Port of Miyako, Port of Hitachi, and so on. 19 million TEUs were handled in Japan throughout the year 2010. 7% of this volume, however, were affected due to this earthquake and the following tsunami (Reuters, 2011).

In addition to the nature disasters, ports and the hinterland are also vulnerable to man-made events, such as strikes and terrorist attacks. In the next half year of 2014, many ports in America and Europe had strikes as the approaching of Christmas Holiday and the winter shopping season, especially in November. For example, as the negotiation between ILWU and PMA in western coast of American having been lasted for several months since June in 2014 but still with no obvious progresses, in November, the launch of strikes started one by one in Port of Los Angeles, Port of Long Beach, and Port of Auckland. Those strikes made the operation in these ports totally breakdown, causing the serious problems of backlog. Numerous containers were delayed accordingly. It was approximated that the economic loss would be up to 2.5 billion US dollars if the strikes went on for 20 days (ISSC, 2014).

Similarly, the strike phenomenon can also be seen in rail freight transportation sector. Till 13th of December, 2013, for example, the employees of Railway Ministry in Korean had been going on a strike for five days. This strike had serious negative impact on freight transportation system in Korean. 64% of the trains were out of work, and only 30% of the capacity were in use during those days in strike. At that time, the government suggested the shippers of cement to turn to road hauliers for transportation service, but was refused by the shippers. Because the cost would than go up for 3 to 4 thousand KRW per ton, which the shippers cannot burden (China News, 2013).

Above are some examples of how ports and their hinterland can be affected by various natural and man-made disasters, which we call them as unconventional emergency events (UEEs) (detailed definition will be given in next section). In sum, due to the critical geography location and the important role played in economy development, seaports and the container transportation network between them and the hinterland are vulnerable to risks including both natural and man-made disasters. Therefore, the ability of a port-hinterland container transportation network (PHCTN) to react and persist its performance against the risks becomes an important attribute of the network. It is one aspect of competitiveness of the transportation service suppliers in the network, and also an important criterial for the shippers in evaluating the network's level of service.

In the researches against disasters, a concept called resilience has been brought up for decades. The definition of the English word 'resilience' given by Oxford Dictionary is "the ability of a substance or object to spring back into shape" and "the capacity to recover quickly from difficulties". The former describes the physical attribute of an object, while the latter makes resilience a characteristics of an abstract system in face with disruptions.

But what is resilience academically? Carpenter et al. (2001) summarized several levels of meaning of resilience based on previous studies: resilience can be a metaphor related to sustainability; a property of dynamic models; and a measurable quantity in the field studies of socioecological

system. Lots of researchers from different researching fields, such as ecology (Holling, 1973), social science (Timmerman, 1981), and supply chain (Christopher & Peck, 2004; Carvalho & Cruz-Machado, 2009), have put their efforts in building the concept of resilience, including definition (Westman, 1983), properties (Carpenter et al., 2001), measurement (Falasca et al., 2008), and even improvement (Christopher, 2004; Carvalho et al., 2012).

On the whole, based on the literature review on resilience concept from different researching fields (first section in Chapter 3), we summarize the following four pieces of our understandings about it:

- Resilience measures a system's ability in coping with the changes inside or outside the system
- The focus of resilience concept is to maintain the performance of a system or to achieve a more desired outcome, but not necessarily the original state or equilibrium, making it different from other confusing concepts like stability and robustness
- While inherent ability is definitely one dimension of resilience concept, adaptability is its distinctive characteristic
- One of the aims to build resilience for a system is to recover itself within an acceptable time at acceptable cost, while at the same time reducing the adverse impact of the changes as much as possible

1.2 Research questions

In this thesis, we will investigate the resilience concept in a concrete context of a port-hinterland freight transportation network (PHCTN), focusing on container flow. Therefore, we aim at answering the following two research questions:

RQ 1: how the resilience concept can be defined in PHCTN context?
RQ 2: how can this resilience definition be measured quantitatively?

To it carry out, we make the following assumptions about the targeted PHCTN: (1) we investigate the single seaport situation, in which there's only one seaport in the network playing a critical role in container transportation; (2) the seaport in this network has developed to the 'port regionalization' (Notteboom & Rodrigue, 2005) phase. It indicates a discontinuous hinterland (Notteboom & Rodrigue, 2007) in which there are many discrete demanding areas served by their corresponding dry ports with no overlapping among each other; (3) the intermodal transport in hinterland is also fully developed. Specifically, by default, the container flow between shippers' sites and the dry ports is transported by road, while from/to the seaport to/from dry ports is all by train. When building our measurement model for resilience of the network, we focus our attention on the rail transportation part; and (4) the dry ports act as consolidation and deconsolidation points and also intermodal terminals offering intermodal operation service. Figure 1 gives an illustration of a typical PHCTN in this study. The theoretical basis for proposing this typical transportation model will be given in the related literature reviews in Chapter 3.
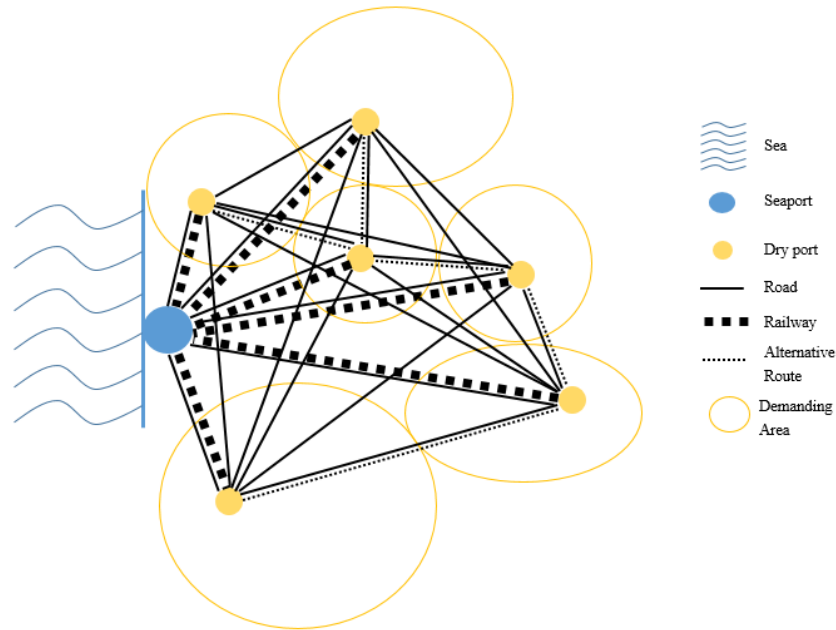
Figure 1 Typical model of PHCTN

In addition, we'd like to point out that the resilience concept we investigate is against unconventional emergency events (UEEs). The first key word "unconventional" refers to the events that are abnormal, devastating and unpredictable. It differs from the so called "conventional" events such as theft, out of electricity, and so on. Often, people don't make a full preparation for such events. And they cannot sometimes, even they plan to. Because, mathematically, the probability that "unconventional" event's happening is very small. Besides, they are also "emergent", indicating them as unpredictable. Or rather, people have difficulty in approximating its distribution function. Therefore, we won't include pre-events preparedness activities in our measurement model. Because these attributes of UEEs—small probability and unpredictable—make it difficult for the players inside the network to achieve high benefit-cost ratio. Having been damaged, the network should act quickly to reduce the loss as much as possible. Overall post-event rebuilding is out of our consideration in this thesis, but just immediate recovery activities.

1.3 Research purpose

According to the two research questions, the aim of this study is twofold. Based on studying the characteristics of PHCTNs, firstly, we will propose our definition of resilience concept in this special context. It is borrowed and modified from other researching fields such as ecology (Holling, 1973), social science (Timmerman, 1981), and supply chain (Christopher & Peck, 2004; Carvalho & Cruz-Machado, 2009), but with its common distinctive attributes maintained. Secondly, having had the definition, we then try to propose a mathematical model to measure it quantitatively.

By achieving these two goals, we hope to have a better understanding of the attributes of a PHCTN from the aspect of risk management using the concept of resilience. The measurement

model we build will provide the abstract resilience concept in PHCTN context a quantitative level, giving the players in the network a more concrete sense about its ability against UEEs. On the other hand, by applying resilience concept in a concrete and practical context, we will make the theories on resilience more complete.

1.4 Expected results

According to the two purposes of this study, hopefully, the established definition of PHCTN resilience will fully reflect the characteristics of its general form, making it distinguished from some confusing concepts such as 'reliability', 'stability', and 'robustness'. Secondly, our proposed resilience definition roots in PHCTN. We aim to include the attributes of this type of network as much as possible into the measurement model. Therefore, the calculated resilience level will serve the players in this network well, providing with them useful and concrete information about the risk level of this transportation network facing with UEEs. Besides, by analyzing some key parameters in this measurement model, we will provide suggestions on improving network's resilience level.

1.5 Contribution and originality

There are two pieces of contribution and originality coming from this thesis. Firstly, we apply the resilience concept into port-hinterland container transportation researching field, and also propose a quantitative measurement approach. Though other scholars (Wang & Ip, 2009; Nair et al., 2010; Ip et al., 2011; Miller-Hooks et al., 2012; Faturechi, & Miller-Hooks, 2014) have already contributed their intelligence, especially the work of Chen and Miller-Hooks (2012) on the intermodal transportation network, no one has ever focused their attention of resilience studying on this concrete context of port-hinterland container transportation. After all, it has unique characteristics and be important in local economy development. This thesis fills this gap. Secondly, we propose a new angle when measuring the resilience level of a transportation network quantitatively. As we will present it in detail in Chapter 5 that it is the user of the network that we take perspective from, instead of the supplier or the social welfare. Therefore, every aspect of constraints, including cost, capacity, and time, now has a clear real-world meaning and also related bearers. Complex issues like "free-ride" can thus be avoided in the measuring process. In this way, the resilience level of a transportation network can be measured more precisely.

1.6 Delimitation

My thesis consists of four pieces of delimitations. First piece of delimitations, the typical model we propose which aims at describing the context where the resilience concept applied in it is much simplified. It only represents networks developing to the "port regionalization" phase (Notteboom & Rodrigue, 2005; Rodrigue & Notteboom, 2006; Notteboom & Rodrigue, 2007) where (1) the hinterland is discontinued; (2) the intermodal transport system is well developed; and (3) the inland terminals function well as ideal dry ports. We are aware that, in reality, the geography and market pattern of a seaport's hinterland may be much more complex with overlapped demanding

areas and scattered container flows. But this situation is out of our consideration.

Second piece of delimitations is that we also limit the number of seaports in a PHCTN to be one, though it might be relaxed in practical as well. It is common to see two seaports compete for the same hinterland, which is a hot issue discussed practically and academically, actually (Cullinane et al., 2004; Cullinane et al., 2005; Yap et al., 2006; Wilmsmeier et al., 2011).

And thirdly, as we will present in Chapter 5, there are two decision makers in the measurement model. One is what we call "the seaport players", while the other is "shippers". We should clarify ourselves that, for "the seaport players", we don't separate them into port authority and port operators specifically (though there may be other players at the seaport like logistic companies, these two are the most influential in providing operation service and taking recovery activities), but viewing them as one "big" and "ambiguous" decision maker. It means we don't consider co-opetition issues between them in this thesis.

Last but not least, even though it's the people that has the highest priority in severe disasters like earthquake or terrorist attack and must be rescued firstly, we only focus on freight transportation, or specifically, the container flow, here in this study. However, we don't look people as non-important because they are out of the scope of this study. After all, "business is not everything", said by an official in municipality of Falköping, Sweden (Interview with the municipality of Falköping, 2014).

1.7 Limitation

The biggest limitation of the study in this thesis lies in the numerical simulation part. In doing the numerical simulation of the measurement model to testify its feasibility, we've tried our best to use the latest real-world data as simulation values as much as possible. However, due to inaccessibility because of business secrete issues, for example, it's impossible for us to have all the parameters in the model assigned with latest real-world data. Therefore, for those we can't, we just have to use approximated values to give them a numerical illustration. However, we have also done the best we can to ensure the approximation as reasonable as possible. The justification of all parameters' simulation values and the accessible real-world data sources are well presented in Chapter 6 and Appendix B.

1.8 Structure of the thesis

The rest of the thesis is structured as follows. Literature reviews on general resilience concept and theories behind PHCTN model will be presented in next chapter. Based on this theoretical framework, we give our definition of resilience concept in this special context in Chapter 4. Then, the measurement model quantifying the resilience level of PHCTN is described in Chapter 5, along with its formulations and solution. In Chapter 6, the feasibility of this measurement model is testified by a numerical simulation in the case of PoG and its hinterland. Finally, we conclude our research in Chapter 7.

2. Methods and methodology

In this chapter, the methods and methodology adopted by this thesis will be discussed. In the first section, we will try our best to clarify the research philosophy we followed doing the study, including issues of theory type, epistemological considerations, ontological considerations, and research strategy. Then, the two main methods that we used for this study—mathematical modelling and case study—are presented respectively in the next two sections. Mind that in the section of case study, we will also discuss the issue of data sources.

2.1 Research philosophy

Based on the research purpose—to define and build a mathematical measurement model for port-hinterland container transportation network resilience—this subsection illustrates how this study should be classified into a category in terms of research philosophy. The discussion is carried out through the four aspects one by one according to Bryman & Bell (2007, pp. 28)—type of theory, epistemological considerations, ontological considerations, and research strategy—in order to make it as clearly as possible.

2.1.1 Type of theory

This issue discusses whether a study is deductive or inductive based on the way it deals with theories. To put it simply, a deductive study is to test an existing based on observations and empirical findings, whereas an inductive one is to generate theories using observations and empirical findings (Bryman & Bell, 2007, pp. 14). In this sense, we prefer to say that the process of this study is deductive while the outcome makes it be inductive. It is said to be deductive in terms of its process in that we carry out this study based on the concept of resilience already existed on other researching fields. We borrow it and test it in PHCTN context. However, when we have defined and built the measurement model and demonstrated its meaningfulness and usefulness, we will also generate the concept of resilience in the context of PHCTN. In other words, we make the theory of 'resilience' more complete.

2.1.2 Epistemological considerations

Studies are divided into positivism or interpretivism in this consideration. We classify our study as one that takes positivism. Positivism originates in natural science, resting on the assumption that social reality is not affected by the act of investigating (Collis & Hussey, 2009, pp. 56). In our study, we believe that 'resilience' is an attribute or a characteristic of a PHCTN. It is there whether there's a researcher investigate it or not, and whether it is measured or not.

2.1.3 Ontological considerations

This issue concerned with the nature of social entities (Bryman & Bell, 2007, pp. 22). Objectivism

takes by researchers who believe "social phenomena and their meanings have an existence that is independent of social actors" (Bryman & Bell, 2007, pp. 22). Our study belongs to this group. Because we believe that the resilience of a PHCTN is determined once it is constructed. It won't affected by any researchers who are investigating it.

2.1.4 Research strategy

Research strategy in Bryman & Bell (2007, pp. 28) refers to whether a study is qualitative or quantitative. In their book, they classify studies into qualitative one and quantitative one based on the above three issues. Quantitative study is usually deductive and takes positivism and objectivism, while qualitative is often inductive one which takes interpretivism and constructionism. Based on the three above issues, we classify this thesis as a quantitative study. The main research method used in our study is mathematical modeling. A mathematical model is used to help people better understand real-world phenomenon and represent it by simplified form (Giordano et al., 2013) where quantitative results are usually derived. When we carried out this study actually, we followed the three steps:

(1) Clarify the definition of resilience concept through doing literature reviews on different researching fields. Study and define the characteristics and structure of a typical PHCTN based on related theories about ports development, hinterland, and the transportation system.
(2) Having had the theoretical framework, we build our resilience definition in the context of PHCTN.
(3) Build a mathematical model to measure the contextual resilience concept; do analysis on the benchmark results from the numerical simulation in the case of PoG's PHCTN; and discuss the validity and reliability of our defined contextual resilience concept and the associated measurement model.

2.2 Mathematical modelling

A mathematical model is to help people better understand the real world. It cannot represent phenomenon completely and precisely, though, but a simplified one with concerned focus. Since resilience is a concept particularly associated with uncertainty (detailed discussion can be found in Chapter 3), it cannot be measured from some simple and static indexes, but should consider the influences from various factors simultaneously. For example, attributes of different UEEs, the structure of the network, the action and attitude of players in the network, the container transport service demand and supply, the cost and time constraints on recovery, etc. Taking all these influential factors into consideration, a stochastic programming model is a rational choice when we try to propose a way to measure the resilience concept mathematically. A stochastic programming aims at achieving an objective value while subjected to certain constraints. More importantly, it reflects uncertainty, which is one critical aspect when we define the resilience concept.

2.3 Case study and data sources

Our purpose of doing the case study in this thesis is to get full background information about PoG and its hinterland container transportation network, plus the opinions on building the network resilience from the players inside it. Therefore, the numerical simulation that is carried out in PoG case will be demonstrated as practically meaningful. We design it as qualitative and instrumental (Stake & Savolainen, 1995). In this circumstance, we use two research methods in doing this case study—interviews and documentary data collection.

Since this is a qualitative case study, we decide to use face-to-face semi-structured interviews (Bryman & Bell, 2011, pp. 466-467). All together we've done three interviews with the most important players in the target network—the authority of PoG, the APM terminal (container terminal) in PoG, and the municipality of one RAILPORT terminal in the hinterland of PoG named Falköping. To carry them out, we've prepared three lists of questions for each of the interviewees. The three lists have similar questions asked with similar wording in similar orders on the same specific topics. Few of the questions in the list are different from others due to different institutions or companies these interviewees come from. Besides, we added one or two questions during the interview to catch as more information as possible according to the specific situation. The summaries of the interviews can be found in the Appendix C.

In addition, we also use documentary source to collect secondary data. The main sources in this study are the official documents and media outputs (Bryman & Bell, 2011, pp. 544). Specifically, the sources we find secondary data on basic information about PoG and its hinterland are the annual reports of PoG and RAILPORT, plus their official websites.

Actually, data in this thesis will be used in the numerical simulation, which aims at demonstrating the feasibility of our measurement model. When assigning simulation values of the parameters in the model, we try our best to use real-world data coming from the primary and secondary sources discussed above. For those we can't, due to inaccessibility, we then have to give them reasonable approximations to illustrate their quantitative level. All the secondary data source and the justification of simulation values' approximation will be presented in Chapter 6 and Appendix B.

3. Literature review

In this chapter, literature reviews will be done to present theoretical bases for our study. According to our two research questions, we focus our attention on two topics—studies on resilience concept and theories on port-hinterland development along with its freight transportation system. These two topics are reviewed in Sections 3.1 and 3.2, respectively. Finally, we give a summary of this chapter in Section 3.3.

3.1 Resilience

Having given briefly the summary of our understandings on resilience concept in Introduction, in

this section, we will present our studying on it in detail. Unlike Ponomarov & Holcomb (2009), who did the literature review on resilience concept from different researching fields, we have it reviewed and organized by different stages of resilience studies from a broader view, from definition to properties, then measurement, and finally to its improvement. After that, we will focus our attention on resilience researches in transportation field, especially, in next section.

3.1.1 Resilience concept in general

3.1.1.1 Definition

The very first time that the word "resilience" proposed in academic research is probably by Holling (1973) in his ecological study. He used this concept to describe an attribute of an ecological system. He gave his definition of resilience as follows:

"Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist."

There are two key words in his definition. One is "absorb changes", and the other is "persist". These two words have described the most important function of resilience, which refers to a system's ability in facing and overcoming changes that happen to or inside the system. Abundant studies on resilience that followed up have kept emphasizing these two key words from time to time, even though they used different terminologies, or gave the definition in a more specific context. For example, Timmerman (1981) is the first one who introduced the concept of resilience into social science, and used this concept to descript the society resilience:

"Resilience, the measure of a system's, or part of a system's capacity to absorb and recover from the occurrence of a hazardous event."

His definition has three key words: "absorb", which is the same as Holling (1973); "recover", whose aim is to "persist" (Holling, 1973) the working of a system; and the last one is "hazardous event". This can be referred to a bad "change" in Holling's (1973) definition. Timmerman (1981) argued himself in his paper that resilience is part of overall strategies to reduce vulnerabilities of a society. The key in resilience analysis lies in the continuation of the possibility of coping the probable adverse consequences of a hazardous event. Here Timmerman (1981) emphasized the word "continuation" in building his concept of resilience, while the basic idea is pretty much the as that in Holling's (1973) work.

Moreover, we can see much more different words used by many other researchers in their own definitions of resilience which are also similar to Holling (1973). For example, in terms of "absorb", other researchers may use "tolerance" (Carpenter et al., 2001), "control" (Reich, 2006), and even "reduce" (Falasca et al., 2008) to express their opinions. And for "changes", words like "disturbance" (Westman, 1983; Carpenter et al., 2001; Christopher & Peck, 2004; Carvalho &

Cruz-Machado, 2009), "disruption" (Falasca et al., 2008; Klibi et al., 2010), "adversity" (Stewart et al., 1997), "threats to survival" (Reich, 2006), "sudden and unexpected" (Christopher & Rutherford, 2004), "unusual conditions" (Murray-Tuite, 2006) can mostly be seen. While for expressing the similar meaning of the word "persist" in Holling's (1973) definition, researches usually use "recover" (Westman, 1983; Falasca et al., 2008), "return" (Christopher & Peck, 2004; Carvalho & Cruz-Machado, 2009), "restoration" (Murray-Tuite, 2006), and "Bounce back" (Reich, 2006) instead.

However, researchers following the work of Holling (1973) did propose something new in constructing resilience concept. One important key word brought up in resilience definition is adaptability (Christopher & Rutherford, 2004; Ponomarov & Holcomb, 2009). Adaptability, we can find its definition in a dictionary as,

"Variability in respect to, or under the influence of, external conditions; susceptibility of an organism to that variation whereby it becomes suited to or fitted for its conditions of environment; the capacity of an organism to be modified by circumstances."

Here, when used in resilience concept, it usually refers to the combination function of what 'absorb' and 'persist' mean. If a system is of high resilience, it must be adaptive to various kinds of 'changes'.

Beside the similar terminologies defining resilience, there are some other concepts different from resilience, which sometimes can be very confusing. One such concept is 'stability'. The difference between 'stability' and 'resilience' was investigated mostly in ecological research field. Stability refers to the ability of an ecosystem to return to the original state or equilibrium when facing with an exogenous disturbance (Holling, 1973; Westman, 1983). The emphasis is on maintaining the equilibrium, while resilience aims to achieve a good final performance of the system, no matter whether it remains its original state after disturbance or not. Thus, a system can have a high degree of resilience while with low stability.

Another confusing concept is 'robustness'. The discussion on 'resilience' and 'robustness' is usually seen in supply chain research. Robustness refers to the ability to maintain its original performance in face of reasonable variability (Christopher & Rutherford, 2004; Klibi et al., 2010). A robust process means the results produced varies little in output, while a resilient process can have a different state from the original but being a more desired one, indicating its adaptability (Christopher & Rutherford, 2004). Robustness differs from resilience in that the system doesn't aim at a better outcome, but just be satisfied with an equal good result. We can say that, in some degree, the stability of an ecosystem and the robustness of a supply chain may have something in common, which only consist part of resilience concept, however.

In addition, in the research field of supply chain, the study on supply chain resilience is usually linked with supply chain risk management and supply chain vulnerability. They do have some relationship between each other, but they are definitely different things. For example, Jüttner & Maklan (2011) empirically investigated the relationship between concepts of supply chain

resilience (SCRES) with supply chain vulnerability (SCV) and supply chain risk management (SCRM) in a disruptive global event context. Their results showed that SCRM has a positive impact on SCRES. SCR effect and knowledge management can enhance SCRES by improving the flexibility, visibility, velocity and collaboration capabilities of the supply chain.

More different definitions of resilience concept proposed by scholars in different researching fields are referred to Appendix A.

3.1.1.2 Property

The properties of resilience can be seen as a summary of researchers' understanding at the resilience concept. They may be investigated from different perspectives or clarified from different levels. Rose (2006) argued that there are three levels to investigate resilience concept: microeconomic (individual); mesoeconomic (sector, market, or cooperative group); and macroeconomic (all individual units and markets combined). And each level, there are two types of resilience: inherent and adaptive resilience in the context of normal circumstances and crisis situations respectively. This classification of resilience further explained the meaning of the two key words—"persist" and "absorb changes"—in Holling's (1973) study, giving his definition an explanation in a more specific context.

Similar opinions can be seen in many other studies. For example, the work of Carpenter et al. (2001), which focused on measurable operational definitions, proposed three properties of resilience: the amount of change the system can undergo; the degree to which the system is capable of self-organization; and the degree to which the system can build the capacity to learn and adapt. It's clearly that the first two properties are consistent with "inherent" resilience, while the last property refers to "adaptive" resilience according to Rose's (2006) classification.

The work of Ponomarov & Holcomb (2009) also agrees with this, though they didn't separate resilience in different two circumstances deliberately. They see resilience as one of the competitive strategies of an organization. Having done a literature review on resilience, they claimed that key words in resilience study from organizational perspective includes adaptability, flexibility, maintenance and recovery.

All the work mentioned above see the maintenance of good performance in normal and static condition and adaptability in changing condition as important properties in resilience concept. Moreover, it is clearly that more emphasis is put on the latter, just as what Carvalho & Cruz-Machado (2009) argued in a supply chain resilience study that a resilient supply chain may not be the lowest-cost, but it can be more capable of coping with the uncertain business environment.

3.1.1.3 Measurement

Unlike the aspects of definition and properties in resilience studies discussed above, which mostly used qualitative methods (Holling, 1973; Carpenter et al., 2001; Ponomarov & Holcomb, 2009),

certain amount of the work in measurement issues of resilience concept are done by using quantitative methods, especially in supply chain (Falasca et al., 2008; Carvalho et al., 2012; Colicchia et al., 2010) and transportation researches (Wang & Ip, 2009; Nair et al., 2010; Ip et al., 2011; Miller-Hooks et al., 2012; Chen & Miller-Hooks, 2012; Freckleton et al., 2012; Faturechi & Miller-Hooks, 2014; Janić, 2015).

However, qualitative work on measurement issue is still needed and important in building resilience concept. Many qualitative studies on resilience focus on the discussion of relationship between resilience and risk management (Stewart et al., 1997; Christopher & Peck, 2004), since one important aspect of resilience concept is the adaptability of a system to cope with changing environment (Carpenter et al., 2001; Rose, 2006; Ponomarov & Holcomb, 2009). For example, Christopher & Peck (2004) classified the risks to a supply chain into five categories from three perspectives: risks arising internal to the firm (process and control); risks arising from external to the firm but internal to the supply chain network (demand and supply); and risks arising from external to the network (environment). One way to build supply chain resilience is to create a supply chain risk management culture (Christopher & Peck, 2004; Christopher, 2004). Thus, it is not strange that Pettit (2008) proposed the risk aspect, or "vulnerability", of a system as a dimension of resilience measurement.

When it comes to the quantitative studies on resilience measurement, as we mentioned just now, it often can be seen mostly in the fields of supply chain management and transportation engineering and management researches.

Falasca et al. (2008) proposed a quantitative way to assess supply chain resilience to disasters by using a simulation framework. There are three determinants of supply chain resilience in their quantitative decision framework: density, complexity, and node criticality of the supply chain. They quantify resilience by using the concept of "resilience triangle", which is proposed by Tierney and Bruneau (2007). It represents the loss of functionality of a system after a disaster and the amount of time it takes to return to the normal performance level. So, improving a supply chain resilience means reducing the size of the triangle.

The work of Carvalho et al. (2012) uses different criterial in measuring supply chain resilience. They evaluated alternative scenarios for improving supply chain resilience to a disturbance by applying on a case study related to a Portuguese automotive supply chain. The performance of supply chain resilience in their study is measured by Lead Time Ratio and Total Cost. Colicchia et al. (2010) used a similar measurement, supply lead time (SLT), as the indicator of the supply chain resilience when they investigated from the perspective of transportation within a supply chain in the context of global sourcing process.

When it comes to measurement issue of resilience concept in transportation researches, more quantitative are found. We will leave this discussion in a separate subsection—Section 3.1.2.2—given its high relativity to the study in this thesis.

3.1.1.4 Improvement

Similarly, there are both qualitative and quantitative studies on resilience improvement strategy issues as well. An example of such qualitative research is referred to Carvalho & Cruz-Machado (2009). They argued that the aim of building a resilient supply chain is twofold: to recover to original system state within an acceptable time period and at an acceptable cost; and to reduce the effectiveness of the disturbance by changing the level of the effectiveness of a potential threat. Thus, flexibility and redundancy are important in building supply chain resilience. The discussion on flexibility and redundancy can also be seen in Sheffi et al. (2003). Their research argued that redundant supply chain network can be more resilient, but will be less cost effective. An alternative to redundancy is flexibility.

Moreover, flexibility and redundancy are continually investigated by a quantitative research of Carvalho et al. (2012). In his study, he viewed flexibility and redundancy as "mitigation strategies". A simulation model was used to study the impact of flexibility and redundancy on supply chain resilience performance. The results showed that the flexibility strategy is better than redundancy strategy in terms of Lead Time Ratio and Total Cost. Actually, the term "mitigation strategies" is also found in Colicchia et al. (2010). They built a simulation-based framework to show the effect of mitigation actions and contingency plans on increasing the supply chain resilience by using Monte Carlo method. They found that both mitigation actions and contingency plans can increase supply chain resilience. But the contingency plans are more effective. And, applying both approaches can increase the supply chain resilience greatly by reducing SLT variability by 40.4%.

3.1.2 Resilience concept in transportation

3.1.2.1 Definition and property

While researches on resilience have been carried on for several decades, the history of transportation network resilience studies is only about ten years long. Defining resilience concept in transportation researches, similar terminologies are used as those in other researching fields (Murray-Tuite, 2006; Wang & Ip, 2009; Nair et al., 2010; Ip et al., 2011; Freckleton et al., 2012; Chen & Miller-Hooks, 2012). For example, one definition referred to Murray-Tuite (2006) is as follows,

"Resilience is a characteristic that indicates system performance under unusual conditions, recovery speed, and the amount of outside assistance required for restoration to its original function state."

This definition is proposed in a general form, not encompassing the context of transportation very much. It emphasized the unusual conditions under which the resilience concept works. Besides, it also stressed that key aspects of a system's resilience are to adapt to the changes and to recover and restore. These two points can always be seen emphasized in resilience studies in other

researching fields (Timmerman, 1981; Westman, 1983; Falasca et al., 2008).

However, one may find that this definition lacks the argument of an important characteristic of resilience concept discussed in previous literature reviews—the ability to reach a more desirable state or to achieve a better performance when a system has adapted itself to the disturbance and recovered from the disruption. Indeed, this important aspect of resilience has been emphasized by many researchers such as Christopher & Peck (2004) and Carvalho & Cruz-Machado (2009). The work of Freckleton et al. (2012) overcome this drawback in Murray-Tuite's (2006) definition. They used the phrase "greater than" to express this distinctive characteristic in their definition of transportation network resilience,

"The ability for a transportation network to absorb disruptive events gracefully, maintaining its demonstrated level of service, or to return itself to a level of service equal to or greater than the pre-disruption level of service within a reasonable timeframe."

This definition is consistent with its counterparts in other researching fields where the concept of resilience is already well established, theoretically. Practically, however, this emphasized characteristic of resilience concept is extremely hard to be reflected in a measurement model if it is going be proposed, especially in the context of freight transportation network. Two of the most important criteria for freight transport performance are fill rate and time aspect (Harrington et al., 1991; Gassenheimer et al., 1989). If all the transport service demand can be met in normal situation, then it will be the best performance level in terms of fill rate. As for time aspect, common sense tells us that it can never be faster than transporting cargos in a normal situation if a disaster happens to the network. In other words, for freight transportation network, the best performance or state is achieved under normal situation. Therefore, when applying resilience concept in freight transportation field, this distinctive characteristic—indicating the achievement of a better state or more desired outcome of a system—should be omitted. Thus, it is no strange that none of the work, including Wang & Ip (2009), Nair et al. (2010), Chen & Miller-Hooks (2012), etc., demonstrates this attribute of resilience concept in their measurement model (more detail of their work can be found in next subsection); while Ip et al. (2011) didn't state clearly whether the system can return to the original performance or to a better one, but just argued that it can "return to a stable state".

3.1.2.2 Measurement

Quantitative method is usually used in this field. Numerous approaches in measuring resilience in transportation have been proposed by many researchers. For example, Murray-Tuite (2006) quantitatively investigated the influence of the system optimal and user equilibrium traffic assignments on the last four dimensions of the proposed ten which consist transportation resilience: adaptability, mobility, safety, and the ability to recover quickly. Results showed that user equilibrium is better in adaptability and safety while system optimum yields better mobility and faster recovery. Freckleton et al. (2012) used a fuzzy inference approach for calculating the resilience. The core of this methodology included four metric groups related to the individual, the community, the economy, and recovery. Liu et al. (2009) built a two-stage stochastic

programming to study the problem of allocating limited retrofit resources over multiple highway bridges to improve the resilience and robustness of the entire transportation system. The two-stage stochastic programming was used to optimize the mean-risk objective of the system loss. L-shaped method and benders decomposition are used in the solution to this model.

Focusing on the studies of measuring freight transportation network resilience quantitatively, we mainly find two approaches adopted in previous literatures. The work of Wang & Ip (2009) and Ip et al. (2011) belong to the first approach. Nair et al. (2010), Chen & Miller-Hooks (2012), and Miller-Hooks et al. (2012) are the representatives of the second one.

To put it simply, the first approach uses weighted sum of the nodes resilience as the whole network resilience. For example, in Ip et al. (2011), transportation network is represented by an undirected graph with cities as the nodes and traffic roads as the edges. The resilience of a city node is measured by the weighted average number of reliable passageways with all other city nodes in the network. The network resilience is then evaluated by the weighted sum of the resilience of all nodes. This idea of calculating a transportation network resilience is also adopted in Wang & Ip (2009), though the research object is logistic network. Again, the logistic network is represented by nodes (including demand nodes and supply nodes) and links (delivery lines). The logistic network resilience is therefore calculated by the weighted sum of demand node resilience, which is evaluated by its redundant resources, distributed suppliers and reachable deliveries.

This approach is very straightforward. However, it has fatal drawbacks as well. Firstly, resilience is a concept built on system level, which cannot be divided into or consists of components' (Carpenter et al., 2001; Murray-Tuite, 2006; Carvalho & Cruz-Machado, 2009). Secondly, the resilience concept is proposed with a special emphasis on coping with abnormal situations, calling "changes" (Holling, 1973; Timmerman, 1981; Klibi et al., 2010). Thus, the effect of unexpected events disturbing the system must be considered. Thirdly, this approach doesn't reflect the impact of any human activities, such as preparing and recovering, on the system after it is disturbed. But just depends on its "inherent resilience" (Rose, 2006), such as redundancy. This makes it be questioned of not revealing "adaptive resilience" (Rose, 2006)—the distinctive characteristic of resilience concept (Christopher & Rutherford, 2004; Ponomarov & Holcomb, 2009). And finally, but the most importantly, there shouldn't be any confusion with the concept of reliability when measuring a system's resilience. Reliability is somewhat the opposite concept of vulnerability, which can be seen as one dimension of resilience (Pettit, 2008). Unfortunately, the calculation of nodes resilience in this approach is actually based on a given reliability of the related path or link. Moreover, the authors didn't make it clear how to determine the value of a path reliability and which type it belongs to—travel time reliability, capacity reliability, or connectivity reliability (Chen et al., 1999; Lyman & Bertini, 2008)? Therefore, the authors have difficulty in clarifying themselves about whether the calculated network resilience is actually the reliability or not, furthermore, of which type.

Given our questionings on the first approach, we prefer the application of the second one in building a measurement model for transportation network resilience. Focusing on intermodal freight transportation network, Nair et al. (2010) investigated it from a nodal level, while Chen &

Miller-Hooks (2012) looked more on a system level. Both of these two studies proposed the resilience quantitative indicator by using a stochastic mixed-integer program, in order to measuring the network's ability in recovering from disruptions due to natural or human-caused disaster. Simulated under different disaster scenarios context, these two studies used the post disruption fraction of demand that can be satisfied by using specific resources while maintaining a prescribed level of service to represent the resilience. The results can aid decision makers in assessing trade-offs between investment and costly security implementations.

This approach overcomes the drawbacks of the first one—it considers the resilience from a whole system and calculates it under different disasters scenarios. More importantly, it includes the impact of human recovery activities into resilience concept, reflecting the adaptability of this system, not just the inherent dimension. In this way, the calculated resilience can be distinguished from the concept of reliability.

Based on Nair et al. (2010) and Chen & Miller-Hooks (2012), Miller-Hooks et al. (2012) further modified the model by incorporating preparedness decisions into resilience measurement besides the post-disruption recovery activities. Moreover, Faturechi, & Miller-Hooks (2014) even developed this approach to include three-stages in the measurement of travel time resilience of roadway network, where information is obtained at different degrees.

More complete literature review on quantitative approach in studying transportation network resilience can be found at Reggiani (2013).

3.1.3 Section summary

In this section, we presented a thoroughly literature review on resilience studies. Generally speaking, resilience can be seen as a concept representing the ability of a system in reacting to the disturbance. The most distinctive characteristic lies in that it can move to a more desired outcome, not just persist its original performance level as much as possible. It differentiates itself from other similar and confusing concepts like stability and robustness (Holling, 1973; Westman, 1983; Christopher & Rutherford, 2004; Klibi et al., 2010).

However, when resilience concept is applied to freight transportation researches, this distinctive characteristic should be omitted. We have justified ourselves for this omitting in the first subsection—the highest performance level of a freight transportation network is already achieved in normal situation. Therefore, a more desired outcome can never occur facing disruptions. In this sense, resilience only measures the ability of a freight transportation network in maintaining its original performance level. In this thesis, we adopt the percentage of transport service demand that can be met to represent this performance level. Obviously, it reaches its highest level of 100% in normal situation.

When carrying out this measurement criteria practically, however, time aspect should be included as a constraint. Because the performance level of a network will finally return to almost 100% as time goes by, given the fact that all damaged infrastructure must be repaired and all transport

service demand must be met considering the need for economic development. Of course, another approach dealing with this issue is to measure the time required for a network to return to its original performance level of 100%, following the idea of "resilience triangle" proposed by Tierney and Bruneau (2007). Due to the difficulty in measuring the time, we prefer to use the ratio of satisfied freight flow over all transport service demand within a certain period of time as the measurement of a freight transportation network resilience level. And this is the very logic in our building the quantitative resilience measurement model in Chapter 5.

3.2 Theoretical basis of PHCTN

This section aims at providing theoretical bases for the assumptions of our typical PHCTN model (see them in Introduction) where we will apply the resilience concept in and also propose its quantitative measurement model. A PHCTN is actually a transport network in the context of a seaport and its hinterland within which container transport service demand is met. Generally, a transport network can be represented by a set of nodes, a set of routes linking these nodes, and the transportation modes providing the transport service (Roso et al., 2009). Therefore, to investigate a freight transportation network in the context of port-hinterland focusing on container flows, three issues needed to be clarified: (1) the framework of a port-hinterland transport network, on which the development of the central role—the seaport—has an influential impact; (2) the roles of the nodes play in the network; and (3) the appropriate transportation modes chosen to provide transport service in the network. Accordingly, literature reviews on the theory of "port regionalization", the concept of dry ports, and the development of intermodal transport will be used to demonstrate the above three mentioned issues respectively.

3.2.1 Port regionalization

Since been brought up, the concept of "port regionalization" is accepted by many researchers (Mangan et al., 2008; Song & Panayides, 2008; Verhoeven, 2010; Flämig & Hesse, 2011; Monios & Wilsmeier, 2012). This concept is within the theory of port development. An exclusive literature review on port development can be found at Monios & Wilsmeier (2012). Here in this subsection, our focus is just on "port regionalization" concept, given its relativity to this study.

"Port regionalization" concept is introduced by Notteboom & Rodrigue (2005) based on the widely accepted port development model—the Anyport model proposed by Bird (1971). Comment by Rodrigue & Notteboom (2009), there are three major steps in the port development process—setting, expansion and specialization—which were studied as six phases in Bird's (1971) Anyport model. Notteboom & Rodrigue (2005) pointed out two weaknesses of Bird's model. One is that it couldn't explain the rise of some seaport terminals which function as transshipment hubs in hub-and-spoke and collection and distribution networks. The other weakness lies in that it doesn't include the dimension of inland as one of the driving factors in port development. Thus, Notteboom & Rodrigue (2005) proposed the fourth phase in a port development process besides those three in Anyport model—the phase of port regionalization.

This new phase emphasizes more on the importance of inland distribution and logistics hubs in

port competition (Rodrigue & Notteboom, 2006). By linking itself more closely to inland freight distribution centers, the port can further expand its hinterland to increase its competitiveness. As the authors put in their paper, port regionalization phase will drive the formation of a 'regional load center network' in which inland terminals have the satellite function to the seaport as cargo bundling points and serve as consolidation and deconsolidation centers. Finally, the composition of many inland terminals forms broader logistics zones. In other words, the phase of port regionalization promotes a discontinuous hinterland.

Moreover, the development of inland terminals (there are numerous terms related to the concept of inland terminals, but we focus on the term of dry port in this study. Details can be found in next subsection) and intermodalism are two critical driving factors facilitating this process (Notteboom & Rodrigue, 2005; 2007).

3.2.2 Dry port concept

Ever since decades ago, the concept of dry port has received much attention from lots of researchers worldwide both in theory (Jaržemskis & Vasiliauskas, 2007; Roso, 2007; Roso et al., 2009; Wilmsmeier et al., 2011) and practice (Ng & Gujar, 2009; Rodrigue et al., 2010; Hanaoka & Regmi, 2011; Monios, 2011; Korovyakovsky & Panova, 2011; Henttu & Hilmola, 2011). Popularity of this issue can be seen from the numerous similar and even confusing terms' springing up in literatures and practical world in recent years such as Inland Clearance Depot, Inland Container Depot, Intermodal Freight Centre, and Inland Freight Terminal. The differences and similarities among these terms have been discussed thoroughly by many scholars in their work in order to make them more clarified academically, including the definition of dry port (Jaržemskis & Vasiliauskas, 2007; Roso et al., 2009; Wilmsmeier et al., 2011).

Till now, dry port's definition hasn't been united. At first, as Cullinane et al. (2012) pointed out that a dry port is defined by UNCTAD (1982) as "an inland terminal to and from which shipping lines could issue their bills of lading, with the concept being initially envisaged as applicable to all types of cargo". However, due to the various specific situations around the world in implementing dry ports, its definition becomes very vague.

One of the widely accepted definitions is from Roso et al. (2009), which has been cited 168 times[1] up to now. In their definition, the dry port concept is "based on a seaport directly connected by rail with inland intermodal terminals where containers can be dealt with in the same way as if they were in a seaport". Based on this definition, the authors continued to classify dry ports into three categories according to the distance to the related seaport—distant dry port, mid-range dry port and close dry port. A distance dry port can secure a wider hinterland by offering shippers with low cost and high quality services, while a mid-range and close dry port can serve as a consolidation point for different rail services and to relieve the seaport's stacking areas by buffering containers and even loading them on the rail shuttle in sequence to synchronize.

[1] This data comes from Google Scholar. Source:
https://scholar.google.com.hk/scholar?hl=zh-CN&q=The+dry+port+concept%3A+connecting+container+seaports+with+the+hinterland&btnG=&lr= [Accessed 08-04-2015]

However, this definition is accused of by Rodrigue et al. (2010) as inappropriate because the word "dry" excludes the inland terminals served by barges. Instead, they proposed inland port as the generic term to label inland facilities, since it considers the relationships between terminals, the associated logistic activities and their hinterland. They used three main criteria to define inland ports: containerization, dedicated link, and massification. Besides, by using six case studies of inland ports development in Europe and North America, Rodrigue et al. (2010) proposed a three tier system "where functionally an inland port can act as a satellite terminal, a load center or a transmodal center and where several logistic activities, such as consolidation, transloading, postponement or light manufacturing can be performed".

However, both the definition of dry port in Roso et al. (2009) and the proposed general term inland port in Rodrigue et al. (2010) are questioned by Monios (2011). He argued that the dry port definition in Roso et al. (2009) fails to demonstrate the function in improving access for poorly-connected regions to global trade flows, but "a conscious tool of the sea port for extending its hinterland" (Roso et al., 2009). Meanwhile, the term "inland port" in Rodrigue et al. (2010) has problems in generalization and fitness when it is used in practice because the six cases used in their study have tremendous difference in the port's size and throughput, which makes the meaning of the term very vague. Nevertheless, by comparing these two studies, Monios (2011) thinks that the classification of inland port in Rodrigue et al. (2010) as satellite terminals, transmodal centers and load centers is somewhat similar to the classification of dry port as close, mid-range and distant in Roso et al. (2009). Instead, based on these previous studies and three cases in Spain, Monios (2011) gave his own definitions on several confusing terms including dry port, inland port, extended gate, and intermodal terminal.

Among other studies related to dry port concept, following all these previous studies, the work of Wilmsmeier et al. (2011) distinguished two different types of dry port developments. One is defined as Outside-In while the other as Inside-Out. Outside-In type is to describe the situation where dry ports are developed by port authorities, port terminal operators or ocean carriers. However, the type of Inside-Out says that the development of the inland facility may be driven by an inland carriage company. This study further clarifies the motivation, definition, and the function of dry ports, helping people to understand this concept in more depth.

Despite all these debates on definition and classification of dry port concept, there's somewhat consensus on the functions and advantages of implementing dry ports (Jaržemskis & Vasiliauskas, 2007; Roso, 2007; Roso et al., 2009; Rodrigue et al., 2010; Henttu & Hilmola, 2011; Padilha & Ng, 2012). Just as Cullinane et al. (2012) wrote in their paper, dry port is "one viable solution to the multifaceted conflicts problems of capacity expansion, environmental considerations, community restrictions and the continued embedding of freight transport and logistics functions within integrated supply chains". To sum, the dry port concept, or in other similar terms, plays an important role in port development, especially in the optimization of port-hinterland transport system such as on freight distribution and intermodal transport development (Notteboom & Rodrigue, 2005; Jaržemskis & Vasiliauskas, 2007; Roso et al., 2009; Rodrigue et al., 2010; Bergqvist & Woxenius, 2011; Hanaoka & Regmi, 2011).

3.2.3 Intermodal transport concept

As the on-going process of globalization and the exposure of international trade, the customers consider more about the whole transportation cost instead of just on shipping part in international freight transportation. Thus, lower cost and higher efficiency of port-hinterland transportation becomes an urgent need (Rodrigue & Notteboom, 2006). Intermodal transport is therefore a satisfactory choice both academically and practically, especially when considering environment issues (ISTEA, 1991; Šakalys & Palšaitis, 2006; Bontekoning et al., 2004; Hanaoka & Regmi, 2011).

Dewitt & Clinger (2000) defines intermodal freight transport as "the use of two or more modes to move a shipment from origin to destination". A more comprehensive but very similar definition can be seen in Hanaoka & Regmi (2011) that "the movement of goods in the same single loading unit or road vehicle that successively uses two or more modes of transport, without the goods being handled in a change of transport mode". More definitions can be referred to Bontekoning et al. (2004), who conducted a review on 92 publications on intermodal transport research in order to propose a research agenda. However, it is hard to say that, up to now, there is a standard or united definition for intermodal transport, though with the aim by some researchers like Jones et al. (2000).

Nevertheless, when it comes to the characteristics of intermodal transport, it is agreed by most researchers is that (1) containerization is the main theme (Jones et al., 2000; Sommar & Woxenius, 2007; Janic, 2008); and (2) it competes with all road transportation in terms of cost and time especially in medium- to long-distance (Sommar & Woxenius, 2007; Bontekoning & Priemus, 2004; Janic, 2007; Kreutzberger, 2008; Bontekoning et al., 2004). Even, it is possible to apply in the context of small flows and short distance (Bärthel & Woxenius, 2004; Trip & Bontekoning, 2002).

One thing to notice is that, among all types of intermodal transport, the rail-road intermodal receives the most attention (Bärthel & Woxenius, 2004; Roso et al., 2009; Hanaoka & Regmi, 2011). The geography reasons may be the primary explanation. Because very few countries have access to inland shipping but most countries can access to rail (Bontekoning et al., 2004). Therefore, in this paper, we only consider the rail-road intermodal type when building the model of PHCTN based on which we propose the measurement model for resilience concept in this context. More specifically, we focus on the rail part when we build the measurement model, given its longer distance compared to that in road part and the more important role in the whole trip.

3.2.4 Section summary

The three concepts reviewed above—port regionalization, dry port and intermodal transport—are the theoretical basis for defining and building our PHCTN model. This model is considered under assumptions that the seaport has developed into the fourth phase as port regionalization according to the port development theory (Notteboom & Rodrigue, 2005). Therefore, we view the hinterland

of the seaport as discontinuous (Rodrigue & Notteboom, 2006). It means there will be several 'regional load centers' in the hinterland. Each of them is responsible for the consolidation and deconsolidation of the containers in a certain area to and from the seaport. Or, put it in another way, each 'regional load center' has its own hinterland (Rodrigue & Notteboom, 2006). We call it the "demanding area" in this thesis. Besides, the implementation of these 'regional load center' in our model is based on the concept of dry port. Though there are some debates on the definition of this concept, its (de)consolidation function and the ability to handle intermodalism have received agreement among the researchers (Roso et al., 2009; Rodrigue et al., 2010; Bergqvist & Woxenius, 2011; Hanaoka & Regmi, 2011). Finally, here in our model, we don't consider other types of intermodal transport but just rail-road, while the reason was already given in the above subsection.

3.3 Chapter summary

After reviewing literatures on resilience studies and PHCTN, we now have theoretical bases for defining resilience concept, and furthermore, building our measurement model under this context. Comparing the two popular approaches in measuring resilience level of transportation networks, we prefer the second one taken by Nair et al. (2010), Chen & Miller-Hooks (2012), and Miller-Hooks et al. (2012).Though the second approach developed through these studies is pretty mature, there's still some space for new researches. Nair et al. (2010) and Chen & Miller-Hooks (2012) measures the resilience in the context of a general intermodal transport network. The former investigated the resilience from a nodal level, while the latter looked more on the links. However, no study has ever combined the nodes and links in measuring resilience concept. Besides, none of previous studies has ever considered resilience in a specific context of PHCTN. Our study fills in this gap. While intermodal transport is often applied in, a PHCTN has its own characteristics, making our study meaningful and different from others. Moreover, as we have mentioned in Section 1.6 that we take a new angle of user's perspective when measuring the resilience of a PHCTN, not the traditional perspective of social welfare that is taken in previous studies. Readers will see it clearly in Chapter 5 that the issue of "free-rides" will be avoided in measurement process. This very advantage will make the measured resilience level to be more precise.

4. Definition of PHCTN resilience

This chapter provides our answer to the first research question—*"how the resilience concept can be defined in PHCTN context?"* Before giving our definition, we like to clarify resilience concept with other two confusing counterparts in transportation field—flexibility and reliability. After that, we present our definition of resilience concept in PHCTN.

4.1 Resilience, Flexibility, and Reliability

Firstly, it is easier to separate resilience concept from flexibility. Although flexibility in transportation can also be used to describe a system's ability in handling and absorbing changes, it

emphasizes the "changes" on demand side (Feitelson and Salomon, 2000; Morlok and Chang, 2004; Chen & Kasikitwiwat, 2011). But in resilience studies, "changes" may come from various aspect (Christopher & Peck, 2004). In this study, we focus on the changes coming from outside the system caused by UEEs, while the transport service demand is assumed to be constant. Therefore, resilience concept here, at least in this study, differentiates from flexibility.

As for reliability, on the contrast, it mainly deals with the supply side (Chen & Kasikitwiwat, 2011). Generally, there are three kinds of reliability in transportation network researches (Chen et al., 1999; Heydecker et al. 2007). The first one is connectivity reliability. It is proposed as the probability of the nodes in a transportation network remain connected. Specifically, it means that there's at least one path linking a given destination from an origin facing disruptions to the network. Secondly, travel time reliability is another kind. It refers to the probability of reaching a destination within a given travel time. The last type is capacity reliability. It describes the probability of whether a network can satisfy a specified demand under the degraded network condition.

Based on these definitions, we are now clarifying resilience concept from the three types of reliability one by one. Firstly, for a resilient transportation network, it may not have a high connectivity reliability. All the original paths between a given OD pair may be destroyed because of external changes. However, effective immediate recovery activities can be taken to restore the operation. In that case, the performance of the network can still persist to some degree. As for travel time reliability, it is usually investigated from traveler's perspective (Chen et al., 2003; Vromans et al., 2006; Lyman & Bertini, 2008). In this study, however, we take the perspective from shippers (see Chap 5 for detail). As for shippers, punctuality in delivery cargos is important. What more important is, however, how many cargos can be transported. Therefore, time is only seen as a constraint in resilience studies, but not the object. Finally, capacity reliability may be the most confusing counterpart when clarifying resilience concept. Actually, what capacity reliability implies can be viewed as one dimension of resilience concept—inherent resilience (Rose, 2006). It is obviously good if a system is equipped with high capacity reliability. But it can still be resilient otherwise, as long as it's another dimension—adaptability—is high enough. The adaptability can be reflected through some post-event activities which are used to repair the damaged infrastructure or find other ways out to ensure transportation service.

4.2 Resilience definition in PHCTN

Having had a better understanding on resilience concept after clarifying it from confusing concepts of flexibility and reliability, we define resilience in this study as follows based on the reviewed theories presented in last chapter:

Resilience of a PHCTN refers to the ability of the system, with the help of immediate recovery activities, in meeting the transport demand, and recovering and persisting the performance level under a rational cost within a limited time period when faced with disruptions to the network due to unexpected UEEs.

We believe this definition reflects our understandings on resilience concept well. Firstly, as what we have argued in sub section 3.1.1.2, one of the distinctive characteristics of resilience concept—the ability of a system in achieving a more desired outcome facing changes—is omitted in this context. Secondly, we emphasize on another distinguished attribute of resilience—adaptability. It is reflected through the immediate recovery activities as reactions to the disruptions to the system (Carpenter et al., 2001; Rose, 2004; Ponomarov & Holcomb, 2009). The function of a transportation network is to provide transport service. Thus, we look on the amount of transport demand than can be met and we don't mind how it is met. This means that the transportation routes and the operation at dry ports may be adjusted facing UEEs, the transport demand can completely or partly be met though.

Unlike Miller-Hooks et al. (2012) and Faturechi, & Miller-Hooks (2014) who also considered preparedness, we just look on immediate post-event recovery activities. By taking interviews with some players in the transportation network of PoG and its hinterland, we find that preparedness for unconventional events is usually out of their consideration, actually (Interview with the authority of PoG, 2014; Interview with APM terminal in PoG, 2014; Interview with Municipality of Falköping, 2014). In practical, for what they prepare themselves are conventional events such as theft and out of electricity. Except from the fact that very few UEEs have ever happened in PoG and its hinterland, one another reason may lie in the difficulty of approximating the probability distribution of UEEs. On the other hand, a transport system usually involves various players. The competition and cooperation between the players makes the issue of cost sharing in preparedness against UEEs very complex. Because no one wants to be the 'dominant pig' as in the famous Boxed Pig Game (Baldwin & Meese, 1979) while letting others to be the free riders. This may also be an explanation for the fact of little preparedness.

5. Measurement model

This chapter, together with the next, answers our second research question—*"how can this resilience definition be measured quantitatively?"* Our measurement model for resilience level of a PHCTN will be presented. It is based on the theories we've reviewed in Chapter 3. It is in accordance with our definition for PHCTN resilience as well, reflecting the characteristics of general resilience concept, especially in transportation context. The first section describes briefly about this measurement model, justifying our logic of building it. Then, the model will be presented in detail, including how a PHCTN is represented mathematically and the notations of parameters used in the model. Next, we will give the formulations of the model, meanwhile explaining how they reflect our ideas about it. Finally, solution of the model will be addressed in the last section.

5.1 Description

Having defined the resilience concept in the context of PHCTN, we now propose our measurement model in order to quantify the resilience level of a given PHCTN. Based on our

definition, it is the persisted "performance level" that we are going to measure as the resilience level of a PHCTN facing UEEs. In this model, we use the ratio of total satisfied container flow over the total container transport demand to represent the "performance level", given the function of a PHCTN is to transport containers successfully. This measurement criteria is also what Chen & Miller-Hooks (2012) adopted in their trying to quantify the resilience concept for an intermodal transport network.

As the title implied, the aim of this thesis is to measure, instead of building, the resilience level of a PHCTN. Therefore, the decision variables in our measurement model are set to determine how to use the resources of a given network in order to maximize its "performance level"—the ratio of satisfied container flow over the total container transport demand—but not how to provide them. In this sense, we take the perspective of shippers when building the model. Shippers can usually have multiple choices to transport their containers within the hinterland, but only through the seaport can they have shipping service[2]. Thus, we divide the transportation of containers in a PHCTN into two parts—with shippers deciding how to transport their containers in hinterland part and the seaport players deciding on the operation service provided at seaport part.

In this way, faced with UEEs, the seaport players have firstly to decide whether to take immediate emergency activities to provide the temporary recovered operation or not. Because failing to provide operation service, they might be suited by shippers, rail operators, etc., for their economic loss due the close of the seaport (Interview with Municipality of Falköping, 2014). Therefore, their objective is to provide the operation service at the seaport as soon as possible but, of course, within an acceptable cost for implementing the recovery activities.

As for shippers, they must be suffered from the UEEs somehow in reality. Thus, their goal is to minimize their economic loss. Seeing the operation service level provided at the seaport, they then decide which actions to take for transporting their containers between the seaport and the hinterland from several optional choices. In this way, their satisfied container volume that can be accordingly decided from their own perspective considering the time and capacity constraints. In a simplified form, the loss of shippers due to UEEs consists of two parts. The first part is the additional transportation cost by using alternative options comparing to that in normal situation. And we call these actions also as recovery activities but in the hinterland. The second part is, if there's a decrease in the capacity of the infrastructures in the network, then there will be a loss in the merchandize value of containers that cannot be transported.

Besides, according to our definition of the contextual resilience concept, all the decisions must be made within a limited time period. We denote it as the maximum time allowed for transporting containers. This constraint is also adopted in Nair et al. (2010), Chen & Miller-Hooks (2012), and Miller-Hooks et al. (2012). These researches didn't specify it clearly but just set it as a given constraint. However, we put it with a real-world meaning. For example, it may depend on the contracts between shippers and their consumers or on the good's life cycle.

---

[2] As we have stated in the sub section of Delimitation, we assume that there's only one seaport in a PHCTN our model

In sum, there are two stages in our measurement model. Facing an UEE, firstly, the seaport players decide on the operation service provided at the seaport. Then shippers make their decisions on how and the number of containers that should be transported in order to minimize their economic loss, considering the constraints on time and capacity they are faced with. We denote the optional actions for shippers to take also as "recovery activities" but in the hinterland, differentiating them from those at the seaport which are decided by the seaport players. After both the seaport players and shippers have made their own decisions against UEEs, the total satisfied containers flow is therefore automatically derived. Further, the ratio of total satisfied container flow over the total container transport demand is therefore got, which is the very representation of the aimed persisted "performance level". Note that the demand for container transportation service in the network is constant and unaffected by UEEs.

5.2 Specification and representation

Developed to an advanced stage, a PHCTN can be defined by three critical components: the set of seaports, a set of related dry ports in hinterland (acting as freight distribution centers and intermodal terminals), and the transportation routes, with the default transport mode as rail-road intermodalism.

The container transportation network in this thesis includes only one seaport and its hinterland. We also limit the hinterland concept in this model as only inland part, without any feeder ports. And the hinterland is assumed as discontinuous, consisting of several demanding areas with no overlapping and are served by related dry ports, where both the inbound and outbound containers transported between a demanding area and the seaport must be loaded and unloaded at. The dry port here acts as both an intermodal terminal and a distribution center. Note that the transportation routes linking dry ports and the seaport may contain several alternative transport modes. We assume the default transport mode is by train. However, any two nodes in the network, including all the dry ports and the seaport, are linked by road. Normally, there's no container flow and railway infrastructure between any two dry ports. However, when dry port A is out of work due to some UEEs, then shippers in demanding area A have an option to turn to its adjacent dry port B instead for loading and unloading the containers, also for the rail shuttle transport service there. Therefore, the resilience measurement model we are going to build is mainly for rail transportation but not for road transportation, given our interested nodes in the network are dry ports and the seaport which are linked by railway.

The capacity of the seaport denotes as $C_{seaport}$. This is a non-negative integer representing the maximum number of containers that can be handled at the seaport per workday. It is similar with all the other parameters referring to capacity that the unit is TEUs/day. Assume that there are W dry ports in the hinterland. Each of these dry ports has a capacity of C_w, where w={1,2, …, W}, indicating its capability of handling containers. l_w is the capacity of the default route (by rail) between dry port w and the seaport. Actually, it represents the maximum transport volume supplied by rail operators. The container transportation service demand of a demanding area denotes as D_w, which is assumed to be constant and inelastic, unaffected by UEEs. We don't separate the demand as inbound and outbound container flows in this study. Finally, the spatial

relationship among the dry ports is given by a symmetric adjacent matrix denoted as AM. The cells in this matrix indicates whether two dry ports are functionally, not geographically, adjacent or not. In other words, whether shippers belonging to dry port w can use the dry port z instead in an emergency circumstance—$\beta_{wz}=1$ if they can; otherwise, $\beta_{wz}=0$, w≠z. And vice versa. Other parameter notations in the measurement model are referred to Table 1.

$$AM = \begin{bmatrix} 1 & \beta_{12} & \beta_{1w} & \beta_{1W} \\ \beta_{21} & 1 & \beta_{zw} & \beta_{zW} \\ \beta_{w1} & \beta_{wz} & 1 & \vdots \\ \beta_{W1} & \beta_{Wz} & \dots & 1 \end{bmatrix}_{W*W} , \text{for } \forall z \in Z, \forall w \in W, \beta_{wz} \in \{0,1\}$$

Table 1 Notation of parameters in the model

Notations of parameters		Meaning
Sets	ξ	The set of UEEs scenarios
	S	The set of seaports, s={1,2, …, S}
	W	The set of dry ports, w={1,2, …, W}
	K	The set of recovery activities in hinterland, k={1,2, …, K}
	J	The set of recovery activities in the seaport, j={1,2, …, J}
Exogenous parameters	p	The merchandise value of one container (TEU) in US dollars
	T_w^{max}	The maximum allowable time for transporting containers between dry port w and the ships, including delivery time in the hinterland and the operation time at the seaport
	v_0	The operation rate at the seaport in normal condition
Random variables	δ_{cw}	A binary parameter indicating whether dry port w is damaged due to UEEs. 1 indicates damaged, while 0 indicates not
	δ_{lw}	A binary parameter indicating whether the default transport mode (railway system) between dry port w and the seaport is damaged due to UEEs. 1 indicates damaged, while 0 indicates not
	$\delta_{seaport}$	A binary parameter indicating whether the seaport is damaged due to UEEs. 1 indicates damaged, while 0 indicates not
	τ_w	The post-event actual delivery time between dry port w and the seaport. We ignore the transport time from shippers to dry ports and vice versa, but just consider that between dry ports and the seaport
	τ_{port}	The post-event actual operation time at the seaport
	ΔC_{wk}	Increased capacity of dry port w due to recovery activity k
	Δl_{wk}	Increased capacity of the default route between dry port w and the seaport due to recovery activity k
	$\Delta C_{seaport\_j}$	Increased capacity of the seaport due to recovery activity j
	t_{wk}	The delivery time between dry port w and the seaport after recovery activity k is taken
	t_{port_j}	The operation time at the seaport after recovery activity j is taken

	Q_{wk}^R	The implementation time of taking recovery activity k in the hinterland as for the shippers in demanding area w
	b_{wk}	The additional transportation cost of taking recovery activity k in the hinterland as for the shippers in demanding area w
	$Q_{port\_j}^R$	The implementation time of recovery activity j at the seaport
	$b_{seaport\_j}$	The cost of implementing recovery activity j at the seaport as for the seaport players
Random variables	$B_{seaport}$	The cost constraint of taking recovery activities as for the seaport players
Decision variables	f_w	The optimal container volume transported from the perspective of the shipper in demanding area w. Non-negative integer
	γ_{wk}	The binary parameter indicating whether recovery activity k is taken or not in demanding area w. $\gamma_{wk} = 1$ means taken, while the value of 0 means not
Decision variables	γ_{wk}	The binary parameter indicating whether recovery activity k is taken or not in demanding area w. $\gamma_{wk} = 1$ means taken, while the value of 0 means not
	$\gamma_{seaport\_j}$	The binary parameter indicating whether recovery activity j is taken or not at the seaport. $\gamma_{seaport\_j} = 1$ means taken, while the value of 0 means not
	TF	Total satisfied container volume

5.3 Formulation

The following Equation (1) is how we measure the resilience level in our model, with resilience level denoted by the parameter R. The consequences of different UEEs is different from one to another. Even for one particular UEE, it can cause various different outcomes to the network. Therefore, we consider each type of a potential UEE as a separate scenario. The resilience level of the network is measured under each specific UEE scenario and calculated as the expected value of difference outcomes.

$$R\left(\bar{\xi}\right) = E\left[\frac{TF(\bar{\xi})}{\sum_w D_w}\right] \quad (1)$$

Given that the container transport service demand D_w is an exogenous parameter, we thus only need to determine $TF\left(\bar{\xi}\right)$ in Equation (1) in order to calculate the resilience level. $TF\left(\bar{\xi}\right)$ is the total satisfied container volume from all the demanding areas in the set W. As we have stated in last section, there are two stages in the measurement model. We therefore have two separate sub-model to determine this value accordingly.

Stage 1

In this stage, the seaport players decide on the operation service level after the happening of UEEs

at the seaport. Their goal is to provide the operation service as soon as possible. Because the close of the seaport will bring their customers and cooperators economic losses. They might be suited for claiming at these huge losses. There are several optional actions to recover the operation service for the seaport players to take. Each of this recovery activity may have a different implementing time, cost, and recovery capability. The seaport player has to choose one of these activities to recover the seaport operation in order to handle the containers as fast as possible but within a rational cost. Therefore, we adopt the following stochastic integer linear programming:

Sub-model 1

$$Minimize_{\gamma_{eaport\_j}(\bar{\xi})} \quad T_{seaport}(\bar{\xi}) =$$

$$\tau_{port}(\bar{\xi}) + \delta_{seaport}(\bar{\xi}) \sum_j \left(t_{port\_j}(\bar{\xi}) - \tau_{port}(\bar{\xi}) \right) \gamma_{eaport\_j}(\bar{\xi}) +$$

$$\delta_{seaport}(\bar{\xi}) \sum_j Q^R_{port\_j}(\bar{\xi}) \gamma_{eaport\_j}(\bar{\xi}), \ \forall j \in J \qquad (2)$$

s.t.
$$\sum_j b_{seaport\_j}(\bar{\xi}) \gamma_{seaport\_j}(\bar{\xi}) \le B_{seaport}(\bar{\xi}), \forall j \in J \qquad (3)$$
$$B_{seaport}(\bar{\xi}) = p * max\{0, (\sum_w D_w - C_{seaport}(\bar{\xi}))\} \qquad (4)$$
$$\sum_j \gamma_{seaport\_j}(\bar{\xi}) \le 1, \forall j \in J \qquad (5)$$
$$\gamma_{seaport\_j}(\bar{\xi}) \in \{0,1\}, \ \forall j \in J \qquad (6)$$

In this sub model, the decision variables are $\gamma_{seaport\_j}(\bar{\xi})$, $\forall j \in J$, indicating which recovery activity to take by the seaport player. The objective function value $T_{seaport}(\bar{\xi})$ represents the minimum time for handling the same amount of containers in normal condition demand based on the capacity after UEEs. Assume that the rate of handling containers at the seaport is constant. Thus, the operation time is proportional to the capacity.

Constraints (3) and (4) indicate the cost aspect for taking immediate recovery activities at the seaport. The cost limit comes from the lost merchandize value of containers that cannot be transported due to the stopping of seaport operation, which the customers and cooperators will claim from the seaport players. In addition, we assume that the seaport player can only take one recovery activity from their optional choices. This is expressed in constraint (5). Constraint (6) indicates the decision variables as binary parameters.

Stage 2

Seeing the operation service provided at the seaport, shippers in this stage make their decision on how to transport their containers in the hinterland ($\gamma_{wk}(\bar{\xi})$) and how many the containers ($f_w(\bar{\xi})$) to transport, with the objective to minimize their economic losses due to UEEs.

Sub-model 2

$$Minimize_{\gamma_{wk}(\bar{\xi}),f_w(\bar{\xi})} \quad \varepsilon \left(\delta_{cw}(\bar{\xi}) + \delta_{lw}(\bar{\xi}) - 1 \right) * \sum_k b_{wk}(\bar{\xi}) \gamma_{wk}(\bar{\xi}) + p * \left(D_w - f_w(\bar{\xi}) \right) \quad (7)$$

s.t.

$f_w(\bar{\xi}) \leq$

$min\{D_w, C_w(\bar{\xi}) + \delta_{cw}(\bar{\xi})\sum_k \Delta C_{wk}(\bar{\xi})\gamma_{wk}(\bar{\xi}), l_w(\bar{\xi}) + \delta_{lw}(\bar{\xi})\sum_k \Delta l_{wk}(\bar{\xi})\gamma_{wk}(\bar{\xi})\}, \forall w \in W, \forall k \in K$ (8)

$\tau_w(\bar{\xi}) + \varepsilon(\delta_{cw}(\bar{\xi}) + \delta_{lw}(\bar{\xi}) - 1)\sum_k (t_{wk}(\bar{\xi}) - \tau_w(\bar{\xi}))\gamma_{wk}(\bar{\xi}) + \varepsilon(\delta_{cw}(\bar{\xi}) + \delta_{lw}(\bar{\xi}) -$

$1)\sum_k Q^R_{wk}(\bar{\xi})\gamma_{wk}(\bar{\xi}) + [f_w(\bar{\xi})/(v_0 * (C_{seaport}(\bar{\xi})/C_{seaport0}))] \leq T^{max}_w, \forall w \in W, \forall k \in K, \forall j \in J$ (9)

$\sum_k \gamma_{wk}(\bar{\xi}) \leq 1, \forall w \in W, \forall k \in K$ (10)

$\gamma_{wk}(\bar{\xi}) \in \{0,1\}, \forall w \in W, \forall k \in K, \forall j \in J$ (11)

$f_w(\bar{\xi}) \geq 0$ (12)

Where $\varepsilon(t) \stackrel{\text{def}}{=} \lim_{n \to \infty} \gamma_n(t) = \begin{cases} 0, & t < 0 \\ \frac{1}{2}, & t = 0 \\ 1, & t > 0 \end{cases}$. It is a step function. We modify it with the point $t = 0$ as $\varepsilon(t) = 1$. Actually, this function acts as a logical operator. It derives the value of 1 as long as either the binary parameters $\delta_{cw}(\bar{\xi})$ or $\delta_{lw}(\bar{\xi})$ equals 1.

We should notice readers that we view shippers in each demanding area as a "big shipper". These "big shippers" have their own constraints. They make their decisions independently and simultaneously with no intra strategies between any two. Therefore, this sub model 2 actually consists of W independent stochastic integer programming problems. Each of them refers to a specific demanding area.

The objective function (7) consists of two parts. The first part is the additional container transportation cost in hinterland by using recovery activities comparing to that in normal situation. And the second part is the loss of merchandize value of the containers that cannot be transported due to the capacity decreased in infrastructures after UEEs.

Inequation (8) identifies the capacity constraints. Specifically, for a demanding area w, the satisfied container flow should neither exceed the demand nor the actual capacity of the corresponding dry port or the railway. Notice that the capacity here is the sum of both the realized capacity under a certain outcome of an UEE scenario and the recovered capacity due to immediate post-event recovery activities.

Inequation (9) says about the important time constraint of implementing recovery activities. As for shippers, we assume that there's a time limit for transporting their containers. They will burden economic losses if the containers are delayed. In other words, the actual transportation time (including delivering time in the hinterland and operation time at the seaport) plus the recovery activities implementation time, if any, should be within the maximum allowable time limit. Notice that the operation time at the seaport is calculated by dividing the container volume by the actual operation rate. The operation rate is inversely proportional to the capacity at the seaport.

Constraints (10) indicates that shippers can maximally take only one type of immediate post-event

recovery activities faced with UEEs. Finally, constraints (11) and (12) give the attributes of the decision variables.

Solving the problems in the above two stages, we can get the maximum container flow that can be transported facing UEEs from shippers' perspective considering the operation service provided at the seaport. As we have stated, however, shippers from different demanding areas make their decisions independently, without considering the decisions from others. In this way, the sum of the container flow derived from every shipper's perspective might exceed the total capacity provided at the seaport. Therefore, the actual total satisfied container volume is calculated by the following equation (13):

$$\text{TF}(\bar{\bar{\xi}}) = \min\left\{\sum_w f_w(\bar{\bar{\xi}}), C_{seaport}(\bar{\bar{\xi}}) + \delta_{seaport}(\bar{\bar{\xi}})\sum_j \Delta C_{seaport_j}(\bar{\bar{\xi}})\gamma_{seaport_j}(\bar{\bar{\xi}})\right\} \quad (13)$$

5.4 Solution

Though under the expression of stochastic programming, this measurement model is actually deterministic—values of all the random parameters can be decided once UEEs are realized. We adopt the Monte Carlo method to deal with the expectation calculation in the resilience formulation (Equation (1)). According to our measurement model, the resilience level of a given PHCTN is calculated following these five steps:

Step 1: Assign scenarios that certain UEEs may threaten the network
Step 2: Approximate the probabilities of different components in the network being damaged in each scenario
Step 3: Set the values of all the exogenous and random parameters under each scenario in every Monte Carlo iteration
Step 4: Solve the deterministic integer programming iteratively in the two sub models
Step 5: Calculate the expected value of resilience in all iterations as the network's resilience level for a particular UEE

The integer programming in sub model 1 is linear. It is simple and convenient to solve it by using advanced professional software like Matlab. In sub model 2, however, the integer programming may be linear or quadratic, depending on whether the recovery activity cost is a function (in linear form) of the satisfied container volume ($f_w(\bar{\bar{\xi}})$) or not. Anyhow, it can also be solved easily through software packages for optimization problems. In this thesis, we adopt the optimization tool of Tomlab based on Matlab.

6. Numerical simulation

In this chapter, we will do numerical simulations to illustrate the application of our measurement model by taking the example of PoG in Sweden. To structure this chapter, we firstly present some

background information about PoG and its hinterland. This is done through three interviews with three managers from different players in the network. Then, scenarios settings for this case will be presented, followed by parameters setting of the measurement model in the third section. After running our Matlab codes, the simulation results will be derived. They are presented and analyzed in section 4. Finally, we will give a summary in section 5.

6.1 Port of Gothenburg and its hinterland

6.1.1 General information

PoG is located at the southeast of Sweden. With a 400-year history, it is now the largest port in Scandinavia, even the largest in Northern Europe. It has over 11,000 vessel calls per year from over 140 destinations around the world. Nearly 30% of Swedish foreign trades pass through this port. (Port of Gothenburg, 2014).

Focusing on container operation, the volume handled at PoG has steadily increased with small fluctuation over the years. In year 2013, 858,000 TEUs containers were handled, with 779,000 TUEs of them through APM terminal which is the only container terminal in PoG (Interview with APM terminal in PoG, 2014). Also, it is the only container port in the Nordic region with deep-sea direct calls to all parts of the world with the ability to handle the world's largest container vessels (Orbis database, 2014).

The hinterland of PoG covers the whole Sweden, and the Oslo area in Norway as well. Some 70 per cent of industry and the population in the Nordic Region can be found within a distance of 500 km (RAILPORT Scandinavia, 2014).This huge hinterland area provides PoG with relatively stable and abundant cargo sources to ensure its yearly turnover. Consistent with the volume of containers handled, the turnover of APM keeps increasing but fluctuates a little in the recent years. The turnover of year 2013 reached about 130 million USD (Orbis database, 2014). In terms of international trade, Sweden is a very balanced market between import and export (Interview with the authority of PoG, 2014). Given its superior geography advantage and natural condition which can provide service for world's biggest vessels to call, PoG has 59 per cent market share in container transportation across Sweden (Port of Gothenburg, 2013). Therefore, the container traffic in PoG is very balanced as well, with 48% import and 52% export (Interview with the authority of PoG, 2014). This very balanced traffic gives relatively high efficiency and low cost at the same time.

6.1.2 Freight transportation system

Generally, PoG has a comparatively good hinterland transportation system. 70% of Nordic industry and population can be found within a radius of six hours (RAILPORT Scandinavia, 2014). Moreover, the modal split of container traffic to and from PoG is also satisfactory and environmentally friendly, with 49% transported by rail and 51% by road. And, the share in rail transportation is still growing (Interview with APM terminal in PoG, 2014; Interview with the

authority of PoG, 2014). This owes to the rail shuttle system that runs between PoG and its hinterland terminals, or what they called the RAILPORT terminals.

RAILPORT terminals are the destinations of the rail shuttles that go from PoG in order to distribute the cargos to inland places of Sweden. They are usually owned by the local municipalities, but run by private terminal operators. Actually, these RAILPORT terminals play the roles of dry ports, acting as a consolidation and deconsolidation point for a certain area and providing intermodal transport operation.

For now, the rail shuttle system provides PoG with more than 70 trains every day and 24 daily rail shuttles which link the most interesting junctions in Scandinavia. Altogether it has 24 destinations in Sweden and one destination of Oslo in Norway. In year 2013, 393,000 TEUs containers were transported by rail in PoG (Port of Gothenburg, 2013). This rail shuttle system provides not only convenient, high efficient, but also very secure transportation service for containers. It is an attraction for the companies of inland Sweden (Interview with the authority of PoG, 2014). Besides, rail transportation is more environmentally friendly than road. According to the sustainability report of PoG (2013), 61000 tonnes of carbon dioxide are saved each year thanks to the port's rail shuttles, which equals to emissions from 21,000 cars per year.

Doing the simulation, we only model part of PoG's hinterland container transportation network based on the RAILPORT Scandinavia system due to simplification. The applicability of the measurement model won't be harmed, but just the complexity, however. Actually, there are together seven different rail operators supporting the RAILPORT Scandinavia system. Each of them is responsible for several destinations. Here we just consider the rail operator of Vänerexpressen AB and its corresponding seven destinations inside Sweden: Åmål, Karlstad, Insjön, Kristinehamn, Hällefors, Avesta, and Fagersta. Their geography location is shown in Figure 2.
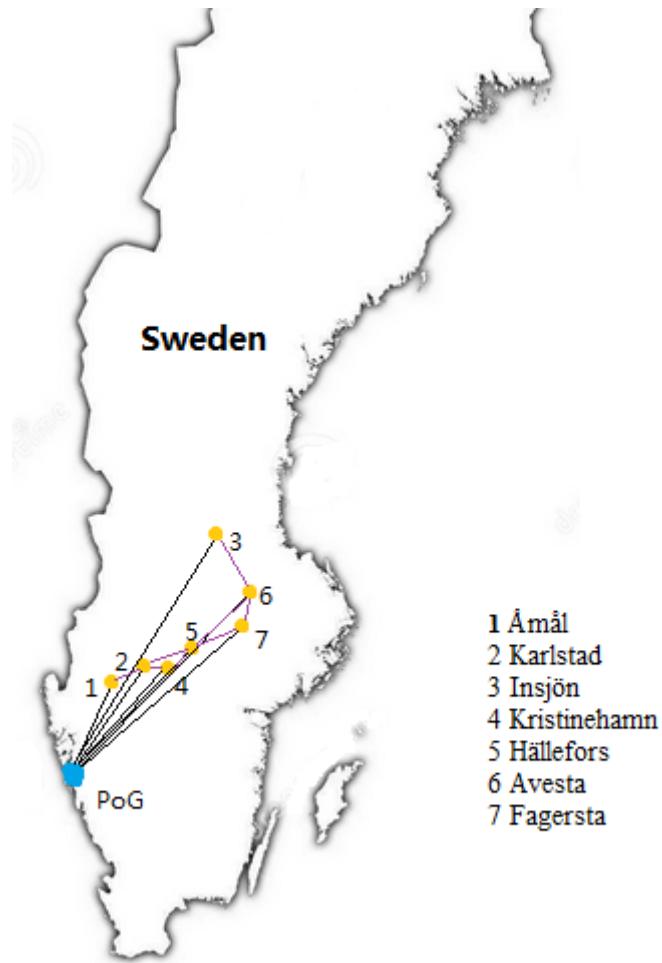
Figure 2 Part of RAILPORT Scandinavia network run by rail operator Vänerexpressen AB

6.2 Setting of scenarios

6.2.1 Potential UEEs

UEEs are usually unpredictable. Therefore, we investigate the performance of the network assuming that a certain UEE is about to happen. We look into three typical UEEs: terrorist attack, strike, and natural disasters. These three scenarios take perspectives from social security, social problem, and natural condition respectively. When discussing natural disasters such as earthquake, tsunami and heavy snow storm, we don't separate them one by one, but discuss them generally.

In terrorist attack scenario, potential terrorists may throw a boom at PoG or wherever in the hinterland. Since the seaport plays the most critical role in the network, the probability of it being attacked is the highest. Besides, the dry ports are also big targets for the terrorists, given many function modals concentrated there which have many people employed and containers handled and stored. As for the railway, they are with the least probability of being attacked comparing to the seaport and the dry ports. But still, they are also threatened. If the network is really attacked by terrorists, the negative impact will be severe. Because the booms threw by the terrorists often

launch fires, destroying facilities and causing casualties. In this case, the capacity of damaged dry ports and railway will decrease heavily.

Natural disasters have similar consequences with terrorist attack, where the damage is extremely sever and the capacity of the network decreases tremendously. However, the difference lies in the probabilities of network components being damaged. Terrorists usually choose the targets with judgments on the resulting impact from the attack. Natural disasters are purposeless. The probability of being damaged is decided by the distance to the center location and the intensity of the disaster. Here in our simulation, we assume the central area hit by the natural disasters is the very seaport—PoG. And the disaster is so destroyable that the capacity will decrease by a steep degree.

When it comes to strikes, it is usually related to the dockmen and the employees in railway sector. During strikes, all the operation at the seaport will be stopped, causing the backlog of containers. It is similar with railways that the capacity will be also reduced tremendously.

All the above characteristics of different UEE scenarios will be reflected in the approximated probabilities and degrees of the components in the network being damaged.

6.2.2 Possible immediate recovery activities

We discuss immediate recovery activities in hinterland and seaport separately, given the assumption that they are decided and taken by different players. In this simulation, we propose three possible recovery activities for shippers and two for the seaport players. We want to clarify ourselves that the recovery activities present here are as general forms, since very specific expressions like what is the exact additional cost if containers in one demanding area are going to be transported to seaport by road instead can only be determined under specific situation with explicit data, which are different from case to case and impossible to include them all in one simulation environment. Rather, what recovery activities we are discussing are more categories of possible actions in terms of costs and time. Therefore, the performance of these recovery activities are more estimated ones just to give a numerical illustration.

When studying the recovery activities at the seaport, we view them as a whole from a general perspective while unlike Nair et al. (2010) who discussed them in a very specific way of separating every port operations into nodes and links. In other words, we assume that all the equipment and transport infrastructures in the seaport are damaged but to different degrees according to the UEEs that happened. We propose two possible options of recovery activities in this simulation. One is to use redundant resources at the seaport. For example, the redundant capacity of gantry cranes and storages. However, this option requires the seaport players to be prepared before the happening of UEEs. Thus, the seaport will have to burden additional costs during normal situation. After all, redundancy and efficiency are usually a trade-off. The other option is to repair the damaged equipment and reconstruct the transport infrastructure for temporarily operation. This option takes longer time for implementation than the first. But it has the advantage of recovering more capacity.

The first recovery activities we propose in the hinterland for shippers is to use an adjacent alternative dry port for handling containers, and also the rail shuttle service. This is applicable only when the adjacent alternative dry port and the related railway are undamaged. Taking this recovery action, the recovered capacity of the damaged demanding area depends on the left capacity of the adjacent alternative one. Given the distance between them is relatively small compared to that to PoG, we assume the additional transportation cost of using an adjacent dry port and the rail shuttle as zero. The related implementation time is the waiting time. Because shippers in the damaged demanding area must wait until the alternative one has satisfied all the transport service demand of their own. Finally, the delivery time after implementing this recovery activity is inversely proportional to the smaller total capacity (realized plus recovered) of the dry port and the rail shuttle[3].

The second possible recovery activity in the hinterland is to transport containers to/from the seaport by road instead of rail shuttle. Taking this recovery activity, the capacity on the route can be increased by a huge amount, since all the nodes in the network are linked by roads. Besides, the road transport is the most adaptable mode to various unfavorable situations. Meanwhile, it is a "fast" solution. The delivery time post-activity is approximated according to Google Map. However, it has its own drawbacks as well. For example, it is more expensive than rail, especially for long distance transportation.

The third potential hinterland recovery activity for shippers is to wait until the damaged facilities are fixed, temporarily though. This option may take the longest time for implementation comparing to the first two. Because the facilities are often badly damaged due to the destroyable impact of UEEs. However, the recovered capacity and the delivery time can have a tremendous bounce back. As for the implementation cost, we also assume it as zero because shippers have to do nothing but wait.

Above are just some examples of the possible immediate recovery activities that can be taken once UEEs have happened. In reality, of course, there must be other optional actions depending on specific cases. One thing to notice is that in UEE scenarios of terrorist attack and natural disasters, these recovery activities are taken upon the finish of the events. For the strikes, however, it is during the event that recovery activities is already taken. Because the performance of the network will return to original level immediately as strikes stop, though there may be some backlog to be dealt with.

---

[3] This is a simplified calculation. In reality, for example, there exists an interval for railway's (or rail shuttle) capacity decreasing within which the recovered delivery time of containers remains the same. Because there's only a limit for the maximum number of containers being transported on one rail shuttle, but with no lower bound. It is the same with other two recovery activities in hinterland.

6.3 Setting of parameters' simulation values

6.3.1 Exogenous variables—transport demand and original capacity $(D_w, C_{w0}, l_{w0}, C_{seaport0})$

To set the exogenous variables of container transport service demand of each demanding area, the capacity of the dry ports and railway, the capacity of the seaport, etc., we have difficulty in finding the exact explicit data though we've tried to. Reasons include business secretes and the difference in railway operations such as the length of the shuttle and the width of the track. We only have the frequency of the rail shuttles that go between the seven destinations and PoG (RAILPORT Scandinavia, 2014). The maximum of a shuttle in Sweden is 640 meters, which can carry about 42 forty foots containers. In other words, counted by TEUs, the maximum capacity of one rail shuttle is 84 (=42*2). Assume that each rail shuttle goes between the seven destinations to PoG takes this maximum capacity. In this way, we have the data for the default route's (rail) capacity in the model. Since the dry ports are usually open terminals, providing intermodal service to all customers but not restricting to one rail operator, we set their capacity as twice that of the rail shuttles'. As for the container transport demand, we set it as 80% of rail shuttles' capacity, given the fact that all the demand can be met in normal condition. Finally, for the capacity of the seaport, we assume it as 1.2 times of the total container transportation demand from the seven destinations.

6.3.2 Exogenous variables—time aspect $(t_{wo}, t_{porto}, T_w^{max}, v_0)$

The original delivery time between the seven destinations and PoG in normal condition is also referred to RAILPORT Scandinavia (2014). The operation time at the seaport depends on its efficiency of handling containers. Given a certain volume of containers, it depends on the operation rate at the seaport. Mathematically, we use the container volume handled per hour to denote this rate. And this value can be estimated according to the information on APM Terminals (Gothenburg) (2015). It roughly has 90 TEUs handled per hour[4]. The maximum allowable time for transporting containers depends on commodity's type[5]. For simplicity, we assume all the containers in this simulation are of the same type. The maximum allowable time for transporting containers is set as times of the original transport time in normal condition. Actually, looking from another perspective, it can represent the efficiency of the transportation work—the longer the allowable transport time the more efficient of the network for transporting containers during normal condition.

---

[4] In 2013, the total volume of containers handled at APM terminal in PoG is 779,000 TUEs (Interview with APM terminal in PoG, 2014). The vessel operation at APM terminal in PoG opens 7 days a week and 24 hours a day. Assume that APM terminal opened 360 days through the year 2013, we can therefore derive an estimation of operation rate as 779000/(24*360) (TEUs/hour)≈90 (TEUs/hour).

[5] As we have stated in last chapter, this maximum allowable time may also depend on other issues, business contracts for example. However, simulation is done as an example. So here we just consider the commodity's type.

6.3.3 Other exogenous variables (AM, p)

The adjacent matrix AM is set based on the geography locations of the seven destinations. As for the merchandise value for one container (TEU), in reality, it varies from one to another. Doing the simulation, however, we set an identical value for all the containers. It is approximated from dividing the import and export merchandise value transported by containers by the volume of containers handled at seaports. In 2013, total merchandise value transported by containers in Sweden is 125383 million USD (United Nations, 2013), while the total container volume handled at the seaports is 1430000 TEUs (Port of Gothenburg, 2013). Therefore, p=125383 million USD/1430000 TEU=87700 USD/TEU.

6.3.4 Random variables—parameters indicating consequences in different scenarios ($\delta_{cw}, \delta_{lw}, \delta_{seaport}, C_w, l_w, C_{seaport}, \tau_w, \tau_{port}$)

Following Table 2 summarizes the probability and consequences in capacity and time aspect under each scenario. When some UEEs happen, however, the post-event delivery time of the rail shuttles and operation time at the seaport depend on how much the capacity decreases in hinterland and at the seaport respectively. We set them as the reciprocals of the percentage that capacity decreased.

Table 2 Parameters relating UEE consequences under each scenario

Parameters	Components	1 Terrorist Attack	2 Natural disasters	3 Strike
Probability of being damaged ($\delta_{cw}, \delta_{lw}, \delta_{seaport}$)	Seaport	50%	100%	80%
	Dry port	30%	50%~100% (according to the distance to the seaport)	10%
	Route	10%	100%	60%
Capacity decreased[6] (related to $C_w, l_w, C_{seaport}$)	Seaport	70%	80%	90%
	Dry port	70%	80%	80%
	Route	70%	80%	80%
Time increased[7] (related to τ_w, τ_{port})	Seaport	233%	400%	900%
	Hinterland	233%	400%	400%

6.3.5 Random variables—parameters of recovery activities ($\Delta C_{wk}, \Delta l_{wk}, \Delta C_{seaport\_j}, t_{wk}, t_{port\_j}, Q^R_{wk}, Q^R_{port\_j}, b_{wk}, b_{seaport\_j}$)

According to the descriptions of recovery activities in hinterland for shippers in subsection 6.2.2,

---

[6] The numbers in the related cells are percentages of original capacities.
[7] The numbers in the related cells are percentages of original time.

we use the following Table 3 to present the summary of related parameters. Some of them are approximated by simple calculations based on real-world data, while the others are just numerical illustrations—when they are complex and unattainable to be represented by a single exact real-world data. We denote recovery activities 1 to 3 as using an adjacent dry port and rail shuttle, transporting by road instead, and waiting for the temporal repair, respectively.

Table 3 Parameters regarding three recovery activities in the hinterland for shippers

Recovery activity (k)	Recovered capacity of damaged facilities (related to $\Delta C_{wk}, \Delta l_{wk}$)		Recovered delivery time (t_{wk})	Implementing the recovery activities (Q_{wk}^R, b_{wk})	
	Dry port	route		time[8]	cost
1	Eq (14)	Eq (15)	Eq(16)	50%	0
2	100%[9] of original level	100% of original level	Real-world data[10]	20%	Eq(17)
3	80% of original level	80% of original level	Eq(16)	100%	0

Where,

$$\Delta C_{w1}(\bar{\bar{\xi}}) = \sum_{z=1,z\neq w}^{W} \beta_{wz} * \left(1 - \varepsilon\left(\delta_{cz}(\bar{\xi}) + \delta_{lz}(\bar{\xi}) - 1\right)\right) * min\{(l_z - D_z), (C_z - D_z)\}, \forall w \in W$$

(14)

$$\Delta l_{w1}(\bar{\bar{\xi}}) = \Delta C_{w1}(\bar{\bar{\xi}}) \quad (15)$$

$$t_{wk}(\bar{\bar{\xi}}) = t_{wo} * max\left\{C_{wo}/\left(C_w(\bar{\xi}) + \Delta C_{wk}(\bar{\xi})\right), l_{wo}/\left(l_w(\bar{\xi}) + \Delta l_{wk}(\bar{\xi})\right)\right\}, k = 1,3, \forall w \in W (16)$$

$$b_{w2}(\bar{\bar{\xi}}) = (c_{road} - c_{rail})^{11} * \left(f_w(\bar{\xi}) - min\left(C_w(\bar{\xi}), l_w(\bar{\xi})\right)\right) (17)$$

Table 4 summarizes the parameters related to recovery activities at the seaport. Recovery activity 1 denotes using redundant resources at the seaport, while recovery activity 2 represents taking temporary repairing. Similarly, given the inaccessibility of the exact data, some simulation values of these parameters are estimated ones just for numerical illustration. The cost limit for recovery activities is calculated according to Eq (4).

---

[8] This parameter is hard to measure. Therefore, we use the percentages of the average original delivery time of all demanding areas just to indicate the order of the three recovery activities while make the value as reasonable as possible at the same time.
[9] Though transporting by road instead can't really increase the dry port capacity at all, its effect is actually equal. In Scenario 2, we set it as return to 80% of original level, however, due to the destroyable effect of natural disasters on road system as well.
[10] It comes from Google Map
[11] The calculation formulas and related data refers to Ye and Shen. (2014).

Table 4 Parameters regarding the two recovery activities at the seaport

Recovery activity (j)	Recovered capacity of damaged facilities (related to $\Delta C_{seaport\_j}$)	Recovered operation time (t_{port_j})	Recovery activity implementation ($Q^R_{port\_j}$, $b_{seaport\_j}$)	
			time[12]	cost[13]
1	60% of original level	167% of original level	50%	310000 \$
2	80% of original level	125% of original level	150%	696980 \$

6.4 Results and analysis

In this section, results from numerical simulations of our measurement model by using PoG case are presented. Firstly, we give our simulation results of the three scenarios which use base simulation values. Sensitivity analysis will then be done on these results. Finally, influences of some network's attributes on the resilience level, such as the efficiency and redundancy, will be investigated.

The base simulation values of exogenous variables are given in the Appendix B, along with their justification and data sources. Once UEE scenarios are realized, simulation values of the random variables are decided accordingly based on sub sections 6.3.4 and 6.3.5 where we've already presented the rationality of assignment.

6.4.1 Benchmark results

The PoG network's resilience level in three scenarios are 86%, 72%, and 77.7% respectively. These values indicate the level of container transportation service maintained in PoG's PHCTN in face of UEEs. Though we do 10000 iterates in Monte Carlo Simulation for each scenario, these three resilience values all come out from the expected value of only two possible resilience levels—72% and 100%—depending on the probabilities of different outcomes to the network in each scenario.

Analyzing every parameters in different iterates, we find that the hinterland part of this PoG's PHCTN can always satisfy the container transport demand whatever the damages caused. Therefore, to what level this network can preserve its performance post-event depends totally on whether the seaport is damaged or not—the resilience level is 72% if it is; otherwise, this network is unaffected by UEEs, indicating a 100% resilience level.

The reason for this interesting phenomenon lies in that the recovery activity 2 in the hinterland—using road transport instead—dominants the other two options, while with a strong recovery capability. In other words, all the decreased capacity in damaged dry ports and railways

---

[12] This parameter is hard to measure. Therefore, we use the percentages of the original operation time just to indicate the order of the two recovery activities while make the value as reasonable as possible at the same time.
[13] The data are taken from Nair et al. (2010). Though it is a rough estimation, it won't affect the result very much. Nevertheless, the cost of doing nothing is enormous.

can be compensated by using trucks. This dominant advantage comes from three aspects—fast implementation, relatively low additional cost, and tremendous recovered capacity.

In this PoG case, the range of the whole network is not that large. The distances between the seven demanding areas and the seaport are all relatively short. Thus, the traditional advantages of transporting by rail, such as being cheaper and faster, become unobvious comparing to road transportation in this circumstance. Based on the data we have, in fact, transporting by road in this PoG case is even faster than by rail shuttles, even when we have included in the average waiting time of half hour at the seaport. Besides, as for implementation time, we assume that finding a truck company temporarily takes the least time comparing to the other two recovery activities in setting the base values for this simulation. Finally, the road network in this case is much well developed. It's able to provide enough capacity for the transport demand. It works well even in Scenario 2 (natural disasters), though we assume its capacity has decreased to 80% of original level. Therefore, as long as the seaport is undamaged and can ensure enough capacity for handling containers, shippers will be able to transport all their demanded containers without tremendous economic loss in face of UEEs, regardless of the damages in dry ports and railways, indicating a resilience level of perfectly 100%. Otherwise, it will decrease to 72%, limited by the shortage of capacity due to the damages caused by UEEs to the seaport.

6.4.2 Sensitivity analysis

Based on the above analysis on the benchmark results, we now do sensitivity analyses on some parameters in order to see how the dominant advantage of recovery activity 2 in the hinterland (using road transport instead) influences the resilience level of PoG's PHCTN. Since it is a given network, the transportation time by rail and road and the costs should be seen as exogenous parameters and as constants. Therefore, we only do sensitivity analysis on two aspects, out of the three, of recovery activity 2's dominant advantage—fast implementation and tremendous recovered capacity.

Firstly, the implementation time of recovery activity 2 actually refers to how long it will take shippers to find enough trucks to transport their containers immediately after the UEEs. It can reflect the adaptability of the network, partially, in providing different transport modes service from time aspect. In benchmark simulation, we assume it as 20% of the average original time for delivering containers in hinterland, plus operating at the seaport of shippers from seven demanding areas. It is the shortest implementation time among the three recovery activities. As it increases to a certain level, however, the resilience level will decrease dramatically in all the three scenarios as shown in Figure 3. This is consistent with the intuition that as the time aspect of road transport's advantage diminishes, the other two recovery activities take over. Given their relatively weaknesses in recovered capacity and implementation time, the resilience level is thus expected to decrease.
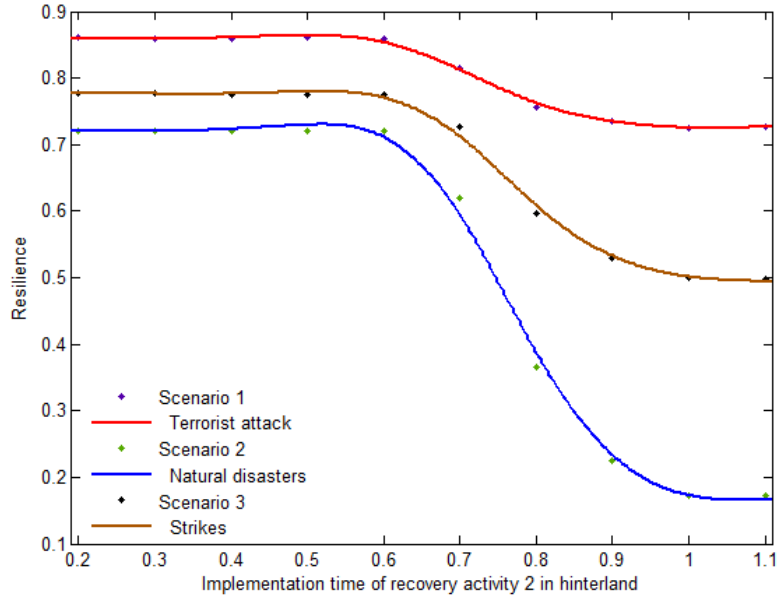
Figure 3 Sensitivity analysis of the impact that implementation time of recovery activity 2 in hinterland (Q_{w2}^{R}) has on network's resilience level

Secondly, we also assume that the road system can provide efficient recovered capacity. This is reasonable in Scenario 1 (terrorist attack). In Scenario 2, however, the road system can be severely damaged by natural disasters like earthquakes and floods. Though we've already assign it as 80% of that the road system can provide in normal condition, it can still be much lower in reality if UEEs are destroyable. We thus expect an obvious decreasing in resilience level if this fact is considered. See Figure 4 for the simulation results on the degree of the damages on road system and the related resilience level in Scenario 2. The horizon axis represents how much the recovered capacity can be provided by road system comparing to that in normal situation. Actually, the capacity provided decreased due to damages is not the only reason for the diminishing of road system's dominant advantage. Time constraints and cost concerns also do matter, accordingly. The more the road system is damaged, the harder for finding truck companies; the more expensive for using trucks instead; and therefore, the more likely shippers will have to wait for temporary reconstruction (recovery activity 3). In this case, however, the total transport time might exceed the maximum allowable time. Thus, the resilience level decreases. Though we didn't reflect the influence of these two aspects in the simulation values of related parameters but just the recovered capacity provided by road system (otherwise we expect a steeper decrease in resilience level), we must be aware of them. As for using an adjacent dry port, it is totally out of shippers' concern in Scenario 2. Because under natural disaster events, there's a high probability that all the possible adjacent dry ports and the related railways are damaged as well. It means no capacity will be left for helping shippers from other demanding areas.
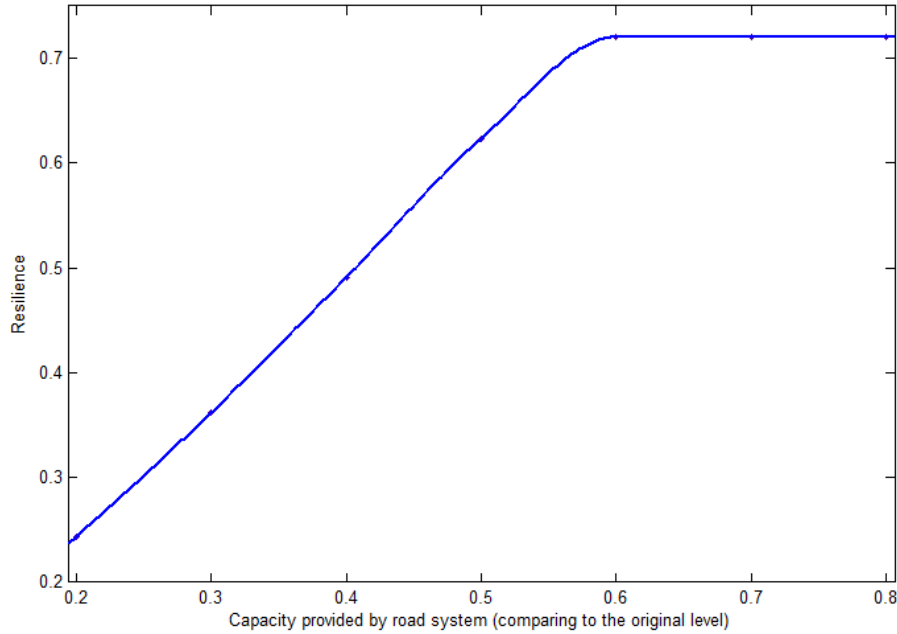
Figure 4 Sensitivity analysis of the impact that road system's advantage in providing recovered capacity has on network's resilience level in Scenario 2

Besides, in Scenario 3, we also assumed that the road system can provide enough recovered capacity. This is reasonable only in the circumstance that we don't consider the possibility of strikes going on in road system. But we can imagine that there will also be an obvious decrease in resilience level if it is considered, just similar to that in Scenario 2 shown in Figure 4. As for hinterland recovery activities in Scenario 3, using road system instead still has the dominant advantage. Though using an adjacent dry port (recovery activity 1) might work in this scenario, it doesn't have the advantages of fast implementation and tremendous recovered capacity as the way of using road system does. Neither do recovery activity 3—waiting for temporary reconstruction, which is, actually, the last choice for shippers to consider. The reason is very straightforward. The recovery activities in the context of strikes should be taken during the event, not after the event like in the first two scenarios. Because the performance of the network will return to its original level as soon as the strike stops, though there may be some backlog to be dealt with. In this case, the third recovery activity of waiting for temporary reconstruction can actually refer to the negotiation between the labor union and the employers. By common sense, it usually takes a very long time. Considering the time constraint, shippers cannot afford to wait.

6.4.3 Further discussion

Looking from shipper's perspective, some attributes of a given network which out of their control may actually have impacts on the resilience level. Here we discuss two such attributes—the efficiency and redundancy of the network. In fact, the efficiency can be reflected by the time constraint in our model, or, the maximum allowable transport time (T_w^{max}). Doing the numerical simulation, we assign the maximum allowable transport time (including time both in hinterland and at the seaport) as times of that in normal condition. The value is 1.5 in our benchmark simulation. Obviously, this ratio must be a positive number that is equal to or larger than one. The

larger it is, the more efficient the network is. The redundancy, on the other hand, refers to how much additional capacity can be provided by the network besides that in meeting all the demand. It can be represented by the parameters related to capacities, such as capacity at the dry ports, on the railway, and at the seaport. Since whether the seaport is damaged or not makes a big difference to the network's resilience level, here we only look at the redundancy at the seaport, indicating by the parameter $C_{seaport0}$. Usually, efficiency and redundancy is a trade-off issue for suppliers considering the ratio of profits to costs when building resilience (Christopher & Peck, 2004). From the perspective of the network's user, meaning shippers, however, they are not a contradiction at all. Because the more efficient and redundant the network is, the more spare time and capacity shippers will have in transporting their containers. Therefore, there's a bigger possibility that the performance level is not affected by the damages to the network caused by UEEs. See Figure 5 for the illustration from simulation.
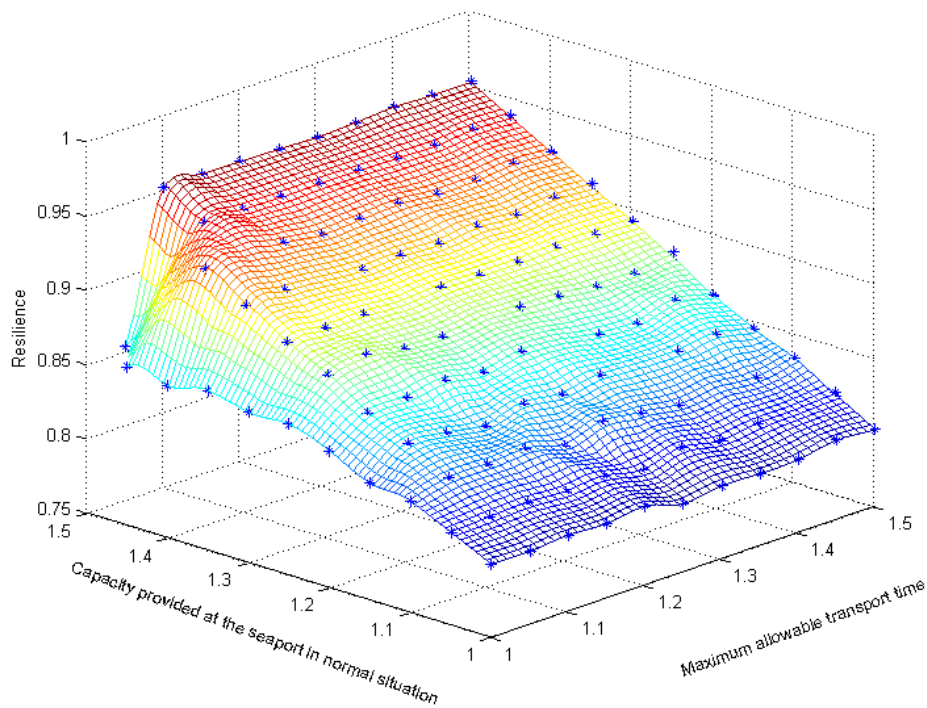
Figure 5 Joint influence of maximum allowable transport time (efficiency) and seaport capacity (redundancy) on network's resilience level in Scenario 1

We see clearly from Figure 5 that the capacity which can be provided by the seaport influences the network's resilience a lot given a fixed maximum allowable transport time. But it is not the same story vice versa, except in the interval where maximum allowable transport time is relatively small (almost equal to the required transport time in normal situation). In other words, it seems that the redundancy of the network has a much more obvious impact on resilience level than the efficiency. Actually, again, this phenomenon owns to the dominant advantage of the recovery activity 2 in hinterland (using road transport instead). As we have analyzed on the benchmark result, using road transport after UEEs ensures shippers in transporting all their containers regardless of the damages caused in the hinterland. Therefore, we expect that as this dominant advantage of road transport diminishes, the maximum allowable transport time (efficiency) will have a more obvious impact

on network's resilience level. Here we diminish road transport advantage from implementation time aspect. See Figure 6 to find the simulation result. Clearly, the resilience level reaches the highest of nearly 86% at the top right corner (point A) where the network is very efficient with dominant recovery activity 2. It decreases to 72.25% (point C) if recovery activity 2's advantage fades away. Furthermore, the resilience level continues to drop down until 50.1% (point B) as the network becomes not so efficient, neither.
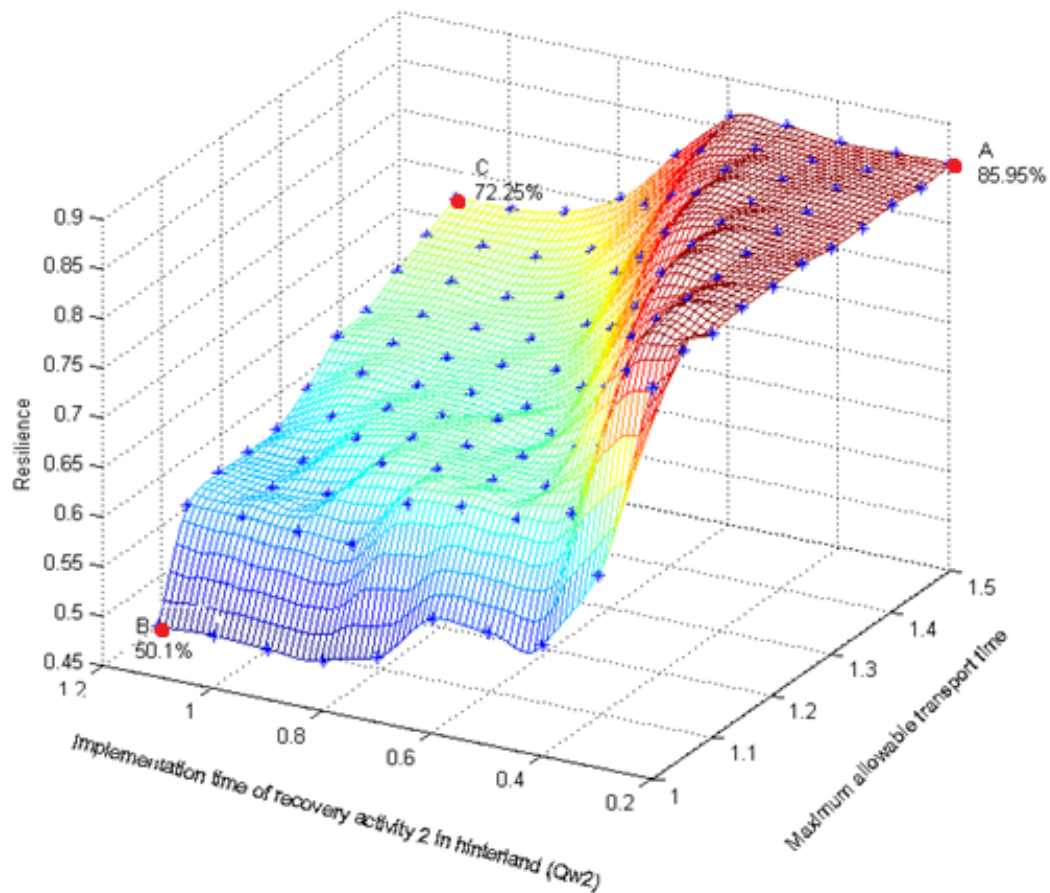
Figure 6 Joint influence of network's efficiency (T_w^{max}) and implementation time of recovery activity 2 in hinterland (Q_{w2}^R) on its resilience level in Scenario 1

6.5 Chapter summary

In this chapter, we use numerical simulations to illustrate the feasibility of our measurement model in quantifying the resilience level of a PHCTN. We carry it out in the case of PoG. Three UEEs scenarios in PoG case are proposed and analyzed—terrorist attack, natural disasters and strikes. We consider three possible recovery activities in hinterland for shippers and two for seaport players at the seaport.

The results show that the resilience level of PoG's PHCTN is relatively high, even the lowest one in natural disasters (Scenario 2) reaches 72%. This is owing to the dominant advantage of recovery activity 2 in the hinterland for shippers that using road transport instead. This dominant advantage, however, has something to do with the characteristics of this unique network in PoG

case. Because the small range of this network provides the possibilities of fast transportation and implementation time while with acceptable additional cost when using road system. However, we should be aware that, in this measurement model, the capacity of the seaport we consider is only for handling containers, not including that of transportation infrastructure. If all the shippers use road transportation instead to deliver their containers, the seaport might probably face a serious congestion. In that extremely case, the road's dominant advantage may not exist. When the other two options (recovery activities 1 and 3) in hinterland becoming more preferable for shippers, the network's resilience level will decrease due to their longer implementation time and less recovered capacity.

Anyway, the benchmark results from the numerical simulation verifies the opinion from Mr. Stig-Göran Thorén, the senior manager of Business Development in the Authority of PoG, in that the container transportation system between PoG and its hinterland is safe and efficient. Because using a nearby RAILPORT terminal or transporting by trucks can always be the final solutions when there's a breakdown in RAILPORT system, given the relatively short distances among those RAILPORT terminals and between PoG (Interview with the authority of PoG, 2014).

We have to notice readers that, in reality, there must be other optional choices for shippers and seaport players to take for immediate recovery beside the ones we proposed in the simulation. Even, the possible UEE scenarios are different from case to case. And the analyses on these recovery activities reflect the adaptability of this network. Besides, the other dimension of resilience concept—inherent resilience—is also investigated. We picked up two factors that influence inherent resilience, and they are efficiency and redundancy, indicated by maximum allowable transport time (T_w^{max}) and the capacity provided by the seaport ($C_{seaport0}$), respectively. The sensitivity analyses' results shown that both the adaptive resilience and inherent resilience have an impact on the PoG's PHCTN.

In sum, the aim of doing the simulation is not to test our proposed measurement model in all possible circumstances, but to show whether and how it can work in quantifying a PHCTN resilience theoretically and practically. Through the numerical simulation with three scenarios and the analysis on benchmark results, we've successfully shown that our proposed measurement model for resilience concept in the context of a PHCTN works well. It can reflect the characteristics of resilience concept such as adaptability and also its inherent dimension. Moreover, it is not restricted to the case of PoG we've taken for the simulation, but can be applied to any other PHCTN. When actually applying it to different networks, one should consider the specific situation. For example, what possible UEEs it may face? What recovery activities can be taken? What are the relevant constraints and outcomes of these recovery activities? Only by concrete analysis of specific situations can the resilience level be measured as accurately as possible.

7. Conclusion

In this thesis, we build a measurement model to quantify the resilience level of a given PHCTN from shippers' perspective. To make the model theoretically meaningful, we firstly studied the

resilience concept thoroughly from its origin to the development nowadays. Besides, a typical PHCTN model is proposed in order to characterize the special context where we investigate the resilience concept. In this PHCTN model, we view the network as having already developed to an advanced stage where the transportation service provided is efficient and environmentally friendly with the help of well functioned dry ports and intermodal transportation system (mainly rail-road in this thesis, and the measurement model targets on the part of rail transportation). Based on the summarized characteristics of general resilience concept and the special context of PHCTN, we then proposed our definition of contextual resilience concept. It provides a fundamental theoretical basis for the measurement model we build. Finally, the feasibility of this measurement model is illustrated by a numerical simulation taking the case of PoG's PHCTN where part of its hinterland is modeled.

Studying the general resilience concept thoroughly, we find that, as presented in Introduction, one of its distinctive characteristics lies in the capability of making systems persist its performance level or even helping them move toward to a more desired outcome. It differentiates the resilience concept from other similar and confusing ones such as stability and robustness, which emphasize on just maintaining the original state or equilibrium of the system.

Applied in the transportation researching field, however, this fantastic characteristic needs modification. The performance of a transportation network has already achieved its highest level in normal situation due to satisfied fill rate and transport time. However, consequences of UEEs must undermine it more or less if happened. Therefore, the resilience concept in transportation context only measures the ability of systems in persisting the original performance level, but not possible anymore to reach a more satisfying state. The performance level is represented by the ratio of total satisfied container flow over the total container transport demand, and that is why we use it as the measurement of resilience level in our measurement model. Nevertheless, as adaptability being one of the properties and studying the "changes" which come from external UEEs, resilience concept still makes itself different from confusing counterparts like reliability and flexibility in transportation researches.

To measure the ratio of total satisfied container flow over the total container transport demand is actually to derive the maximum total satisfied container flow of a PHCTN facing UEEs, given the assumption that the demand is exogenous and constant. We adopt the method of stochastic integer programming but using two sequential sub models. Firstly, the seaport players decide on the service level at the seaport with the aim to provide operation as soon as possible. Seeing this, shippers in every demanding area then take proper actions independently to transport their containers to/from the seaport in order to minimize their economic loss due to UEEs. We simultaneously considered the constraints faced by shippers from time and capacity aspects.

Results from the numerical simulation in PoG case testifies the feasibility of this measurement model. The resilience level in this case is found to be comparatively high. Even the lowest one in the natural disasters situation (Scenario 2) still reaches 72%. This owns to the unique characteristics of this PoG case in that the range of the network is relatively small and its road system is well developed and efficient. In this way, the traditional advantages of intermodal

transport, mainly cheaper and faster, cannot be demonstrated very much. But the road system can always ensure all the transport service demand in hinterland whatever the damages caused by UEEs. This finding is in accordance with the opinions from practical world when the players give their reasons why they think the container transportation system in PoG and its hinterland is safe and sound (Interview with APM terminal in PoG, 2014; Interview with the authority of PoG, 2014; Interview with the municipality of Falköping, 2014). It also explains why these players don't bother to prepare themselves with UEEs, besides the reason of very low probability for its occurrence.

To have a further discussion through sensitivity analysis, however, we've shown that this dominant advantage of using road transport isn't robust on the network's resilience level. As it diminishes to a certain degree, the resilience level of PoG's PHCTN decreases dramatically. Moreover, we also find that both the efficiency and redundancy of the network are welcomed by shippers through the analysis of their joint influence on the resilience level. Usually, they are a trade-off for transport service suppliers, however, considering the ratio of profit paid off to cost of investments. Actually, the recovery activities and the attributes of the network in efficiency and redundancy represent the adaptability and inherent dimension of resilience concept, respectively. The results from sensitivity analyses demonstrate both their influences on PHCTN resilience, verifying the theory proposed by Rose (2006).

When it comes to validity and reliability issues, we are confident to declare this thesis satisfactory in both levels. Generally speaking, validity concerns with the integrity of the conclusion from a research (Bryman & Bell, 2011, pp. 42), while reliability refers to the repeatability of a study. That is, if a study can be repeated by other researches and get the same result, then it has high reliability (Bryman & Bell, 2011, pp. 41).

We claim the result as having high validity lies in that our measurement model has a strong theoretical basis. We did thoroughly literature reviews on general resilience concept and the theories on port-hinterland transportation development. Therefore, the measurement model captures the characteristics of resilience concept in the context of a PHCTN very well. In addition, we use stochastic programming to build our model in which the time and capacity constraints are both considered simultaneously, reflecting its practical meanings. Moreover, we did a numerical simulation by using the case of PoG and part of its hinterland in the end with its results analyzed. The discussion on the results indicate our measurement model functioning well. Not only the impact of PoG network's unique characteristics on its resilience level is reflected, but also those of some general attributes commonly existing on any other PHCTNs. In addition, the findings from numerical simulation verify both the opinions from practical world and the theory of previous literatures. In this way, it is proper to say that this study has a satisfactory internal validity.

As for the reliability, we are also confident. Before actually running the measurement model in numerical simulation of PoG case, we justified the way of assigning the simulation values to all the parameters. Following our logic and checking the data sources we provided, any other researchers can repeat the simulation on their own computers and will surely get the same results. Besides, this measurement model is not restricted to this special case of PoG, but can be

generalized to other PHCTNs as long as they can be represented by the typical model we've proposed for port-hinterland container transportation. In this sense, we can claim that our measurement model also possesses high reliability.

The contribution of this thesis is two-folds. Firstly, among the various researches applying resilience concept in transportation field, works relating quantitative measurement are few. Miller-Hooks is one of the outstanding scholars in this topic. She and her co-authors have contributed a lot to quantitative measurement issue in freight transportation network and intermodal transportation network, specifically. Though the PHCTN belongs to intermodal transportation network, it has its own characteristics differentiating itself from the general forms where the seaport has a pivotal role to play in the network. This thesis just fills this gap by applying the resilience concept in this special context and then measuring it quantitatively.

Secondly, we propose a new angle in measuring resilience concept. We take the perspective from the user of the network—shippers—but not the suppliers, nor do the social welfare perspective. Usually, there are multiple suppliers in a PHCTN, such as local municipalities, rail operators, dry port terminal operators, etc. In this sense, aiming at maximizing their own profits, issues like 'free riders', coming from the Boxed Pig Game (Baldwin & Meese, 1979), may become a concern when implementing recovery activities if we take the perspective from these suppliers. It has the same problem taking the social welfare perspective. Because it will make things every vague when talking about who should burden the cost of recovery activities and who sets the budget constraint. Even, these costs are hard to measure and approximate without a clearly bearer. Therefore, the measured resilience level might be less accurate. However, taking shippers' perspective, who are the users of the network, we can avoid this complex issue. Because in this way, every parameter in aspects of cost, time, and capacity, now has a very clear real-world meaning and the responsible bearer. Thus, the resilience level of a network can be measured more precisely. After all, our goal doesn't aim at building nor neither improving the resilience level but just measuring.

In this thesis, we discussed the situation where there's only one seaport in the network. It will be interesting and worthwhile to expand this model into a network where there are two or more seaports inside it. Because in reality, seaports compete on their common hinterland is very usual. Measuring the resilience level of the whole network in this case thus becoming more difficult but will make more practical sense. Besides, the resilience level of the subnetwork belonging to each seaport may make up of one aspect of their competitiveness, which makes the topic even more interesting and meaningful. Following the work of measurement, the next stage is to study how to improve the resilience level of a given PHCTN. Therefore, the coordination issue on balancing the competition and cooperation among the various players in the network becomes extremely important. Problems like "free-riders" must be treated properly. Besides, the cost-profit trade-off, involving risk evaluation and profit estimation, also matters a lot in building and improving the resilience level of a network. All these questions are what we want to continue studying based on the work of this thesis.

Reference

APM Terminals (Gothenburg). (2015). Operation Hours. Available at < http://www.apmterminals.com/operations/europe/gothenburg/information/operation-hours> [Accessed 2015-03-17]

Baldwin, B. A., & Meese, G. B. (1979). Social behaviour in pigs studied by means of operant conditioning. Animal Behaviour, 27, 947-957.

Bärthel, F., & Woxenius, J. (2004). Developing intermodal transport for small flows over short distances. *Transportation Planning and Technology*, *27*(5), 403-424.

Bergqvist, R., & Woxenius, J. (2011). The Development of Hinterland Transport by rail: the story of scandinavia and the Port of Gothenburg. *Journal of Interdisciplinary Economics*, *23*(2), 161-177.

Bird, J. H. (1971). *Seaports and seaport terminals* (Vol. 158). Hutchinson.

Bontekoning, Y., & Priemus, H. (2004). Breakthrough innovations in intermodal freight transport. *Transportation Planning and Technology*, *27*(5), 335-345.

Bontekoning, Y. M., Macharis, C., & Trip, J. J. (2004). Is a new applied transportation research field emerging?—A review of intermodal rail–truck freight transport literature. *Transportation Research Part A: Policy and Practice*, *38*(1), 1-34.

Bryman, A., & Bell, E. (2007). *Business research methods*. Second Edition. Oxford University Press, c2007.

Bryman, A., & Bell, E. (2011). *Business research methods*. Third Edition. Oxford university press.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: resilience of what to what?. *Ecosystems*, *4*(8), 765-781.

Carvalho, H., & Cruz-Machado, V. (2009). Integrating lean, agile, resilience and green paradigms in supply chain management (LARG_SCM). *Supply Chain Management*, 27-48.

Carvalho, H., Barroso, A. P., Machado, V. H., Azevedo, S., & Cruz-Machado, V. (2012). Supply chain redesign for resilience using simulation. *Computers & Industrial Engineering*, *62*(1), 329-341.

Chen, A., & Kasikitwiwat, P. (2011). Modeling capacity flexibility of transportation networks. *Transportation Research Part A: Policy and Practice*, *45*(2), 105-117.

Chen, A., Yang, H., Lo, H. K., & Tang, W. H. (1999). A capacity related reliability for transportation networks. *Journal of Advanced Transportation*, *33*(2), 183-200.

Chen, C., Skabardonis, A., & Varaiya, P. (2003). Travel-time reliability as a measure of service. *Transportation Research Record: Journal of the Transportation Research Board*, *1855*(1), 74-79.

Chen, L., & Miller-Hooks, E. (2012). Resilience: an indicator of recovery capability in intermodal freight transport. *Transportation Science*, *46*(1), 109-123.

China News. (2013). *A long-term strike goes on in railway ministry of Korean.* Available at < http://news.china.com.cn/world/2013-12/14/content_30893856.htm > [Accessed 22-02-2015]

Christopher, M., & Peck, H. (2004). Building the resilient supply chain. *International Journal of Logistics Management, The*, *15*(2), 1-14.

Christopher, M., & Rutherford, C. (2004). Creating supply chain resilience through agile six sigma. *Critical Eye*, *24*, 28.

Christopher, M. (2004). Creating resilient supply chains. *Logistics Europe*, *11*.

Colicchia, C., Dallari, F., & Melacini, M. (2010). Increasing supply chain resilience in a global sourcing context. *Production planning & control*, *21*(7), 680-694.

Collis, J., & Hussey, R. (2009). *Business research. A practical guide for undergraduate and postgraduate student.* Third Edition. Pan Macmillan.

Cullinane, K., Bergqvist, R., & Wilmsmeier, G. (2012). The dry port concept–Theory and practice. *Maritime Economics & Logistics*, *14*(1), 1-13.

Cullinane, K., Fei, W. T., & Cullinane, S. (2004). Container terminal development in Mainland China and its impact on the competitiveness of the port of Hong Kong. Transport Reviews, 24(1), 33-56.

Cullinane, K., Teng, Y., & Wang, T. F. (2005). Port competition between Shanghai and Ningbo. Maritime Policy & Management, 32(4), 331-346.

Cullinane, K., Wang, T. F., Song, D. W., & Ji, P. (2006). The technical efficiency of container ports: comparing data envelopment analysis and stochastic frontier analysis. *Transportation Research Part A: Policy and Practice*, *40*(4), 354-374.

Dewitt, W., & Clinger, J. (2000). Intermodal freight transportation. *Transportation in the New Millennium*.

Falasca, M., Zobel, C. W., & Cook, D. (2008, May). A decision support framework to assess supply chain resilience. In *Proceedings of the 5th International ISCRAM Conference* (pp. 596-605).

Faturechi, R., & Miller-Hooks, E. (2014). Travel time resilience of roadway networks under disaster. *Transportation research part B: methodological*, *70*, 47-64.

Faturechi, R., & Miller-Hooks, E. (2014). Travel time resilience of roadway networks under disaster. *Transportation research part B: methodological*, *70*, 47-64.

Feitelson, E., & Salomon, I. (2000). The implications of differential network flexibility for spatial structures. *Transportation Research Part A: Policy and Practice*, *34*(6), 459-479.

Flämig, H., & Hesse, M. (2011). Placing dryports. Port regionalization as a planning challenge–The case of Hamburg, Germany, and the Süderelbe.*Research in Transportation Economics*, *33*(1), 42-50.

Freckleton, D., Heaslip, K., Louisell, W., & Collura, J. (2012, January). Evaluation of transportation network resiliency with consideration for disaster magnitude. In *91st annual meeting of the transportation research board, Washington, DC*.

Gassenheimer, J. B., Sterling, J. U., & Robicheaux, R. A. (1989). Long-term channel member relationships. *International Journal of Physical Distribution & Materials Management*, *19*(12), 15-28.

Giordano, F., Fox, W. P., & Horton, S. (2013). *A first course in mathematical modeling*. Cengage Learning.

Hanaoka, S., & Regmi, M. B. (2011). Promoting intermodal freight transport through the development of dry ports in Asia: An environmental perspective.*IATSS Research*, *35*(1), 16-23.

Harrington, T. C., Lambert, D. M., & Christopher, M. (1991). A methodology for measuring vendor performance. *Journal of Business Logistics*, *12*(1), 83-104.

Henttu, V., & Hilmola, O. P. (2011). Financial and environmental impacts of hypothetical Finnish dry port structure. *Research in Transportation Economics*, *33*(1), 35-41.

Heydecker, B. G., Lam, W. H., & Zhang, N. (2007). Use of travel demand satisfaction to assess road network reliability. *Transportmetrica*, *3*(2), 139-171.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, 1-23.

Intermodal Surface Transportation Efficiency Act (ISTEA). (1991). Available

at: http://ntl.bts.gov/DOCS/istea.html [Accessed 08 February 2015]

Ip, W. H., & Wang, Q. (2011). Resilience and friability of transportation networks: evaluation, analysis and optimization. *Systems Journal, IEEE*, *5*(2), 189-198.

ISSC. (2014). *A wave of strikes springs the ports all over the world.* Available at http://www.issconline.com/lanmu/xinwenzhongxin/hangyunshichang/2014-12-01/35254.html [Accessed 22-02-2015]

Janic, M. (2007). Modelling the full costs of an intermodal and road freight transport network. *Transportation Research Part D: Transport and Environment*, *12*(1), 33-44.

Janic, M. (2008). An assessment of the performance of the European long intermodal freight trains (LIFTS). *Transportation Research Part A: Policy and Practice*, *42*(10), 1326-1339.

Jaržemskis, A., & Vasiliauskas, A. V. (2007). Research on dry port concept as intermodal node. *Transport*, *22*(3), 207-213.

Janić, M. (2015). Modelling the resilience, friability and costs of an air transport network affected by a large-scale disruptive event. *Transportation Research Part A: Policy and Practice*, *71*, 1-16.

Jüttner, U., & Maklan, S. (2011). Supply chain resilience in the global financial crisis: an empirical study. *Supply Chain Management: An International Journal*, *16*(4), 246-259.

Jones, W. B., Cassady, C. R., & Bowden Jr, R. O. (2000). Developing a standard definition of intermodal transportation. *Transp. LJ*, *27*, 345.

Klibi, W., Martel, A., & Guitouni, A. (2010). The design of robust value-creating supply chain networks: a critical review. *European Journal of Operational Research*, *203*(2), 283-293.

Korovyakovsky, E., & Panova, Y. (2011). Dynamics of Russian dry ports.*Research in Transportation Economics*, *33*(1), 25-34.

Kreutzberger, E. D. (2008). Distance and time in intermodal goods transport networks in Europe: A generic approach. *Transportation Research Part A: Policy and Practice*, *42*(7), 973-993.

Leif Bigsten, 2014. Interview with Municipality of Falköping. Interviewed by Hong Chen. [Record] School of Business, Economics and Law, University of Gothenburg, 2014-12-02

Liu, C., Fan, Y., & Ordóñez, F. (2009). A two-stage stochastic programming model for transportation network protection. *Computers & Operations Research*, *36*(5), 1582-1590.

Lyman, K., & Bertini, R. L. (2008). Using travel time reliability measures to improve regional

transportation planning and operations. *Transportation Research Record: Journal of the Transportation Research Board*, *2046*(1), 1-10.

Mangan, J., Lalwani, C., & Fynes, B. (2008). Port-centric logistics. *The International Journal of Logistics Management*, *19*(1), 29-41.

Miller-Hooks, E., Zhang, X., & Faturechi, R. (2012). Measuring and maximizing resilience of freight transportation networks. *Computers & Operations Research*, *39*(7), 1633-1643.

Monios, J. (2011). The role of inland terminal development in the hinterland access strategies of Spanish ports. *Research in Transportation Economics*,*33*(1), 59-66.

Morlok, E. K., & Chang, D. J. (2004). Measuring capacity flexibility of a transportation system. *Transportation Research Part A: Policy and Practice*,*38*(6), 405-420.

Murray-Tuite, P. M. (2006, December). A comparison of transportation network resilience under simulated system optimum and user equilibrium conditions. In *Simulation Conference, 2006. WSC 06. Proceedings of the Winter* (pp. 1398-1405). IEEE.

Nair, R., Avetisyan, H., & Miller-Hooks, E. (2010). Resilience framework for ports and other intermodal components. *Transportation Research Record: Journal of the Transportation Research Board*, *2166*(1), 54-65.

Ng, A. Y., & Gujar, G. C. (2009). Government policies, efficiency and competitiveness: the case of dry ports in India. *Transport Policy*, *16*(5), 232-239.

Notteboom*, T. E., & Rodrigue, J. P. (2005). Port regionalization: towards a new phase in port development. *Maritime Policy & Management*, *32*(3), 297-313.

Notteboom, T., & Rodrigue, J. P. (2007). Re-assessing port-hinterland relationships in the context of global commodity chains. *Ports, cities and global supply chains*, 51-66..

Orbis Database, 2014. APM TERMINALS GOTHENBURG AB. Available at:<https://orbis-bvdinfo-com.ezproxy.ub.gu.se/version-20141214/Report.serv?_CID=78&context=22EPAUXUH0YHZJ6&SeqNr=3> [Accessed 14 December 2014]

Padilha, F., & Ng, A. K. (2012). The spatial evolution of dry ports in developing economies: The Brazilian experience. *Maritime Economics & Logistics*, *14*(1), 99-121.

Patrik Thulin. (2014). Interview with APM terminal in PoG in PoG . Interviewed by Hong Chen. [Record] School of Business, Economics and Law, University of Gothenburg, 2014-11-25

Pettit, T. J. (2008). *Supply chain resilience: development of a conceptual framework, an assessment tool and an implementation process* (Doctoral dissertation, The Ohio State University).

Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. *International Journal of Logistics Management, The*, *20*(1), 124-143.

Port of Gothenburg. (2013). Sustainable Port--Sustainability report of Gothenburg Port Authority 2013.

Port of Gothenburg. (2014). [Online] Available at: < http://www.portofgothenburg.com/en/ > [Accessed 13 September 2014].

RAILPORT Scandinavia. (2014). Port of Gothenburg. [Online] Available at: http://www.portofgothenburg.com/Line-selection/RAILPORT-Scandinavia/ [Accessed 13 December 2014]

Reggiani, A. (2013). Network resilience for transport security: Some methodological considerations. *Transport Policy*, *28*, 63-68.

Reich, J. W. (2006). Three psychological principles of resilience in natural disasters. *Disaster Prevention and Management*, *15*(5), 793-798.

Reuters. (2011). *Impacts of the great earthquake in Japan on energy, bulk commodity, and ports*. Available at < http://cn.reuters.com/article/2011/03/24/idCNCHINA-4029920110324?pageNumber=1> [Accessed 22-02-2015]

Rodrigue, J. P., & Notteboom, T. (2006). Challenges in the maritime-land interface: port hinterlands and regionalization. *The master development plan for port logistics parks in Korea; Seoul: Ministry of Maritime Affairs and Fisheries*, 333-363.

Rodrigue, J. P., & Notteboom, T. (2009). The terminalization of supply chains: reassessing the role of terminals in port/hinterland logistical relationships. *Maritime Policy & Management*, *36*(2), 165-183.

Rodrigue, J. P., Debrie, J., Fremont, A., & Gouvernal, E. (2010). Functions and actors of inland ports: European and North American dynamics. *Journal of transport geography*, *18*(4), 519-529.

Rose, A. (2006). Economic resilience to disasters: toward a consistent and comprehensive formulation. *Disaster resilience: An integrated approach*, 275-303.

Roso, V. (2007). Evaluation of the dry port concept from an environmental perspective: A note. *Transportation Research Part D: Transport and Environment*, *12*(7), 523-527.

Roso, V., Woxenius, J., & Lumsden, K. (2009). The dry port concept: connecting container seaports with the hinterland. *Journal of Transport Geography*, *17*(5), 338-345.

Stewart, M., Reid, G., & Mangham, C. (1997). Fostering children's resilience. *Journal of Pediatric Nursing*, *12*(1), 21-31.

Šakalys, A., & Palšaitis, R. (2006). Development of intermodal transport in new European Union states. *Transport*, *21*(2), 148-153.

Sheffi, Y., Rice Jr, J. B., Fleck, J. M., & Caniato, F. (2003, June). Supply chain response to global terrorism: a situation scan. In *Center for Transportation and Logistics, MIT, Department of Management, Economics and Industrial Engineering, Politecnico di Milano, EurOMA POMS Joint International Conference*.

Sommar, R., & Woxenius, J. (2007). Time perspectives on intermodal transport of consolidated cargo. *European Journal of Transport and Infrastructure Research*, *7*(2), 163-182.

Song, D. W., & Panayides, P. M. (2008). Global supply chain and port/terminal: integration and competitiveness. *Maritime Policy & Management*, *35*(1), 73-87.

Stake, R. E., & Savolainen, R. (1995). *The art of case study research* (Vol. 95004979). Thousand Oaks, CA: Sage publications.

Stig-Göran Thorén, 2014. Interview with the authority of PoG. Interviewed by Hong Chen. [Record] School of Business, Economics and Law, University of Gothenburg, 2014-12-03

Tencent News. (2011). *A Magnitude 9.0 Earthquake Happens in Eastern Coast of Japan.* Available at < http://news.qq.com/zt2011/rbdz/> [Accessed 22-02-2015]

Timmerman, P. (1981). Vulnerability, Resilience and the collapse ofSociety.". *A Review of Models and Possible Climatic Applications. Toronto, Canada: Institute for Environmental Studies, University of Toronto*.

Tierney, K., & Bruneau, M. (2007). Conceptualizing and measuring resilience: A key to disaster loss reduction. *TR news*, (250).

Trip, J. J., & Bontekoning, Y. (2002). Integration of small freight flows in the intermodal transport system. *Journal of Transport Geography*, *10*(3), 221-229.

UNCTAD. (1982) Multimodal transport and containerization. TD/B/C.4/238/Supplement 1, Part Five: Ports and Container Depots. Geneva: United Nations Conference on Trade and Development.

United Nations. (2013). *International Merchandise Trade Statistics.* Available at < http://comtrade.un.org/pb/CountryPagesNew.aspx?y=2013> [Accessed 23-02-2015]

Verhoeven, P. (2010). A review of port authority functions: towards a renaissance?. *Maritime Policy & Management*, *37*(3), 247-270.

Vromans, M. J., Dekker, R., & Kroon, L. G. (2006). Reliability and heterogeneity of railway services. *European Journal of Operational Research*, *172*(2), 647-665.

Wang, Q., & Ip, W. H. (2009). Evaluation and analysis of logistic network resilience with application to aircraft servicing. *Systems Journal, IEEE*, *3*(2), 166-173.

Westman, W. E. (1986). Resilience: concepts and measures. In *Resilience in Mediterranean-type ecosystems* (pp. 5-19). Springer Netherlands.

Wilmsmeier, G., Monios, J., & Lambert, B. (2011). The directional development of intermodal freight corridors in relation to inland terminals.*Journal of Transport Geography*, *19*(6), 1379-1386.

Xianfeng Wang, Yun Feng, Chen Chen, & Biao Ge. (2011). Analyze of the impact that earthquakes in Japan on Chinese ports transportation. *China Ports*. 4,004.

Yap, W. Y., Lam, J. S., & Notteboom, T. (2006). Developments in container port competition in East Asia. Transport Reviews, 26(2), 167-188.

Appendix

Appendix A—Definitions of resilience in previous literatures

Literature	Researching field	Definition of resilience
Holling, 1973	Ecological	"Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist."
Westman, 1983	Ecological	"resilience, which refers to the degree, manner, and pace of change or recovery in ecosystem properties following disturbance"
Carpenter et al., 2001	Socioecological	"Resilience is the magnitude of disturbance that can be tolerated before a socioecological system (SES) moves to a different region of state space controlled by a different set of processes."
Timmerman, 1981	Social Science	"Resilience, the measure of a system's, or part of a system's capacity to absorb and recover from the occurrence of a hazardous event."
Stewart et al., 1997	Psychological	"We defined resilience as the capability of individuals to cope successfully in the face of significant change, adversity, or risk. This capability changes over time and is enhanced by protective factors in the individual and the environment."
Reich, 2006	Psychological	"Resilience implies the ability to bounce back and even to grow in the face of threats to survival."
Christopher & Peck, 2004	Supply chain	Resilience is "the ability of a system to return to its original state or move to a new, more desirable state after being disturbed".
Christopher & Rutherford, 2004	Supply chain	"A resilient supply chain is certainly robust, but it offers much more; as well as being responsive to predictable input variability it is also able to respond to a sudden and unexpected shift in the level and variability of input"
Falasca et al., 2008	Supply chain	"Resilience is defined as the ability of a supply chain system to reduce the probabilities of disruptions, to reduce the consequences of those disruptions, and to reduce the time to recover normal performance."
Klibi et al., 2010	Supply chain	"Resilience is the capability of a SCN to avoid disruptions or quickly recover from failures."

Literature	Researching field	Definition of resilience
Carvalho & Cruz-Machado, 2009	Supply chain	"Resilience refers to the ability of the supply chain to cope with unexpected disturbances. It is concerned with the system ability to return to its original state or to a new one, more desirable, after experiencing a disturbance, and avoiding the occurrence of failure modes"
Wang & Ip, 2009	Logistic network	"Resilience is a kind of intrinsic ability to return to a stable or normal operating state following a strong perturbation or shutdown due to serious failure or outside attack."
Murray-Tuite, 2006	Transportation network	"Resilience is a characteristic that indicates system performance under unusual conditions, recovery speed, and the amount of outside assistance required for restoration to its original function state."
Ip et al., 2011	Transportation network	"Resilience can be understood as the ability of a system to return to a stable state following a strong perturbation caused by failure, disaster or attack."
Freckleton et al., 2012	Transportation network	"The ability for a transportation network to absorb disruptive events gracefully, maintaining its demonstrated level of service, or to return itself to a level of service equal to or greater than the pre-disruption level of service within a reasonable timeframe."
Nair et al., 2010	Intermodal freight system	"Resilience accounts for both the innate reliability of a facility and the ability of short-term recovery actions to mitigate negative effects."
Chen & Miller-Hooks, 2012	Intermodal freight system	"Resilience is defined as a network's capability to resist and recover from a disruption or disaster."

Appendix B—Presentation of simulation values for exogenous variables

Parameter	Simulation value[14]	Data source or justification[15]
D_w	[48,67,48,29,29,29,29] (TEUs)	80% of rail shuttles' capacity
C_{w0}	[120,168,120,72,72,72,72] (TEUs)	Twice the capacity of rail shuttles
l_{w0}	[60,84,60,36,36,36,36] (TEUs)	Approximated based on RAILPORT Scandinavia (2014)
$C_{seaport0}$	335 (TEUs)	1.2 times of the total container transportation demand in the seven destinations
t_{wo}	[4.5,5.5,10.5,5.5,6.5,7.5,7.5] (hours)	RAILPORT Scandinavia (2014)
t_{porto}	3.1 (hours)	Dividing the demand by operation rate at seaport
T_w^{max}	[7.55,9.37,16.55,8.73,10.23,11.73,11.73] (hours)	1.5 times of the original transport time (delivery time in the hinterland plus operation time at the seaport)
v_0	90 TEUs/hour	Calculated by using the data from APM Terminals (Gothenburg) (2015)
AM	[1,1,0,0,0,0,0; 1,1,0,1,1,0,0; 0,0,1,0,0,1,0; 0,1,0,1,1,0,0; 0,1,0,1,1,1,1; 0,0,1,0,1,1,1; 0,0,0,0,1,1,1]	Based on the geography locations of the seven destinations
p	87700 USD/TEU	Approximated based on United Nations (2013) and Port of Gothenburg (2013)

---

[14] Parameters related to hinterland are presented as vectors. Each of their element indicates a demanding area. Parameter AM is a matrix, however, according to its definition.

[15] The detailed justification has already been given in the main body of the text in section 6.3. Here just presents a summary.

Appendix C—Interview summaries

Summary of the interview with the Authority of Port of Gothenburg

Date: 3ʳᵈ Dec, 2014
Place: a meeting room in the authority of Port of Gothenburg
Interviewee: Mr. Stig-Göran Thorén, Senior Manager Business Development
Interviewer: Hong Chen

1. General information about POG

PoG is the largest port in Scandinavia, even the largest in Northern Europe. It has more than 140 direct routes throughout the world, for example, USA, China and India. It can handle close to 900,000 TEUs yearly, followed by Port of Helsingborg whose yearly volume is only about 120,000 TEUs. And Port of Gavle and Port of Norrkoping are the No.3 and No.4 largest ports in Sweden, respectively. The freight traffic in PoG is very balanced with 48% import and 52% export.

PoG has very good liner system with more than 140 direct routes throughout the world. Without transshipment at ports, PoG can provide more secure and efficient logistic chain for the cargo owners. Due to this reason, many companies in Gavle choose to transport their cargos to PoG by rail shuttle first, and then to load the cargos on big vessels for deep-sea shipping from PoG instead of Port of Gavle, even though it is the nearest port to them and the third largest port in Sweden.

The port authority owns the land, quays, and all the fairways. There are four terminals in PoG focusing on different types of cargos, which are all operated by private terminal operators. Majority of the containers are handled in APM terminal, which is the largest container terminal in Scandinavia. Besides, the Ro-Ro Terminal, operated by Alvsborg Ro/Ro AB, can handle a small number of containers.

PoG has a good rail system inside terminals, named "on-dock rail terminal". The rail track, connected to the whole area of Sweden and part of Norway, goes directly to APM terminal in the port from the downtown of Gothenburg city through a bridge. On the dock yard, there are cranes to load and unload the trains, making the distance between the vessels and the train very short, thus increasing the efficiency of transshipping for intermodal transport.

About 50% of the containers in PoG are transported by rail through the rail shuttle system, called RAILPORT, with a very balanced container traffic of inbound and outbound. Today, PoG has 24 destinations with 24 daily rail shuttles going between the most interesting junctions in Scandinavia to PoG. With the help of RAILPORT, the hinterland of PoG covers the whole Sweden and Oslo's area in Norway.

For now, there are two logistic centers in function in PoG, and there are another two under constructing and planning. PoG invests in building logistic centers in order to provide more and better services to take care of the cargo for both export and import.

2. The cooperation between PoG and other actors in the transport network

2.1 With APM terminal

The authority of PoG and APM terminal operator have a 25 years long contract. PoG authority leases out the operation of the container terminal to APM terminal, a private terminal operator. APM terminal owns the equipment, but the authority owns the land. When the contract reaches its end, APM terminal should return the port to the port authority as the same shape when they took it.

2.2 With RAILPORT terminals

The cooperation with RAILPORT terminals is very close. It is mainly carried out from four aspects.

Firstly, the authority of PoG arranges regular meetings with both the private terminal operators of RAILPORT terminals and the municipalities where these RAILPORT terminals are located, thus making PoG been informed with the RAILPORT terminals very well.

Secondly, PoG is working very close with the RAILPORT terminal operators and the municipalities in marketing the activities in the RAILPORT terminals and the rail system between them, aiming at promoting the business performance of RAILPORT terminals, the rail system, and PoG itself, by offering a very secure and efficient intermodal transported logistic chain.

In addition, the rating system at the RAILPORT terminals is another aspect of the cooperation between them. PoG rates the RAILPORT terminals based on four criteria: geographic location, range of services on offer, safety, and the condition of the area/premises. This rating system is used to measure the performance and quality of service of RAILPORT terminals. The interviewee thinks that it is very good for the RAILPORT terminal operators since they can present PoG's analysis to their municipalities to point out in what way the RAILPORT terminals can be improved.

And last but not least, the running of rail shuttles between RAILPORT terminals and PoG is the most important aspect of the cooperation between them.

These four aspects mentioned above give a picture of how PoG cooperates with RAILPORT terminals, which are also its hinterland terminals. However, PoG has no investment in these RAILPORT terminals. And there's no plan to do so, either. It is the private operators together with the municipalities who should invest, according to the interviewee.

2.3 With rail operators

The cooperation with rail operators is mainly performed by APM terminal, not the authority of PoG. It is APM terminal and the rail operators who work together in transporting the cargos to and from the port. However, the authority of PoG knows the rail operators and the cooperation between them.

The three parties meet one or two times every year to exchange information and also to discuss about the plans for the future.

2.4 With forwarders or road haulers

According to the interviewee, PoG has no cooperation with any forwarders or road haulers for now. However, PoG knows these forwarders and road haulers very well, and has meetings with some of them in order to take the temperature of the climate of the relationship between the truck and forwarder companies and APM terminals. The aim of this meeting is to promote the performance of the cargo transportation in the port, to reduce the waiting time, for example.

3.   Unconventional emergency events inside and outside PoG

3.1 Inside PoG

On the whole, the interviewee doesn't foresee any unconventional emergency event that could happen inside PoG. For example, natural disasters, fire, terrorist attack, and so on. However, there's one special place that PoG has been worried about for many years. And that is the bridge which is the only rail connection to the port, since the port is on the island separated from the mainland. If there would be some sort of accidents happen to this bridge, the train could not cross the river. Then the port would become isolated. In that case, the cargos which used to be transported by rail will turn to road transportation, causing heavy congestion on the port and in the city. Moreover, some special cargos which are high and heavy will have to wait at port, for they are specially designed rail wagons that must go on trains. All these make the bridge extremely important to the freight transport network system between PoG and its hinterland.

Up till now, nothing has ever happened to this highly risky bridge nevertheless. And PoG doesn't have any pre- and post- accident plan focusing on this bridge for now. However, PoG is well aware of the risk in this bridge. For example, PoG had a workshop together with the Swedish Rail Administration a couple of years ago. The workshop did some work of risk analysis on the consequences and post-accident activities based on the degree of the bridge's breakdown due to some reason. Besides, years ago, some students from Lund University also did a research on the estimation of economic loss to Swedish industry when the bridge is out of function.

Moreover, today, together with Volvo, PoG has lend huge amount of money to the Swedish Rail Administration, which PoG has been working with very closely for many years, to build another bridge parallel to this one. The construction of this new bridge will be finished in about two years. By then, the rail connection between the port and the mainland can be more secure since the possibility of two bridges breakdown at the same time is extremely small. Besides, this new bridge will improve the efficiency of cargo transport to and from PoG, thus increasing the volume handled accordingly.

All mentioned above, the workshop, the research from Lund University, and the action of lending money to the Swedish Rail Administration by PoG in building the new bridge can all be seen as preparation activities of PoG against the happening of unconventional emergency events, even though they don't have specific plans for that.

However, if there's any unconventional emergency event did happen to the bridge and makes it out of function, there are post-accident activities that can be carried out based on two different situations.

Firstly, if the technical repair of the bridge will only take one or two days, PoG will transport the cargos by trucks instead. At the same time, the train will also be relocated, making the transshipment of containers between trucks and trains outside the port area, but inside the city. For those special cargos with big units, they will survive for one or two days in a buffer in the port.

However, if the stop of the bridge is for a longer time, then PoG will need the help from other seaports to transport the cargos. For example, barges will be used for transshipment.

In words, this bridge is PoG's only concern when talking about the risk of unconventional emergency events. Others, like fire and terrorist attack, are not foreseen by the interviewee. For fire, for example, the distance between the areas where there exists a possibility and the port is long enough to avoid affecting the normal operation of containers. Even if there's a fire affects the rail tracks to the port, the stop will only be a couple of hours, which is not a big problem.

3.2 Outside PoG

The possibility and consequences of unconventional emergency events outside, in RAILPORT terminals for example, are out of PoG's consideration as well due to the structure and the characteristics of the freight transport network between PoG and the hinterland terminals.

Most of the RAILPORT terminals are located very closely to each other with a relative short distance. If there's something unexpected happens to the RAILPORT terminals or the railway connecting between them, the cargos can always be transported through another RAILPORT terminal nearby to the one which is breakdown. Or, the cargos can be transported by road instead. Anyway, the rail system in Sweden is quite good and redundancy. The worst case where an unconventional emergency event did happen to any RAILPORT terminal or the railway is to delay the cargos until next vessel. But this is really seldom according to the interview.

Thus, there aren't plans of PoG for now against the happening of unconventional emergency events outside the port. And PoG doesn't have any investment in the RAILPORT terminals or the railway system to cooperate with other partners in this issue. Though one of the four criteria for rating the RAILPORT terminals by PoG is safety, this consideration is more focused on conventional events, such as gates, cameras, and IT system, not the unconventional emergency events we are talking about.

4.   The interviewee's opinion on the issue of unconventional emergency events

According to the interviewee, PoG hasn't considered any issue of unconventional emergency events so far. And it is this interview that has made him more aware of that it can be a situation that has never been expected. In his opinion, PoG will discuss this kind of questions more in the future. For example, to have a workshop or to sit down to discuss the possibility of healing the breakdown in the system. Besides, PoG will also start thinking the positive way of what they can do to avoid such problem or to prevent some dangerous events.

However, the interviewee doesn't foresee the possibility to invest in the RAILPORT terminals on these unconventional emergency events issue. Because the business model of PoG is that they do not own anything in

the inland terminals. In the future, however, APM terminal might invest themselves in inland terminals, said by the interviewee. But not the port authority.

Summary of the interview with APM terminal in PoG

Date: 25th Nov, 2014
Place: an office in APM terminal in Port of Gothenburg
Interviewee: Mr. Patrik Thulin, Sales Manager
Interviewer: Hong Chen

The container operation in APM Terminal

In 2013, APM terminal has handled 779,000 TEUs throughout the year. Usually, the distribution of the volume of the containers handled in APM terminal during the year is almost uniform, except for that there's a little bit decrease at the end of the year, mainly due to the slowing down of foreign industries in winter time.

Nowadays, 49% of containers transported to and from APM terminal are by rail, with the rest 51% by truck. And there's a trend that the rail share will still increase. Moreover, APM terminal now has a big investment in its rail product. It is now building one more rail track besides the existed five ones. In that way, they will have 750 meters long EU standard rail tracks which can accommodate three trains when it is ready to go during Q1 next year. And that will increase the capacity by 50%.

Cooperation with other actors in the freight transportation network

APM terminal has short-term, but more long-term, relationship with forwarders and carriers. The commercial activities of APM terminal have been mainly focused on the carriers and rail operators traditionally. With formal agreements, APM terminal sends invoice to rail operators, haulers and truckers. In addition, they have regular meetings and more physical directions, which can be seen as an improvement for the cooperation between them. Through these cooperation, APM terminal can improve the performance of container operation by shifting the traditional peak, which comes in the afternoon, to the rest of time periods during a day, for example. Thus, waiting time in APM terminal can be reduced.

APM terminal also has a good cooperation with RAILPORT Terminals. For example, APM terminal discusses a lot with RAILPORT Terminals in exploring new opportunities where new shuttles and destinations can be developed, and also in improving the performance of the existing ones. However, APM terminal doesn't have any investment or any plan to invest in the RAILPORT Terminals.

With rail operators, APM terminal has both short-term and long-term relationship in the cooperation. And this cooperation is kind of a success story. Together with rail operators, APM terminal has managed to increase the rail transportation in PoG to nearly 50% of the whole container traffic starting from zero. Fortunately, this environmentally friendly trend is still ongoing.

Security issues inside APM terminal

In the interviewee's opinion, Sweden is not the country which has frequent natural disasters. So, he doesn't foresee any security issue resulting from natural disasters here in PoG. However, APM terminal does have programs in place if it should be Level 3 based on the ISPS code, meaning APM terminal needs to close down the whole port. In that circumstance, the Swedish industry will suffer a lot since 50% of Swedish container traffic goes through APM terminal. However, in terms of other unconventional emergency events, such as strike, terrorist attack, and fire, APM terminal does have continuance management plan in place from perspectives of security information, IT system, operation, communication, and so on. This continuance management plan is general and high-level which functions as preparation and recovery manual for the unconventional emergency events.

However, when these unconventional emergency events do happen, the damage caused and the money lost is hard to estimate and measure according to the interviewee. Since it depends on the type of unconventional emergency event and severity of the event, he can only say that it will be a large quantity of money lost. Moreover, the interviewee also thinks that if there's too much damage happens to the terminal, the whole Swedish industry will be suffered. And that will be a big problem.

When it comes to the prevention of unconventional emergency events, the interviewee thinks that the importance lies in having related plans in place and having cooperation in the cluster with customs, police, the authority of PoG, and various other authorities.

Security issues outside APM terminal

If one of the RAILPORT Terminals breaks down due to any unconventional emergency event, APM terminal will have two approaches to maintain its operation. One is to use another nearby RAILPORT Terminal or another destination to transport containers, and the other is to truck the containers instead. However, it's also case by case, since the interviewee does not foresee if one of these really breakdown. But if they do, APM terminal will try to find a solution, though the interviewee can't say there's a specific plan for this situation.

When asking the question whether APM terminal is willing to invest in RAILPORT Terminals to prevent the happening of unconventional emergency events there, the answer from the interviewee is "maybe" and "long-term". According to the interviewee, APM Group has inland terminals segment. In China, for example, they have 40 locations providing their own inland services. So maybe in the future, APM terminal will have some activities in cooperating with RAILPORT Terminals in investment on preventing the happening of unconventional emergency events. However, the interviewee doesn't think APM terminal is willing to have RAILPORT Terminals' investment in conducting preparation activities inside APM terminal, and there's no specific case right now. APM terminal has agreement with the city of Gothenburg, and it owns the possession. So APM won't be allowed to actually to let someone else to invest.

On the other hand, if a railway between a RAILPORT terminal and APM terminal breakdown, the damage, according to the interviewee, is more on APM's customers, meaning to the carriers, cargo owners, and the 3PLs than on APM terminal, since it's them who have to find new ways to transport their cargos. Besides, APM terminal has no investment in the rail tracks, so it doesn't have additional costs in this situation, though APM terminal may face some problems. For example, in the short-term, APM terminal may not suffer much, since the containers can be transported by trucks instead. However, if something bad happens to the entire railway network which causes a long-term breakdown, then the situation will become severe for APM terminal. Because the cargos will have to

find another way to distribute than going to PoG, then APM terminal will suffer a decreasing in volume of containers handled. And, it will cost a large quantify of money. However, the interviewee doesn't foresee the happening of this extremely severe situation.

When it comes to the cooperation with rail operators in preventing unconventional emergency events happening to the railway, the interviewee doesn't think the security aspect will matter whether APM terminal invests together with rail operators in railway system or not. Because it is not the rail operator who owns the rail tracks, but the state.

Similarly, the damages to APM terminal due to the happening of unconventional emergency events on other actors in the network cannot be measured or estimated, either, according to the interviewee.

The interviewee's opinion on security issues in port-hinterland freight transportation network

In the interviewee's opinion, what APM terminal can do is to ensure everything is under control inside the terminal. APM terminal sees it as its responsibility to ensure a security system in place. However, according to the interviewee, security of cargos cannot be ensured as soon as the trains leave APM terminal, and the containers will face much higher risk than inside the terminal. Thus, the interviewee considers the importance in cooperation with other actors within the transportation network on security issue.

Summary of the interview with the municipality of Falköping

Date: 2rd Dec, 2014

Date: 2rd Dec, 2014
Place: School of Business, Economics and Law, University of Gothenburg
Interviewee: Mr. Leif Bigsten, Project Manager
Interviewer: Hong Chen

1. General information about Skaraborg Logistic Center (SLC)

SLC is located in the region of Falköping with special focus on intermodality. Now it has four terminals. For the intermodal terminals, it can handle 10,000 TEUs yearly. And the volume is still growing, where 14,000 or 15,000 TEUs is predicted in some years.

The distribution of the volume of the containers handled is mainly depending on the customers of SLC. For example, JULA is the biggest customer of SLC. JULA itself partly owns the rail shuttle between SLC and PoG. They are the main company using the shuttles. When JULA has some seasonal collections to fill up their warehouses, there will also be some up and down in the volume of containers handling in SLC accordingly. For instance, JULA has started building their new warehouse which is about 50,000 m^2 more than they have today. In this case, a really peak of containers handled in SLC can be predicted in next spring, since JULA has to fill up this new warehouse.

However, SLC is now trying to balance the traffic by having other six companies using the shuttle. JULA usually uses the rail shuttle from PoG to SLC, while the other six companies are using the opposite direction ones. Thus, the cargos of inbound and outbound can be balanced as well.

There are some other factors contributing to the seasonal pattern. The Chinese New Year, for example, is one such influence. When the Chinese New Year comes, the production in China slows down. This directly makes the volume of containers in SLC decreases since it has less containers coming in.

It is often said that the hinterland of SLC covers the whole region of Falköping, with the population of nearly 0.2 million. It is consistent with one of the aims of SLC that to be primarily the only terminal for the region of Skaraborg and to take control of this market. However, when it comes to containers only, the hinterland of SLC is actually a little bit less than the whole region. Some of the companies in the region which are near to the city of Gothenburg may probably transport their containers to PoG directly by road, not by train through SLC. In this circumstance, it cannot be said that the hinterland of SLC covers the whole region of Falköping. However, there exists possibility for SLC to attract more companies outside the region of Falköping but very close to use SLC to transport their cargos by rail shuttles to PoG.

The pattern of the modal split of containers transported to and from SLC is somewhat simple. All the containers transported between SLC and its hinterland are by road, or by lorry, specifically. While the transportation between SLC and PoG is all by the rail shuttle. SLC acts as intermodal operator, providing transshipment between lorry and train. In this case, the road transportation network between companies in the hinterland and SLC is very vital. The traffic of inbound and outbound is not totally balanced today, but SLC is trying very hard by finding new customers to balance it.

2. The cooperation with other actors in the network

2.1 Between municipality and private terminal operators

SLC has four terminals. Two intermodal terminals are owned by the municipality. They are rented out to private terminal operators. The agreement between them says that private terminal operators have the possibility to run the terminals, make business strategies, and so on, by paying money to the municipality. The municipality, however, is responsible for managing the infrastructure in the terminals to help the private terminal operators in developing the business. The municipality is part of the development of the business in these two terminals, but not the one who conducts the business. The timber terminals in SLC, however, are owned by private terminal operators of Stora Enso/Sydved and Sodra, not by the municipality. They just use the infrastructure connecting the SLC and the main rail-road, which is owned by the municipality.

2.2 With forwarders, rail operator, and road haulers

The cooperation with forwarders is performed by the private terminal operators. It's the private terminal operator who makes the business mode. And there are many different partners involved in this business. For example, the rail shuttle between PoG and SLC is owned by DB Schenker, while JULA is the biggest customer using these rail shuttles. However, JULA has its own wagons and DB Schenker also has its lorries as well. In sum, it's the private terminal operator, TBN, DB schenker and companies like JULA, who together make the transportation network work.

However, it should be noticed that there are many other players in this transportation business except DB Schenker and JULA as mentions above. The intermodal terminals in SLC are open terminals. Other rail operators, besides DB Schenker, are also allowed and welcomed to use the terminals. Though DB Schenker is the only rail operator running the rail shuttle between SLC and PoG nowadays. Similarly, JULA is just one customer, though the biggest, of DB Schenker and the intermodal terminals in SLC. DB Schenker, actually, wants to take all the business in the hinterland of SLC in rail transportation to PoG. And they want larger market share in lorry transportation as well.

In a word, the cooperation between different actors in the network is mainly depending on the players' business interests and business ambitions. Some are contradicted and some are common. The volume of containers handled is one common interest of all the players. But the cooperation in transportation field is often long-term and strong, since the investment is usually huge. For example, as the biggest customer, JULA has signed a five years contract with the municipality of SLC. It says that JULA should give money to the municipality for five years even if they don't use the terminal. In this way, the municipality is guaranteed to invest in building the terminal.

2.3 With PoG

For now, PoG is the only seaport cooperated with SLC. The most important aspect of the cooperation with PoG is the rail shuttle system. They also have cooperation in the marketing side. However, there's much room for improving the cooperation, according to the interviewee.

Firstly, the plan and action of PoG's building an industrial site near the port is not appropriate, in the interviewee's

opinion. Environmentally speaking, the building of an industrial site near the port will probably bring road congestion to the port where it is already a crowded area. In addition, this action will make PoG and SLC become competitor to each other. The terminals in SLC cannot be self-financed nowadays. It depends on the input of tax money. One way for the SLC to get financed is to build their own industrial site. In this way, they can attract companies to invest in SLC in building their warehouses, for example. Thus, working places can be created, more people moving to this region, and the local government can get more tax money. By doing this, SLC can thus have the ability to persuade the politicians to support the running of the terminals financially. At the same time, the volume of containers handled at SLC can also be increased, which decides how much income can SLC achieve. However, if PoG has built up their own industrial site in the port area, many companies will be attracted to the port instead, not to invest in SLC. And that isn't what the municipality of SLC wants to see. Because then the local government won't have additional income to fill the deficit of the terminals in SLC. In that circumstance, there will be a danger to close the terminals in SLC. It would become a very worrying situation whether economically, environmentally, or socially. What is even worse it that the similar situation is faced by other hinterland terminals. On the other hand, for the companies, putting the warehouses in the hinterland, SLC for example, is much cheaper and equally convenient, since the rail shuttle can provide excellent transportation service to the port, said by the interviewee.

Secondly, the cooperation with PoG can be made tighter in terms of ownership. Nowadays, PoG hasn't invested in any of the hinterland terminals, and doesn't totally or partly own them, neither. Hinterland terminals like those two in SLC are not partners to PoG, but supporters. In the interviewee's opinion, it could be safer for PoG to have ownership in the hinterland terminals. On the one hand, these hinterland terminals are usually very small. They need some kind of financial support from the seaport they cooperate with. On the other hand, one of the strong competitors that PoG has is Port of Hamburg. Now there's no rail shuttle going to Port of Hamburg from SLC or other hinterland terminals. But there do exist a possibility of running a rail shuttle to Port of Hamburg. In addition, if Port of Hamburg really decides to buy or partly own the hinterland terminals some day in the future, SLC for example, then PoG will face the risk of losing part of or even all of the containers in those regions. In that case, PoG will possibly even lose some direct calls of big vessel, thus losing its container volume dramatically.

Anyway, PoG is a very important seaport for Sweden. The municipalities of hinterland terminals do expect its development. They just need tighter cooperation and support, however.

2.4 With other RAILPORT terminals (hinterland terminals)

For now, there's no real cooperation between the RAILPORT terminals themselves. They don't have rail shuttles or lorry shuttles connected to each other. According to the interviewee, however, they have some discussion regarding that. For example, they discussed in becoming partners when having words with PoG. They are trying to find a way of cooperation in handling and transporting different types of goods more efficiently. All these issue are under discussion. Besides, the interviewee sees a bigger chance of cooperation in trailer transport comparing to containers.

3.   Unconventional emergency events inside SLC

When talking about the happening of any UEE inside SLC, the interviewee admits its possibility, but doesn't see it as a big problem to container transportation. The distance between SLC and PoG is only about 120km. Within such

a short distance, the containers can be transported by road instead if there's some UEE happening to SLC and causing damage to the normal operation in SLC. Transported by road can cost more, but not that much.

Specifically, the interviewee doesn't see strike as a potential problem for SLC, since SLC is a small party. What is more possible to happen is a strike at the Swedish Rail Authority for the maintenance of the rail, for example. If it did happen, then it would be a national problem, not just a terminal problem. And for terrorist attack, it is more likely that big ports like PoG will be targeted, not the SLC since it is very small. They haven't had any discussion about this, nevertheless.

The interviewee doesn't foresee any natural disasters which can bring problems, neither. The most probably natural disaster that can happen in the region of Skaraborg is the snow. However, the disruption caused by heavy snow just lasts only one or two days in estimation. Thus, the damage won't be sever.

For this circumstances, SLC doesn't have any plan on UEE. However, they do have plans for other accidents like electricity falling down, which they have some agreements with private companies to fix it quickly. But that's belong to conventional emergency events, not the UEE we are discussing about.

In sum, the interviewee doesn't think UEE being a threat to SLC and container transportation. Because the ultimate solution is to transported cargos by road instead, which won't cost too much. Moreover, even if there's a very sever disaster happened, then the whole society will be affected. In that case, the more important thing to do is to save people and lives, not the business part. The terminals, then, become a positive resource for delivering goods and suppliers for the people in the disaster area. And these are what the municipality of SLC has discussed with related authorities and the military party. "Business is not everything", said the interviewee.

4. Unconventional emergency events outside SLC

It is agreed by the interviewee that if PoG breakdown due to any UEE, the SLC will lose money. The municipality makes money out of the volume of containers handled at SLC. If the operation in PoG breakdown, SLC will not get any containers transported from or to PoG. It will damage the profit made by SLC. In addition, other actors such as rail operators and the companies will also be suffered as well. However, this damage can't be estimated in terms of money. Not by the interviewee, at least. In that case, the municipality of SLC might probably go to PoG to claim the compensation, according to the interviewee. Just as the terminal operators might suit the municipality to the court if they cannot provide the infrastructure or services they promised to in the contracts. However, he also admits that this may also be a risk that they must burden. But there's no discussion or agreement between different players on risk sharing and interest sharing issue yet, which are complicated and sensitive. On the whole, the disruption on the port will make everyone in the network suffer. The complicated risk and interest sharing problem will make the situation even harder to deal with. For now, the municipality of SLC doesn't have plan for this situation.

When it comes to a disruption in a railway connected between SLC and PoG, the interviewee thinks that the municipality will lose money definitely, since their profit is depending on the volume of containers handled at SLC. When there's no way to transport the containers by rail, the companies will use trucks or lorries instead, which means they will not use the intermodal terminals in SLC. Besides, the companies will also lose money because road transportation is more expensive than rail. However, the money lost by the municipality due to this situation

cannot be measured, neither. But it won't be huge. SLC is very small anyway.

When asked whether SLC is willing to do something to prevent the UEE happening in the railway, the interviewee said that it's the state and the government who should be responsible for providing and maintaining the railway system. The responsibility of the municipality of SLC is to ensure good main infrastructure and good business environment in SLC. After all, railway system concerns not only the freight, but also people. It is thus a national problem, and mainly political.

5.   The interviewee's opinion on the issue of UEE in the network

In the interviewee's opinion, it is the seaport who should take the lead in this issue, and in a much stronger way than they are doing today. PoG has a good security system. However, the cargos are less safe when they go out of the port. The interviewee thinks that PoG should give more support to the hinterland terminals and cooperate with them in a tighter way—to invest in the hinterland terminals and partly or totally own them, for example. Though PoG now has rating system for the hinterland terminals, but that isn't enough. Instead, the municipalities of the hinterland terminals expect more practical actions in polishing the security system of the whole transport network, rather than just numbers. Moreover, security is just one aspect.