UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master Degree Project in Logistics and Transport Management

Strategies to Cope with Unconventional Emergency Events in a Port-Hinterland Transportation Network

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Master Degree Project No. 2016:75
Graduate School

Abstract

Within the context of global integration, the increasingly important role of a port is illustrated by the growth of world seaborne trade. The modern port has evolved from a single transshipment node into an integrated functional region. The port is becoming the logistics hub and the normal operation of the port-hinterland transportation network (PHTN) has a significant impact on the whole regional economy. Meanwhile, this system is susceptible to unconventional emergency events (UEEs). Both natural disasters and man-made events will cause serious damage to the PHTN and this is becoming a very important issue for the regional economy. In this thesis, we analyze and evaluate the existing practices adopted by the players in the PHTN. We first review the research and publications related to the port-hinterland interface and summarize this into a theoretical framework. Then we conduct a case study of the Port of Ningbo-Zhoushan (PONZ) based on the gathered information. Towards identifying the potential weaknesses of existing management systems in coping with UEEs, a coalition model involving all the freight carriers in the PNTH is proposed. To make the coalition stable, a profit sharing mechanism is established based on Shapley values. Finally, the model is applied using a numerical example.

Key words: port-hinterland transportation network, unconventional emergency event, coalition model, Shapley value

Acknowledgement

To start with, we would like to give our thankfulness to the people who have kindly offer their knowledge, trust and support when conducting this research. First, we want to express our thankfulness to our supervisor, Prof Kevin Cullinane, who has sacrificed much time to meet with us. From the very beginning of this thesis's work, his valuable suggestions keep us in the right direction and give us a lot of confidence when exploring in some unknown territory. Second, we would like to show our appreciation to the people in our home country, Prof Nan Liu, Miss Xianhong Li. Without them, we will not have the chance to study in the University of Gothenburg. Third, we want to give our thankfulness to the three interviewees in this paper, Mengda Tong, Hangming Sheng and Yahui Teng. With the information and knowledge they shared with us, we are able to improve our research. Last but not least, we both want to deeply thank our family members, who have supported us during the whole period studying and living abroad in Sweden.

Zixiang Gong   Yiming Zhong

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ABBREVIATIONS

CCTV	Closed Circuit Television
CRC	China Railway Corporation
IFT	Intermodal freight transport
PHTN	Port-Hinterland Transportation Network
PONZ	Port of Ningbo-Zhoushan
PONZG	Port of Ningbo-Zhoushan Group
POS	Port of Shanghai
SOLAS	International Convention for the Safety of Life at Sea
TEU	Twenty-foot Equivalent Unit
UEE	Unconventional Emergency Events
UNCTAD	United Nations Conference on Trade and Development

1 INTRODUCTION

The purpose of this chapter is to provide some background about this master thesis. The research questions are formulated and analyzed based on some crucial issues related to the background information. In order to give readers a clearer understanding of this thesis, an outline of the remaining chapters is presented at the end of this chapter.

1.1Background

1.1.1 The increasingly important role of the port-hinterland network

With global economic integration, maritime transportation is experiencing its longest and fastest growth (Skjong and Soares, 2008). The demand for shipping has dramatically increased since the mid-1990s (Cullinane and Bergqvist, 2014). It is estimated that around 80% of global trade by volume and over 70% of global trade by value are accomplished by sea (UNCTAD, 2015). Meanwhile, the port-hinterland network plays a more and more important role in the freight distribution system. The port is no longer a conventional single cargo handling terminal. Instead, absorbing its foreland and hinterland, it has become a region that has a more complicated economic function.

Developing countries account for a lot of the growth in maritime transportation. Because of both economic and geographical reason, their trades are highly dependent on shipping. The share of cargo handled by sea and port in these developing countries is usually higher than the average level. Take China as an example, 90% of foreign trade has been accomplished by maritime transportation in recent years. The amount of cargo throughput is still increasing with the expansion of China’s import and export trade. The amount of seaborne trade in developing economies has increased 24.7%, from 8474 in 2006 to 10564 in 2014 (measured in millions of metric tons). In Asia, the related data is especially prominent. From 2006 to 2014, the amount of seaborne trade changed from 5980 to 8724, an increase of 45.9%. By the end of 2014, the amount of seaborne trade in developing economies accounted for 60.4% of world seaborne trade (UNCTAD stat, 2015).

Moreover, maritime transport is the best choice when trading key strategic materials such as oil and minerals. Over 90% of crude oil is accomplished by maritime transportation. In 2014, the amount of seaborne trade crude oil (both loaded and unloaded) reached 3570 (measured in millions of metric tons). The number of petroleum products and gas (gasoline, jet fuel, heavy fuel oil, light oil, naphtha, LNG and LPG) also increased at a very fast speed, from 531 in 1970 to 2239 in 2014 (UNCTAD stat, 2015).

In summary, the increasingly important role of the port-hinterland can be reflected in two aspects. The first one is the changing model of a seaport. It bears more economic value-added functions than a conventional port. By integrating its foreland and hinterland, seaports grow from a single transport terminal to an active logistics region that becomes a key driving factor in its regional economy. The second aspect is the growth of seaborne trade along with globalization. Because of this, the world economy relies more on the proper management and cargo handling ability of a seaport. The seaport with its foreland and hinterland has become an essential link in the world economy.

1.1.2Port-hinterland disruption

Port disruption is a very serious problem nowadays. The reason that leads to a disruption is divided into two different categories. The first is at the managerial level. It happens due to improper operation in the cargo handling or transport process. For example, if the inventory level in the distribution chain is too low, this causes an interruption of supply in the commodity chain. Similarly, if the equipment used is too old, this could be a potential security liability. Among all these issues, the most prominent and discussed is perhaps the empty container and empty haul issue. In 2005, nearly 70% of the slots of containerships leaving the US were empty (Boile, 2006). The second reason is the unconventional emergency event (UEE). These unusual events often cause an abrupt termination of normal operations and tremendous damage to the port-hinterland transportation network (PHTN). The major concern of this paper will be focused on the second reason, i.e. port disruption caused by UEEs.

As the size of port grows larger and there is the emergence of port regionalization, the port-hinterland system is able to accomplish more complex logistic functions in a more effective way. The hub-and-spoke structure of the port-hinterland network increases the integration between port and its hinterland. Value delivery will be a function of the level of integration of chain systems (Robinson, 2002). Ports have already developed into an element in the value chain, acting as a third-party service provider for a number of firms in the import and export supply chains of individual firms. This allows the distribution network to adjust to the regional economy more easily, but at the same time increases the vulnerability of the system. Once the port is affected or shut down by a UEE, the entire system may become paralyzed.

The UEE affecting the PHTN can be natural disasters (earthquakes, hurricanes and volcano eruptions) or man-made events (terrorist attacks, political movements and strikes). In some cases, these events can be interrelated and occur simultaneously.

They may cause different degrees of damage to the system depending on the severity of the cases. The Great Hanshin earthquake happened in 1995 and completely shut down the Port of Kobe in Japan. It is estimated that the loss caused by the damage was 100 billion US$, in which the city of Kobe suffers the most. It took the government two years and tremendous human and material resources to fully repair the damaged transportation system (Chang, 2000). Hurricane Sandy, which lasted for 10 days, from October 21-31, 2012, caused major damage to the ports in the eastern United States and led to the complete shut-down of five ports along the coast, which included America's third largest port, the Port of Jersey Marine Terminal (Janic, 2015).

Besides the natural disasters, some man-made events will also affect PHTN, like terrorist attacks and strikes. Strikes are very common phenomenon in ports, especially in western countries. In 2012, rolling strikes broke out in the Los Angeles-Long beach Port, causing a near collapse of American's busiest port. Nearly 10,000 dock workers refused to go to work. 10 of the 14 container terminals were completely shut down. A lot of large shipping companies like Maersk and the Mediterranean Shipping Company (MSC) were affected by this strike. The economic cost was estimated to be 1 billion US dollars every day (Tencent News, 2011). Similar examples can be found in the ports of Europe. In 2006, due to the dissatisfaction towards the new policy proposed by the European Union, strikes broke out in six European countries, including France, Sweden, Denmark, Belgium, Greece and the Netherlands. Some major ports like Rotterdam, Antwerp and Marseilles were temporarily shut down. It is estimated that at least 7 million Euros loss was caused by this massive strike (People News, 2006).

In summary, port disruption is a very serious issue that happens a lot around the world. Both natural disasters and man-made events could damage or potentially destroy the PHTN. The consequence of these disruptions usually tends to be economically catastrophic. The duration of recovery depends on the severity of the disaster, but generally, it takes a long time to fully recover to the normal level.

1.2 Problem Analysis

1.2.1 Research purpose

By summarizing some of the information in the previous sections, we pointed out the importance of this research.

- With the integration of the global economy, the demand for seaborne transport is increasing at a very fast speed. As a crucial link in the commodity chain, the port-hinterland transport network is becoming more and more important.

- The port-hinterland network is very susceptible to UEEs. Numerous examples have proved that the consequences of UEEs often lead to massive loss and it often takes a very long time to fully recover the system.
- With the change of Port-Hinterland relationships in the context of global commodity chains, the performance of inland transport is considered as a major factor in evaluating the entire PHTN system. Thus, to cope with a UEE, it is crucial to involve the inland players.

1.2.2Research questions

Based on the background and with the examples of port disruption mentioned in the previous sections, it is clear to see the fragile nature of the PHTN. The contradiction between the increasing importance of seaports and the vulnerability of the transportation system needs to be paid more attention to. To mitigate the damage from a UEE, all the related players need to be involved. What's more, the decision makers should consider problems from a more comprehensive perspective. We propose the research questions as follows:

In a port-hinterland transportation network, what are the existing practices adopted by players to cope with the damage from unconventional emergency event?

How can a coalition model be established to properly allocate the payoffs from investing in risk management among all the freight carriers?

To answer these research questions, first, we will investigate what existing practices are invoked by the players involved. For example, is there a staff training program specifically aimed at risk management? Is there a quick response system to some emergency situation like a fire? The major work in the first part is to categorize, analyze and evaluate these practices. However, players in different PHTNs may apply different strategies. Thus, in order to generalize a conceptual model, a case study of the Port of Ningbo-Zhoushan (PONZ) will be conducted in this research. The second part is performed based on the results from the first part. By evaluating existing practices, the strengths and weaknesses of the PHTN safety management system will be summarized. Thus, we will be able to present some beneficial suggestions that help improve the reliability of the system. Finally, a coalition model among freight carriers will be proposed in chapter 5.

1.3 Master Thesis Outline

The rest of this thesis is organized as follows: Chapter 2 is the theoretical framework extracted from the investigation and previous publications. For the readers to have some preliminary ideas about this research topic, a relatively comprehensive review about related theories is provided. Chapter 3 is a summary of the chosen methodologies relevant to this research. Both qualitative and quantitative methods are applied and some data-related issues are discussed. Chapter 4 is a case study within the context of the PONZ. We summarize and analyze the existing practice adopted by PHTN players in risk management based on the information extracted from interviews. Then, a coalition model involving the inland freight carriers is proposed in chapter 5, which is aimed at strengthening the connection between port players and inland players. Also, a numerical example is provided to further explain our model. The last chapter is the conclusions, including the contribution and limitations of this study. The master thesis outline is shown in Figure 1.

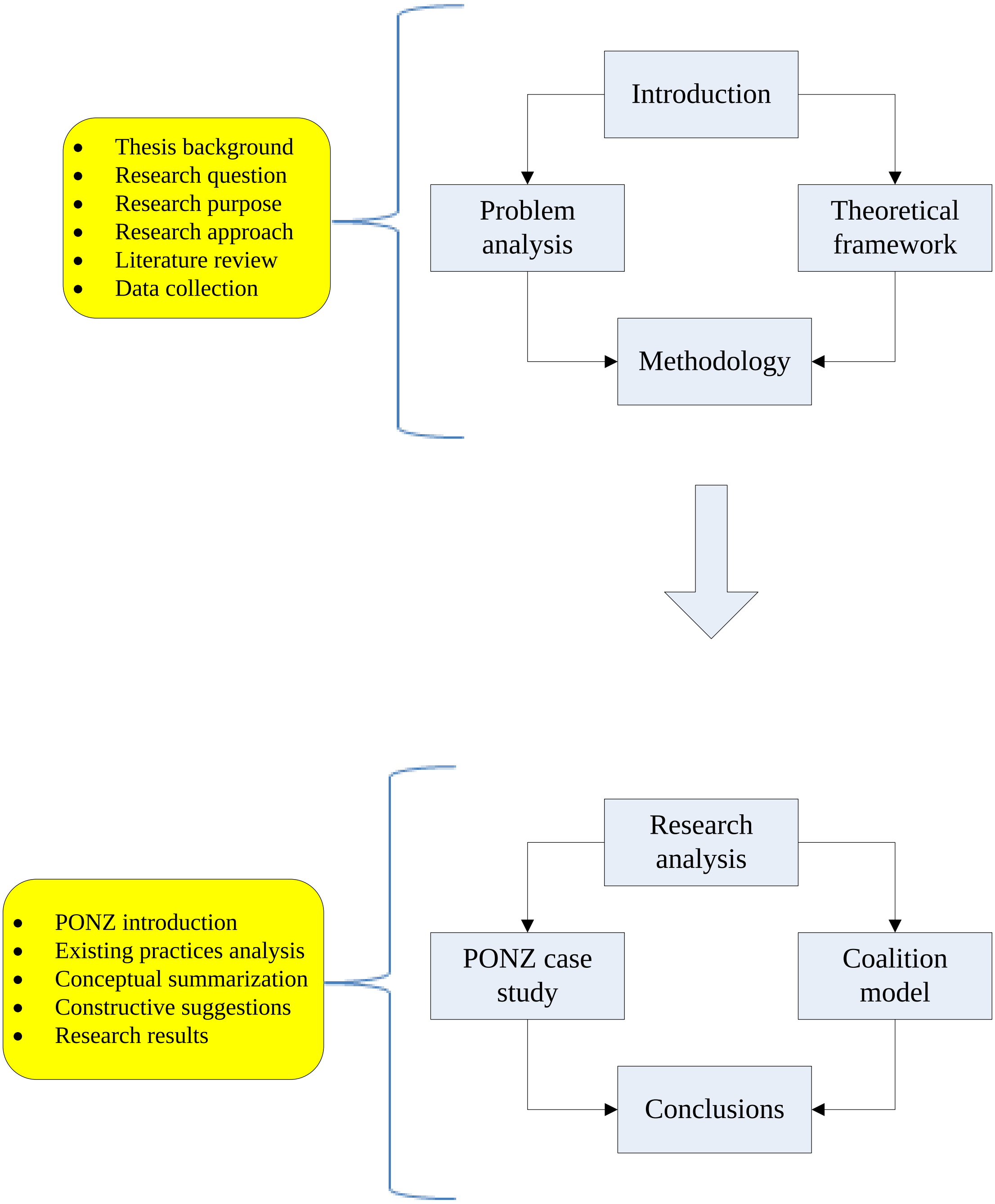

Figure 1: Master thesis outline

2 THEORETICAL FRAMEWORK

The purpose of this chapter is to analyze the previous literature and propose a theoretical framework supporting the following analysis. Some key concepts like ‘port regionalization’, ‘hinterland evolution’ and ‘intermodal freight transportation’ are reviewed. Then we analyze the spatial structure and the regulatory system of a typical PHTN. Risk management studies are discussed in section 2.6. At the end of this chapter, a brief review of Game Theory, which is the method adopted in chapter 5, is provided.

2.1Port Regionalization

The ‘Anyport model’ proposed by Bird (1971) is one of the most widely acknowledged conceptual perspectives on port development. To increase the capability of cargo handling, the port expands its size from an initial logistics node. Three major steps can be identified in this model: setting, expansion and specialization. This model provides a relatively comprehensive explanation for port development processes, especially in some traditional large ports. However, it is not enough to explain contemporary port development. This weakness is mainly reflected in two perspectives. First, it lacks the introduction of hub terminals in "offshore" or island locations, which is an increasingly important segment in modern port analysis. Second, there is no explanation about the rise of hub terminals, with little analysis of the inland dimension as a driving factor in port development dynamics.

Notteboom and Rodrigue (2005) proposed an improved model to reflect the modern port development process. Two extensions have been emphasized in this research. The first one is an explanation of the rapid rise of "offshore" hub terminals in island locations or with a limited hinterland. Usually these "offshore" hub terminals have greater depth for accommodating container drafts since they were built in recent years. Thus approach is an important factor here. Moreover, the investment in the hinterland can be much less since most of the cargo is transshipped, and the labor cost also tends to be lower. In addition, their locations usually have land available for future expansion. The second extension is about the incorporation of inland freight distribution centers as active nodes in shaping load center development. Since the emergence of global production systems and large consumption markets, the approach to distribution has changed, with logistics activities becoming more and more complex. It is not possible to create an efficient chain without integrating the entire transportation network. The process of the development of a modern port is shown in Figure 2.

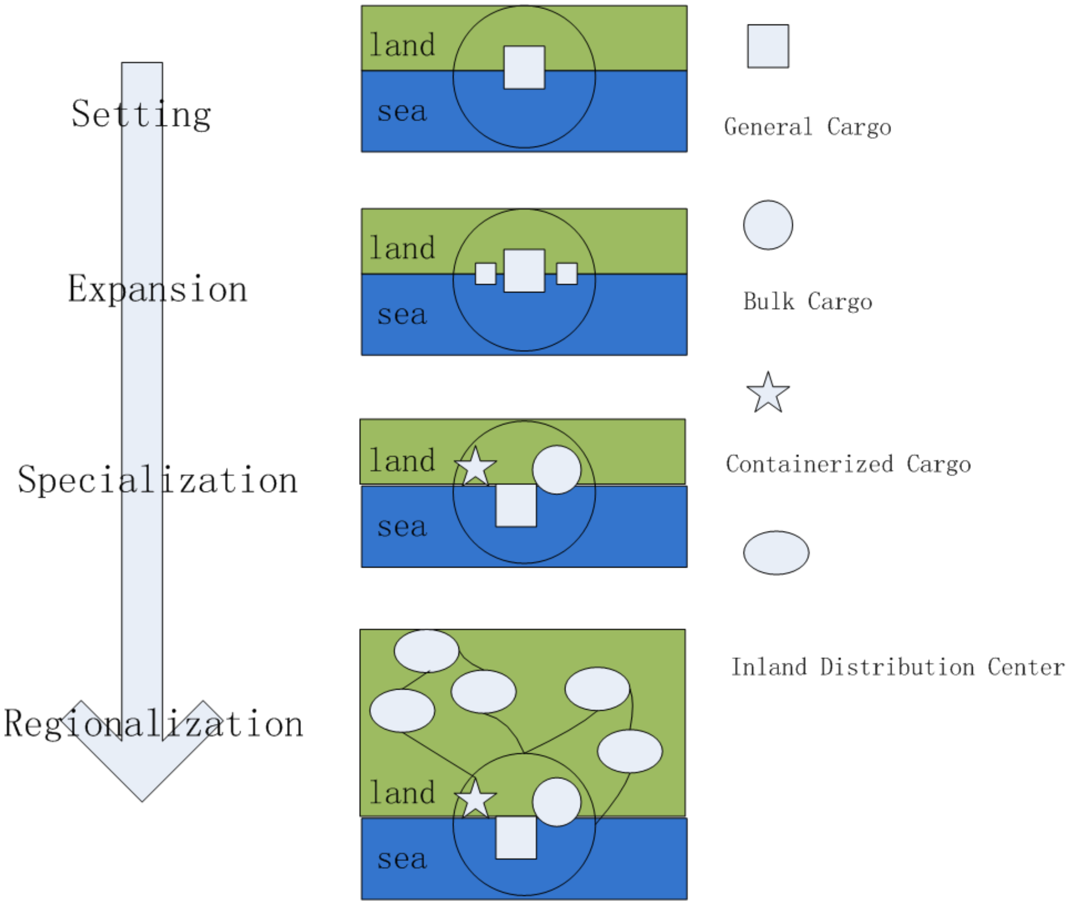

Figure 2: The evolution of a port
(Source: Notteboom and Rodrigue, 2005)

A port that has developed from a single node into a service supply chain will possess a PHTN. The phase of port regionalization not only exists in the Anyport model, numerous works in other literature address the characteristics of the spatial development of modern ports and their PHTN.

The model of Taaffe et al. (1963) proposes an ideal-typical sequence of transport development including six phases:

- scattered ports

In this phase, there are a scattering of small ports and trading posts along the coastline. Only small indigenous fishing craft and irregularly scheduled trading vessels have interconnections with them, and the size of the hinterland is extremely limited.

- penetration lines and port concentration

Hinterland transportation cost is reduced due to the emergence of major lines. At the same time, both the port and the interior market begin to expand and then port concentration begins.

- development of feeders

Feeders will design their routes with a focus on major ports and interior centers. These feeder routes create enough conditions for the major port to enlarge its hinterland at the expense of smaller ports which are close to it.

- beginnings of interconnection

Since the main lines are fully penetrated, small nodes begin to develop, and as feeders keep developing, some nodes become focal points for feeder networks of their own. Interconnection then begins, and these nodes will provide the hinterland of other small nodes around them.

- complete interconnection

As the feeder networks continue to develop around the ports, interior centers and main nodes, certain of the large feeders begin to link up.

- emergence of high-priority ‘main streets’

Theoretically lateral interconnection will continue until all operators are linked. After that the next stage consists of the development of ‘main streets’, which means a higher level of concentration. Since some centers will grow at the expense of the others, there must be a set of high-priority linkages among them.

Generally speaking, Taaffe et al. (1963) propose an increasing level of port concentration as feeder routes have more obvious development than others, in association with the increased importance of particular urban centers.

The structures of these two models are shown in figure 3 and figure 4 respectively .The comparison between these two port development models is summarized in Table 1.

<table>
<tr><th>Taaffe et al.</th><th>Notteboom et al.</th></tr>
<tr><td>Scattered port</td><td>Scattered port</td></tr>
<tr><td>Penetration lines and port concentration</td><td rowspan="2">Penetration and hinterland capture</td></tr>
<tr><td>Development of feeders</td></tr>
<tr><td>Beginnings of interconnection</td><td rowspan="2">Interconnection & concentration</td></tr>
<tr><td>Complete interconnection</td></tr>
<tr><td>Emergence of high-priority "main streets"</td><td>Centralization</td></tr>
<tr><td rowspan="2"></td><td>Decentralization and insertion "offshore" hub</td></tr>
<tr><td>Regionalization</td></tr>
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Table 1: The comparison between different development models of the port transportation system

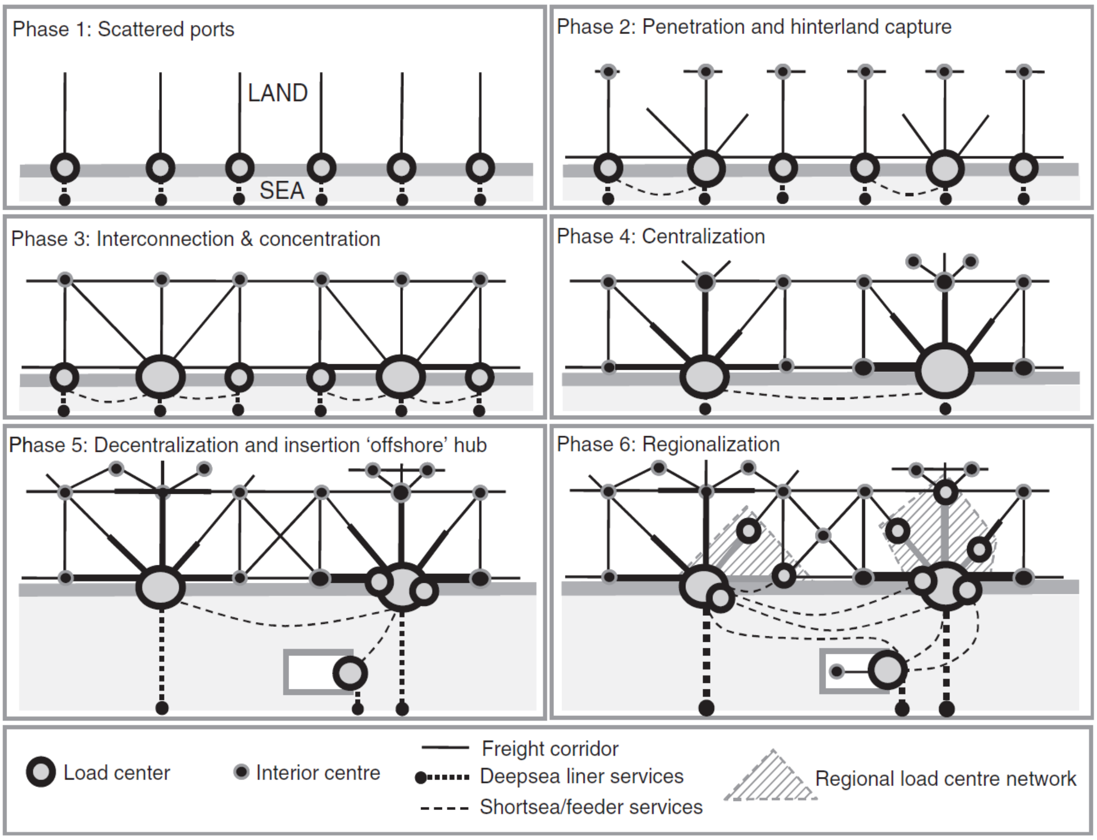

Figure 3: The spatial development of a port system
(Source: Notteboom and Rodrigue, 2005)

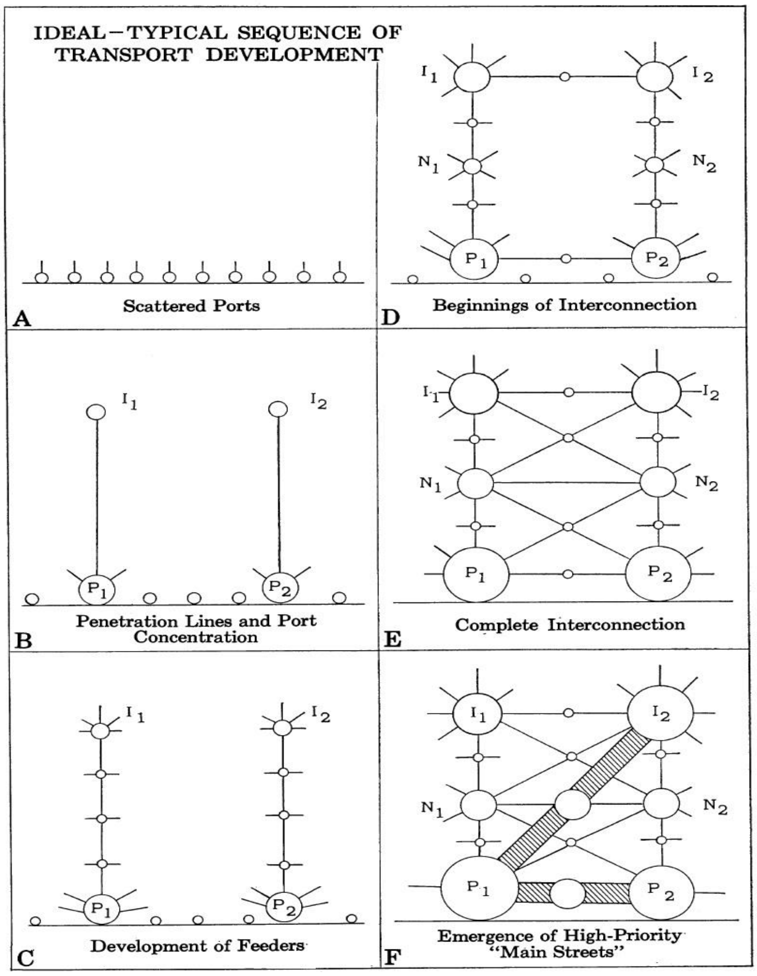

Figure 4: Ideal-typical sequence of transport development of a port
(Source: Taaffe et al., 1963)

Barke (1986) proposes a five phase model to illustrate the dynamic development process of a container port system and the rationale behind such development. It is similar to the model of Taaffe et al. to a large extent, except for introducing a de-concentration process.

2.2 The Evolution of a Hinterland

The process of port development is highly dependent on the geographical constraints of its hinterland and the characteristics of the regional economy. The first category is the "offshore" hub on an island. Because these "offshore" ports usually function as a transshipment terminal with some simple value-added operations, there is a lack investment in the hinterlands of these ports. Typical examples are Salalah in Oman and Tanjung Pelepas in Malaysia. The reason for the emergence of "offshore" ports in these places is diverse, but include convenient access to the main shipping routes and accommodating modern containership drafts. Normally, the local labor cost is relatively low with no unions. The terminals are owned partly or in whole by the carriers that often use the facilities (TRI maritime research group, 2003). The second category is the port with a very small hinterland. A typical example is the Tianjin port in China. This is partly due to China's export-oriented economy and the manufacturing activities are arranged close to the port (Wang and Olivier, 2006). The third category is the port with a large hinterland and long inland corridors. It is quite common to see this type of structure in the ports of the US and Europe, where the Intermodal Freight Transport system is highly developed (Notteboom and Rodrigue, 2007). A classification of PHTN is shown in table 2. However, it is by no means a comprehensive framework because the factors shaping the type of ports and their hinterlands are very complicated. As it is not the major concern of this paper, so only a rough classification is provided here.

type	Characteristics
Off-shore hubs	small islands, low labor costs, developing countries
Ports with small hinterland	short distance corridors,export-oriented economy, manufacturing activity close to the port,
Ports with large hinterland	long distance corridors, advanced intermodal transportation system, usually in developed countries

Table 2: A classification of port-hinterland system

The geographical definition of hinterland can be interpreted from a spatial focus, but the logistics operations in this area can be very complex and the importance of the hinterland has been discussed by many researchers. The hinterlands have become a key component for linking more efficiently elements of the supply chain, namely to ensure that the needs of consignees are closely met by the suppliers in terms of costs, availability and time in freight distribution (Notteboom and Winkelmans 2001; Robinson 2002). Because of the numerous elements, there are many challenges from different perspectives influencing the development of a hinterland. Visser et al. (2007) discuss the challenges of a new hinterland transport concept from the organizational and technological perspectives. In their paper, new port concepts in which the 'port entry' is shifted to an inland location, accompanied by the movement of all kinds of operations such as buffering, stripping and stuffing and warehousing, contribute to solving port problems, such as congestion and lack of space.

In the phase of port regionalization, inland distribution becomes the foremost process in port competition, favoring the emergence of transport corridors and logistic poles. The port itself is not the chief motivator for and the instigator of regionalization. Regionalization results from logistical decisions and subsequent actions of shippers and third-party logistics providers (Notteboom and Rodrigue, 2005). Similarly, the port-hinterland can be represented within three dimensions: macro-economic, physical and logistical. The departure point of the macro-economic hinterland is transport demand especially in the context of a global setting. The physical hinterland focuses on the natural environment and extent of the transport supply, both from a modal and intermodal perspective. Finally, the logistical hinterland tries to find the point of balance between transport demand and supply for their organization of flows (Notteboom and Rodrigue, 2007). Intermodal freight transport (IFT) as a crucial concept, will be analyzed in the next section.

2.3 Intermodal Freight Transport

There are multiple statements with different emphases defining intermodal transport. Some definitions focus on a more general level. ECMT (1997) defined it as "the movement of goods in one and the same loading unit or vehicle by successive modes of transport without handling of the goods themselves when changing modes". The European Commission (2002) illustrated the characteristic of IFT as "providing transport for consolidated loads such as containers, swap-bodies and semi-trailers by combining at least two modes". Some research focused on pointing out the role of containerized cargos in IFT (Jennings & Holcomb, 1996; Norries, 1994). More definitions were discussed by Bontekoning (2004) where 92 publications were reviewed and a comprehensive identification of the intermodal research community was provided.

IFT has a clear benefit because of the containerization of cargo. It increases the efficiency when changing from one transport mode to another (Alessandri et al., 2009). Nowadays, the research of IFT is often discussed from the perspective of the supply chain. Intermodal related activities are seen as a value-added process within supply chains (Rodrigue and Notteboom, 2009; Rodrigue et al., 2013). Terminal operational issues, such as available storage space, are strongly tied in with the performance of the supply chain. Thus, a number of studies address this issue as a factor when building a lean supply chain (Beskovnik and Twrdy, 2011). Also, with the trend towards greater containerization in maritime transport, IFT is often considered within the role of the port. Martin (2014) reviewed the application of spatio-temporal ordering strategies and practices in delivering intermodal shipping containers. By systemic standardization in packaging, the intermodal container achieved global hegemony. Parola and Sciomachen (2005) evaluated a possible future growth of container flows in the northwestern Italian port system. They considered the factor of land transport and modal split re-equilibrium and used a simulation model to draw their conclusion. Casaca (2005) pointed out a lack of lean practices in small or medium-sized intermodal terminals, which is not synchronous with a lean port.

In addition to a more efficient handling process, another prominent benefit of IFT exists in its being less environmentally damaging (Hanaoka and Regmi, 2011). It is pointed out that solution optimizing cost in the intermodal network is one-sided and the green issues should be taken into account (Lee and Gu, 2013). Previous publications that address the sustainable development of intermodal container networks are multi-dimensional. We categorized them into three different aspects. The first aspect is about reducing waste in cargo handling in the process of transportation, like the application of foldable containers (Shintani et al., 2012) and the repositioning of empty containers (Shintani et al., 2007; Choong et al., 2002). The second aspect can be concluded as a routing problem in the intermodal network in order to achieve a shortest possible initial and final journey. As a result, energy consumption is reduced. Among the previous research, there is no shortage of both general modelling (Ayar and Yaman, 2012; Barnhart and Ratliff, 1993) and case studies (Bookbinder and Fox, 1998) when it comes to this topic. The last aspect is related to the amount of carbon dioxide emissions in the transportation chain. Liao (2009) proved the advantage of intermodal container transport by comparing its carbon dioxide emissions with trucking in Taiwan. The results show that by increasing the efficiency of maritime fuel, the amount of carbon dioxide emission is reduced significantly. Kim and Wee (2014) compared the carbon dioxide emission of three types of freight system in Europe: a vessel-based intermodal system, a rail-based intermodal system and a truck only system. The results show that generally an intermodal system emits less CO_2 than the truck-only system but that, under some extreme circumstances, this may not be true.

2.4 Spatial Structure of Port-Hinterland Transportation Network

As mentioned above, the structure of a PHTN could be different across countries and regions. In this section, we introduce a typical PHTN by combining the concept of port regionalization, hinterland development and intermodal transportation.

The port itself is a functional region that covers land and offshore area. It is a complex system where both public and private stakeholders come into play. Geographically, the handling processes can be divided into offshore operation and terminal operation, including anchoring, unloading and distribution. The port is composed of several terminals, in which the types of processed cargo could be different (e.g. general cargo, bulk cargo and containerized cargo). The terminals could be run by the same or different port operators. These operators are relatively independent, developing facilities for their purposes. The daily operational system of a port consists of different types of cargoes and different operators.

After finishing the handling process in port, these cargos are going to be delivered to the hinterland, in which the inland transportation system comes into play. An advanced intermodal transport system is the major driving factor in reducing the cost and increasing the logistics reliability. Normally, this system is composed of road and rail (sometimes waterway) with several distribution centers or transfer centers for modal change. These centers are connected by intermodal links and corridors and their functions are diversified. They could be used as a 'factory' for value-added processes, a station for changing the transport mode or a distribution center directly which satisfies the demand area.

No unified structure can be used to describe all the PHTNs in the world. To give a clear picture of the port-hinterland system that is going to be investigated in this research, a typical model that describes the structure of the network is provided in Figure 5. More discussions are provided in the next section.

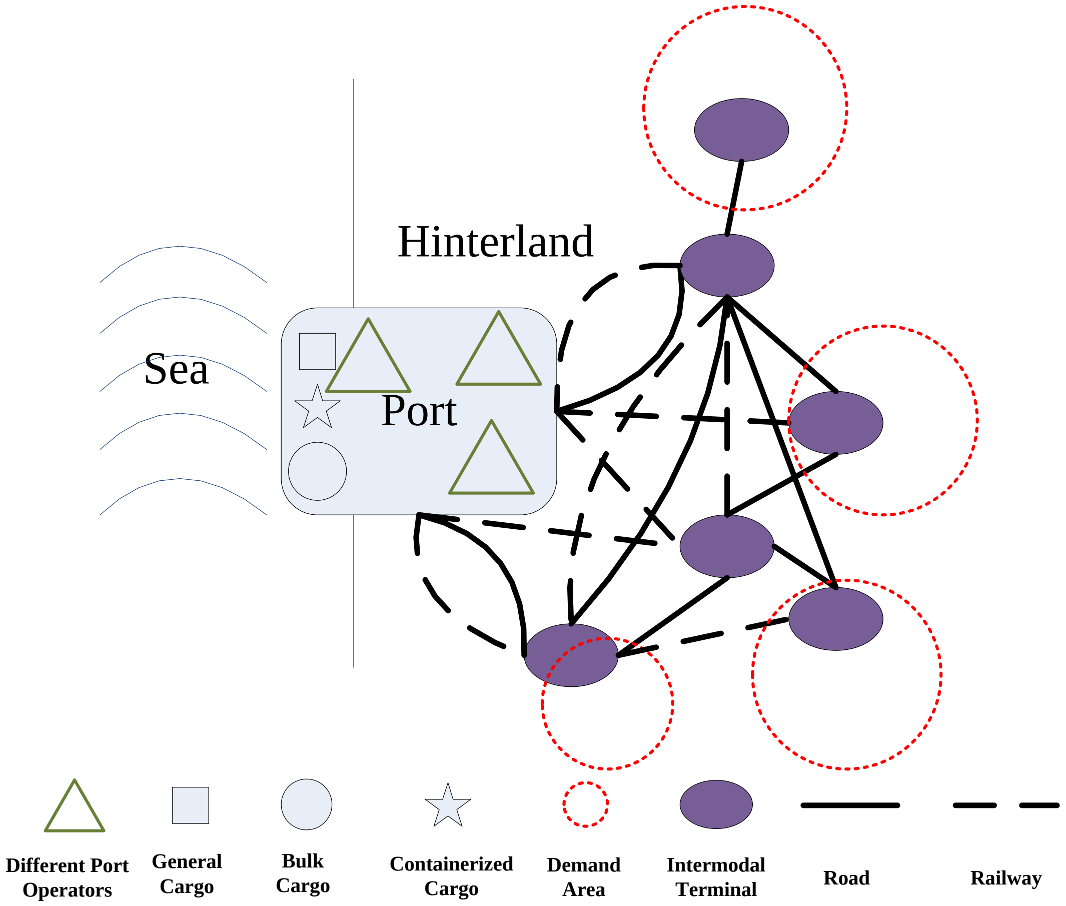

Figure 5: A model of a port-hinterland transportation network

2.5 Functional Role of Involved Players

From a global perspective, the structure or the constitution of involved actors in a PHTN is very diverse. There are two extreme cases in terms of the role of port authority. The first is where the function of the port authority is more like a landlord, where the maximum amount of cargo handling activities is left to the private sectors. The second is where the port authority directly takes responsibility for almost all the activities carried on in the port area (Goss, 1990). For example, the management mechanisms of ports in Europe and in China are quite different. In most European ports, the port authority is a totally different concept from a port operator. The port operations are usually run by several different operators. One operator runs a terminal or deals with a certain type of cargo, like bulk cargo or containerized cargo. The operators are most often independent from each other and the port authority has almost nothing to do with the daily operation of the port. Most ports in China have a different system, where the port authority is the major actor responsible for the cargo handling process. To a certain degree, the port authority is the port operator or, at least, acts like a port operator. Also, some of the Chinese ports have only one operator or several sub-operators affiliated to one operator. The port authority is similar to the port operator in this case.

The inland transport operators can also be different. Many factors come into play here. For example, the geographic characteristics, the condition of the infrastructure and the level of development of the local economy. The simplest case is where only one transportation mode is connected to the port, for example, a railway. The cargo is delivered from the port through the railway to the final destination. There is only one inland transport operator, i.e. the rail operator who is responsible for all the inland transport. Where there is more than one inland operator, the hinterland is shaped by an intermodal transport network. The logistics link is a combination of road, railway and waterway and is connected by intermodal terminals. The inland transport operators are composed of rail or road operators. Within a certain transport mode, there are multiple different operators. For example, the road mode in the hinterland could be run by more than one transport operator. All these operators are responsible for part of the road transportation of the goods.

To conclude, because the functional role of the major players involved in a PHTN is very diverse, it is very difficult to summarize a framework that captures all aspects in all the different PHTNs. We have tried to extract some statements answering this question from a more general perspective (see table 3), but it is by no means a comprehensive summary of the roles of each player, since this differs across countries and regions.

Players	Functional role
Port authority	Two types: 1. More like a 'landlord', the cargo handling process left to other players; 2. Directly involved in daily operation of the port.
Port operator	In charge of or participating in the cargo handling process in port. Sometimes also covers the inland part.
Inland transport operator	Responsible for some infrastructure construction in the transport system. Sometimes also provide logistic service.
Logistics service provider	Provide logistics service about delivering the cargo to the end consumer.

Table 3: A summary of the functional roles of players in a PHTN

2.6 Risk Management of a PHTN

Alises et al. (2014) suggest that risk perception in project management has yielded an increasing interest in risk analysis in operational processes in many disciplines and areas. This explains the massive emergence of risk concepts and assessment methods. As a consequence, there is no common definition of risk.

Risk management is a relatively advanced topic in the academic field. The issue of risk management has been studied for a quite a long time in supply chain analysis. There are three major perspectives, including supply, demand, and a combination of the two.

Smelzer and Siferd (1998) discuss the supply of risk management in the supply chain. In order to have a better understanding of risk management from the view of procurement, they do their research based on transaction cost theory and a resource dependence model and point out that proactive procurement management is risk management. Svensson (2000) discusses the risk in supply chains when the logistics activities become chaotic, and he develops a conceptual analysis framework relating to the vulnerability of supply chain. This framework focuses on the internal logistics process of manufacturing enterprises. He does a survey in a Swedish car manufacturer, and points out that the framework consists of two components, one is the risk of category management and another is the risk of procurement management. Hallikas et al. (2004) propose a general structure of supplier risk management and an approach to it within a complex network environment. The results show that the risk goes to a higher level when more members join in the supply chain. Zsidisin and Ellram (2004) believe that supply risks exist in any manufacturing enterprise and put forward the following key supply risks: suppliers' operational risks（e.g., the financial stability of the supplier）, suppliers' productivity constraint risks (e.g. lack of equipment or people), quality and technology risks (e.g., the obsolescence of current production technology), the change of product design (e.g., dynamic customer demand) and disasters. The results of their research show that many enterprises realize the problem of supplier risks, but most of them do not take necessary action to reduce the risk, with only a few of them undertaking a risk assessment of procurement to reduce the risk by planning. They also point out that even if an unexpected event occurs with a very small possibility, this can lead to a serious loss in the supply chain. In addition, they believe that through a variety of strategies and techniques the possibility of occurrence of an unexpected event can be minimized or associated adverse effects at least reduced. Assessment should be the first step in supply chain risk management. In order to respond to risk, contingency plans should be established at the beginning and a manual drawn up to show how to control the procurement risk.

Carr and Tah (2001) discuss the demand risk of the supply chain and find shortcomings in management processes, tools and technology. They propose a kind of description language to measure the level of risk which can be regarded as a shared knowledge-driven approach to risk management. They define the meaning of supply chain risk in their own way and establish appropriate remedial measures. In addition, they discuss how to establish a database to support risk management.

Ritchie and Brindley (2000) make a comprehensive analysis of variety of risks in the supply chain. They believe that the majority of existing supply chain relationships embodied within linear models will soon be replaced by some more complex and disorderly supply chain models. The new business model will appear soon and the ability to create a flexible resilience alliance will be a key management technique. Nagurney et al. (2004) develop a super network structure of the supply chain, including manufacturers, distributors and retailers and taking into consideration both the demand and supply risks, and modifying the standard model to account for multi-attribute decisions which simultaneously maximize profits and minimize risks.

There is also some risk management research based on small probability events. Sheffi (2001) analyzes the risk of terrorist attacks on the supply chain and proposes that because of the vulnerability of the supply chain, operators and other players should cooperate with government to enhance security measures to prevent terrorist attacks. Meanwhile, it is necessary to keep inventory at a high level and restructure operational processes to improve the security of the operating environment.

Nowadays, the risk management of port-hinterland is an important research area because it is often accompanied by the safety, efficiency and reliability of transport (Kristiansen, 2013). While efforts have been devoted to the identification of weather trends (Athanasatos et al., 2014), there always exists the danger of overwhelming hazards (Alises et al., 2014).

The aim of risk management is to identify risks and reduce their negative effects as much as possible by formulating response strategies. This process is always similar to five phases (Dorofee et al., 1996): Identify (identify the risk factors, their causes and their potential consequences), analyze (determine the nature and level of risk), plan (planning and scheduling preventive and corrective actions), follow-up (implementation of plans) and control (monitoring under the existing mechanism). It is important to note that communication and the interaction of information are essential (Figure 6).

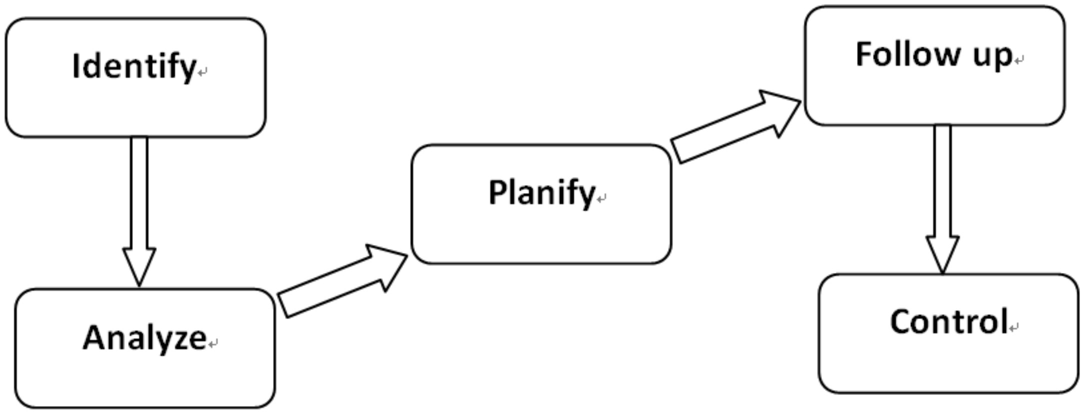

Figure 6: Risk management process

2.7 Theoretical Basis of the Modelling

As shown in the thesis outline, a coalition model will be proposed in this research to further answer the research questions. In this model, some classical approaches in Game Theory will be used (see chapter 5). In order to provide a theoretical basis of modelling, it is necessary to briefly review some of the Game Theoretical research before actually implementing the modelling.

Game Theory is a tool for analyzing situations where players make interdependent decisions and influence each other (Rasmusen, 1994). There are two branches in Game theory, so called non-cooperative and cooperative games. A non-cooperative game is used for analyzing strategic moves while a cooperative model is more used for discussing how much power the different players have in a given setting. Also, some recent research mixed these two branches together in order to solve the research questions (2006; MacDonald and Ryall, 2004; Esmaeili et al., 2009). As a well-developed academic area of research, there are enormous publications and papers in the field. Thus, we only review some of the research that is most relevant to this thesis.

Specifically, the upcoming model can be summarized as a profit sharing model and a model like this has been proposed by many researchers within the context of a cooperative game. It is widely used in studying the coordination and risk management among supply chain partners. Nagarajan and Sosic (2008) studied the profit allocation and stability problem by surveying some applicants. The issue of feasibility in commonly seen supply chain models is discussed and a bargaining model is applied as a method to solve the profit allocation problem. Hennet and Arda (2008) combined queuing theory and game theory to study the conflict between the individual's own economic criterion and global optimization. By making use of the classic supply chain model, i.e. a producer facing a random demand and a supplier facing a random lead-time, they evaluated the efficiency of different types of contracts between partners in a supply chain. Lippman and Rumelt (2003) propose a theory of sustainable 'rent' within a form of cooperative game. They pointed out that the unpriced resource or resource bundles cannot be accurately guided in the market, which means sometimes they will lose value and be underestimated in attaining advantage.

Game theory is also considered a widely used method in port-related research, particularly in addressing issues like port competition (Zhao and Xiao, 2014; Zhuang et al., 2014; Park et al., 2010) and port alliances (Xu et al., 2015; Ding, 2015; Wu, 2014). Generally speaking, non-cooperative games, like the Stackelberg game, are more often used to depict and simulate the situation of port competition. While the cooperative game is more involved in analyzing port alliances where limited resource are made full use of. However, there is little research directly applying the cooperative game in the relationship between port and its own hinterland. Thus, the application of the coalition model in this research will be able to fill in this gap.

Game Theory is suitable in this research because there are different players involved in a PHTN and they make interdependent decisions when it comes to coping with the damage from a UEE. What's more, the coalition model proposed in chapter 5 is a typical profit allocation problem. Thus, cooperative game theory is applied in this study as it is an effective and well developed tool for addressing this issue.

2.8 Summary

This chapter is very crucial as it provides the theoretical background to the entire research study. We review a number of relevant publications or research and summarize some insights that are of benefit to the upcoming research. Specifically, three broad categories of publications are discussed in this chapter: port related research, risk management related research and the application of Game Theory (see figure 7). By analyzing previous research and combining the knowledge we already have, we are able to properly choose the research method and generate the following research.

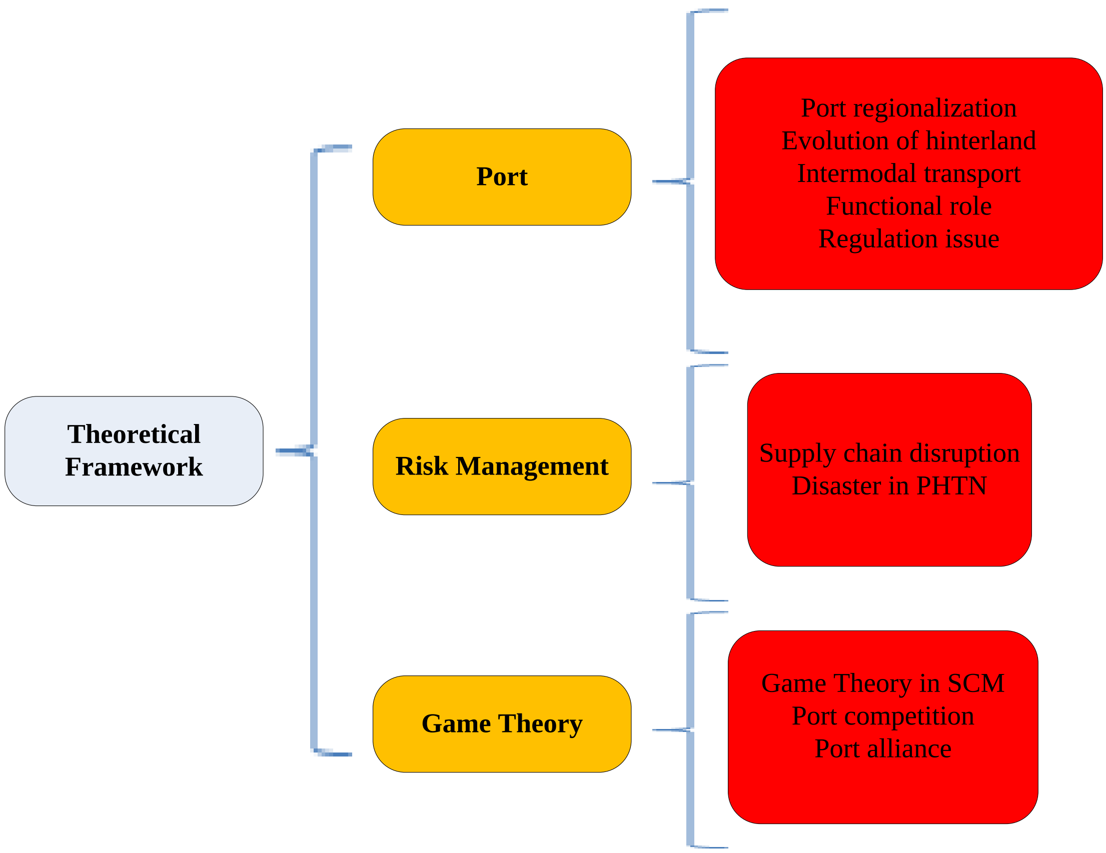

Figure 7: A summary of the theoretic framework

3. METHODOLOGY

This master thesis covers several different dimensions relating to the research using both qualitative and quantitative methods. Each method is adopted for some certain reasons and they are all important to achieving the results. The aim of this chapter is to give a clear picture to the readers about the chosen methodology in this study. An explanation and justification of the methods applied in this research are also provided in this chapter.

3.1 Research Philosophy

The research questions and problem analysis in previous chapters have shaped a general framework for this present thesis and have established several fundamental characteristics of this research. In this section, we clarify the research philosophy from four aspects based on the theory proposed by Bryman & Bell (2007): type of theory, epistemological considerations, ontological considerations and research strategy.

Type of theory

According to Bryman and Bell (2007), deductive research is used to test an existing theory based on empirical observations, while an inductive study is using these observations to generate new theories. We prefer to say that this research is a combination of both deductive and inductive study. First, we conduct a case study of PONZ to formulate a conceptual framework that summarizes the practice within a PHTN to cope with the damage from a UEE. The purpose of chapter 4 is to analyze and evaluate existing observations. In this sense, it is aligned to the process of deduction. Second, when finding the weakness in existing observations, we propose a mechanism to improve the disadvantages, i.e. the coalition model proposed in chapter 5. In this part, we generate a new theory and reflects inductive characteristics. Thus, this paper is classified as involving both deductive and inductive study.

Epistemological considerations

In the issue of positivism or interpretivism, we consider our research as positivism. Positivism is defined as a theory stating that positive knowledge is based on natural phenomena and their properties and relations and the reality will not be affected by the process of investigating (Collis & Hussey, 2009). In this study, the structure of a PHTN and the relationship among the PHTN players will not change regardless of how the researcher chooses the methodology

Ontological considerations

Within this aspect, we classify this research as objectivism, which is defined by

Bryman and Bell (2007) as ‘social phenomena and their meaning have an existence that is independent of social actors’. Solutions to the issue like how to deal with the damage from a UEE will not change no matter if it is investigated or not, or who is investigating it.

Research strategy
Both qualitative research and quantitative methods are invoked in this research. In chapter 4, a case study is conducted based on information obtained from interviews. It is organized more in terms of qualitative descriptions, rather than any form of quantitative representation or analysis. In chapter 5, we generate a coalition model based on the analysis from chapter 4. With the application of the Shapley value, an appropriate profit allocation mechanism is established. Also, several numerical examples are provided after the model description. This part is more resonant of quantitative research. More discussion can be found in the next section.

3.2 Research Strategy

3.2.1 Qualitative research

Qualitative methods are applied in this paper to obtain some preliminary results relating to the current practices adopted by involved players when it comes to coping with UEEs in a PHTN. By conducting qualitative research, the authors enrich the content of this paper and further improve the theoretical framework of this research. More material is provided to increase the reliability of the results. What’s more, qualitative research offers some useful insights when establishing the coalition model and makes the assumptions in the model more convincing. More exactly, a case study of PONZ is proposed in chapter 4.

As mentioned above, the regulatory structures of a PHTN vary across different countries and regions. Sometimes even the players with the same name can have different functions, for example, port authorities in different ports have different functional roles (see section 2.5). It is not possible to establish a general model that is suitable for explaining all the PHTNs in the world. Thus, a case study is more suitable for drawing insights and to verify the model.

The Ningbo-Zhoushan port is the chosen case in this thesis. We choose this port because of two reasons. The first reason is the rapid growth of Ningbo-Zhoushan port in recent years. More introduction to PONZ can be found in chapter 4. The second reason is about the availability of data. The authors have been keeping in touch with the management staff of Ningbo Port Company Limited and have established a strong relationship with some of the employees of this company. Thus, the quality of data collected, such as via interviews, is considered acceptable.

3.2.2 A coalition model

In addition to a qualitative approach, a quantitative method, i.e. a coalition model, is applied in this paper. This will increase the reliability of the study and the insights drawn from the model will make the final research conclusions more convincing. The motivation for developing this model is the importance attached to involving more players in PHTN to deal with UEEs, which is a factor illustrated in, and derived from, the case study.

In the process of modelling, some assumptions (see chapter 5) are made to simplify the less important information and make the model more focused on the relevant issue. It is inevitable that these assumptions will reduce the generality of the model and make the result less reliable. But the purpose of mathematic modelling is to give a better understanding about the real world. It is less likely that one model will precisely cover all the relevant phenomena. Thus, as long as the assumptions are convincing and based on reality, then the conclusions obtained from the model may be considered realistic and acceptable.

3.3 Data Collection

3.3.1Primary data

In this research, interviews are considered to be the major approach to collecting primary data. This is a method in which the interviewers ask selected interviewees questions about what they do, feel or think (Collis and Hussey, 2009). In order to collect more primary data and enrich this research, three interviews are conducted in this research. The three respondents are all from PONZ. The related information of these three interviews is listed in table 4. Specifically, because we want to leave some room for flexibility, a semi-structured strategy was adopted in all these three interviews. We list some key questions prepared before the interview. The structure is established to cover questions from two categories. The first is the management structure of the port hinterland network. For example, which part of the network is under the charge of which player? The other is the existing practices applied by the players to cope with the negative effect of UEEs. The details of the interview outline and the record of the interviews are provided in Appendix B.

Respondent	Position	Department	Interview type	Date	Duration
Mengda Tong	Chief Engineer	Ningbo Port Company Limited	Face-to-face Ningbo	27.05.2015	26min
Mingsheng Hang	Director	Ningbo Municipal Port Administration Bureau	Face-to-face Ningbo	27.05.2015	32min
Yahui Teng	Vice Director	Ningbo Port Company Limited	Telephone	22.04.2016	24min

Table 4: Information of interviewees

3.3.2 Secondary data

Secondary data are collected from an existing source, such as publications, databases and international records (Collis and Hussey, 2009). In this research, Secondary data comes from annual reports and other academic papers. In order to get some timeliness data with high reference value, we focus on those reports and papers which were published in recent years. Since we only need some general information about PONZG, we chose the Annual Report Summary 2015 of PONZG (Ningbo Port Company Limited, 2015).. We also obtained some secondary data from other papers to obtain geographical information (Huang & Bao, 2011) and economic information (Yang, 2009).

3.4 Summary

In summary, both qualitative and quantitative approaches are an indispensable part of this present research. A framework that summarizes the chosen methods is shown in Figure 8.

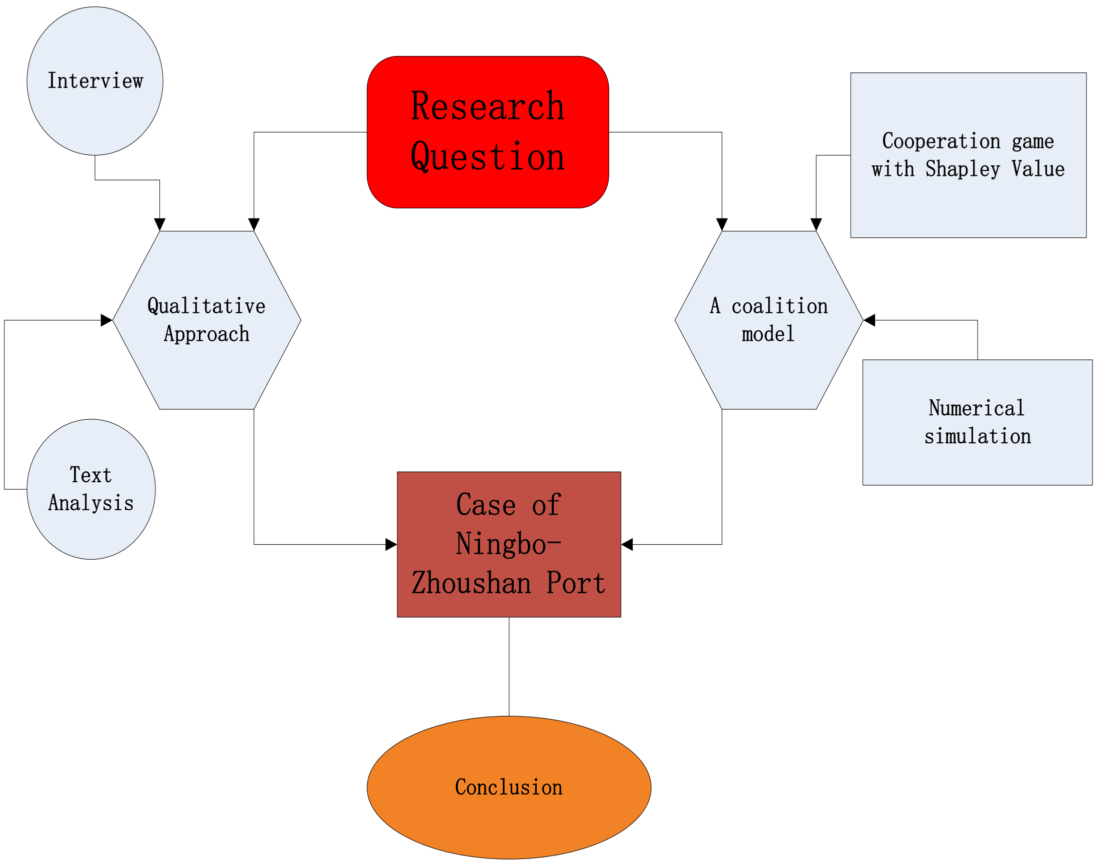

Figure 8: A framework of research methodology

4 CASE STUDY OF PONZ

In this chapter, we will conduct a case study of PONZ focusing on its risk management in the case of UEEs. To structure this chapter, first we will make a brief introduction of PONZ and its hinterland. Second, existing measures, rules and settings for risk management will be presented. Both background and risk management information is collected by three interviews conducted with people from the Port of Ningbo-Zhoushan Group (PONZG) or port authority, and through pervious annual reports and related literature. After that we will analyze and summarize them, and some conclusions will be proposed at the end.

4.1 General Information

The PONZ belongs to the city of Ningbo, a famous port city with a very long history. Ningbo is located in the middle of China's mainland coastline, and south of the Yangtze River Delta (Figure 9). It covers a land area of 9816km^2 and an ocean area of 9785km^2 (Huang, 2011). In 2015, the total cargo throughput was 535 million tons, essentially the same as the previous year and ranks first in the world in tonnage handled (PONZG, 2015). Also in this year, 22.19 million TEUs were handled, an increase of 6.1% from one year earlier. The ranking of Ningbo in container throughput surpassed that of the Port of Hong Kong to reach number 5 among all ports in the world (PONZG, 2015). Dry cargo throughput was almost the same as the previous year, as was the throughput of liquid chemical products. However, crude oil throughput came to 51.78 million tons with a growth of 2.1% over the previous year (PONZG, 2015).

PONZ has 19 terminals in total, in which the wharves can be divided into two types: public wharves and cargo owner’s wharves, with the latter including private wharves, foreign investment wharves and state-owned wharves. Public wharves account for 60% of the total, while the other 40% are cargo owner’s wharves. For some specific cargo like containers, more than 99% are operated by PONZG (Interview with Yahui Teng, 2016).

According to its geographical location and the situation of the transport market, there is a common idea about its hinterland. The major part of the hinterland is the Yangtze River Economic Belt which is made up of 7 provinces (Jiangsu, Zhejiang, Anhui, Jiangxi, Hunan, Hubei and Sichuan) and 2 cities (Shanghai, Chongqing). The Yangtze River Delta is the direct hinterland among them, while the other areas are the public hinterland of the port (Yang, 2009).

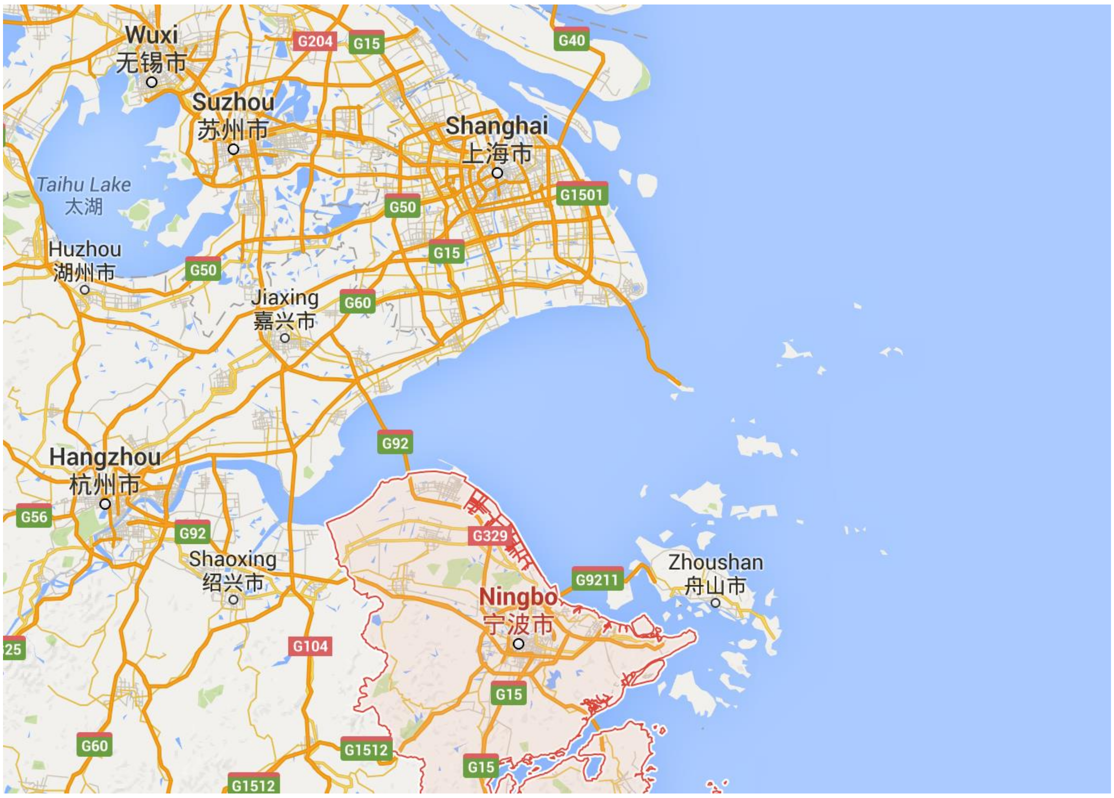

Figure 9: Location of Ningbo city
(Source: Google maps, 2016)

4.2 Existing Problems and Practices

PONZ has an advanced operational system where the practices for risk management are comprehensive. Different emergency plans exist within the system and can be divided into different types according to specific events (e.g., typhoons, strikes etc.) or the type of wharf at the cargo level (e.g., bulk cargo wharf, chemical products wharf). To summarize its existing measures, we introduce the existing practices with respect to different types of unconventional events.

(1) Natural disasters

Firstly the chief economist Tong mentioned earthquake. Because of geographical reasons, the probability of an earthquake which will have a strong influence on the PONZ is almost zero. Moreover, earthquakes are very hard to predict. Thus, the port has no specific measures for earthquakes (Interview with Yahui Teng, 2016). On the other hand, Typhoons can be a higher probability unconventional disaster when compared with earthquakes. Indeed, typhoons are quite a common natural disaster for the ports of China. There are a number of measures available for responding to typhoons. The first barrier comes from the advantageous geographical location of the port of Ningbo. As can be seen in Figure 10, no matter which direction a typhoon might come from, the speed and force of it will decrease due to the obstruction of surrounding islands. Secondly, typhoon forecasts are very precise nowadays. Usually, the port operators will have enough time to prepare and implement their measures. What's more, PONZ has certain safe anchorages for vessels or ships to moor in during typhoons.

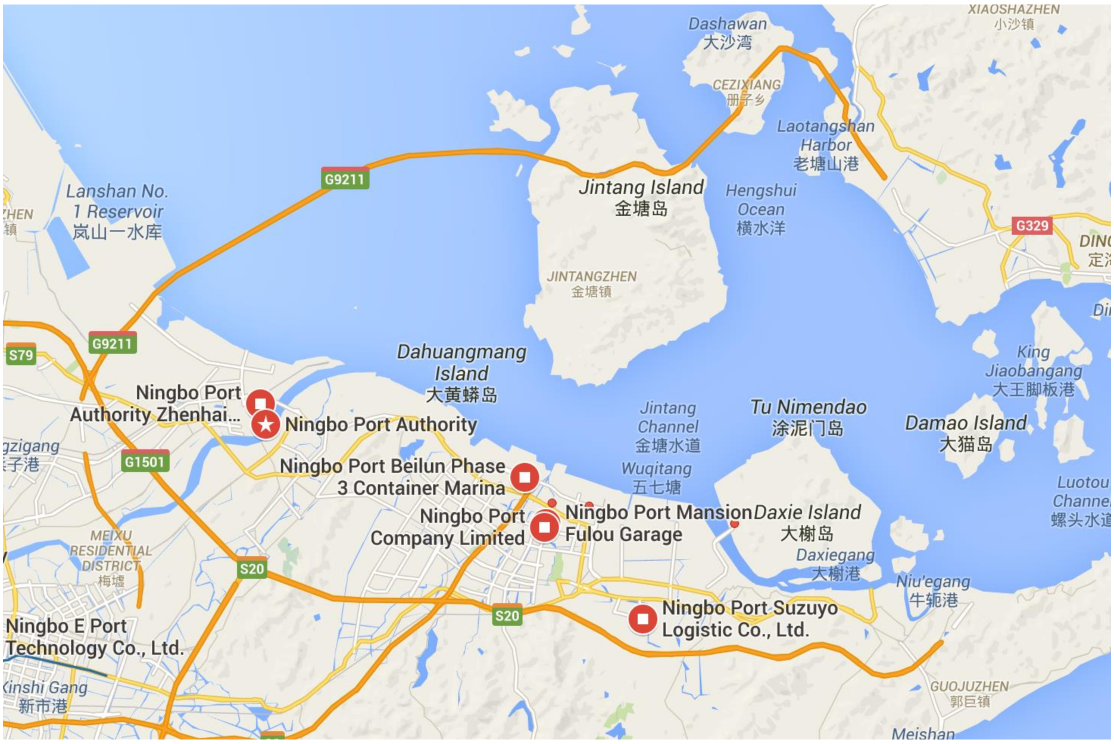

Figure 10: Location of PONZ
(Source: google map, 2016)

(2) Social or public events

There are many operators involved in a port's daily operation, including port authorities, third-party logistics companies and shipping companies. Different port operators or inland operators have their own standard of management and security, but they are always linked with each other.. E.g., the standards applied to partial load containers is different between waterway and highway, with the latter having more strict requirements. Trucker strikes sometimes happen outside the port. When this sort of problem arises in China, the government plays a leading role and other operators are responsible for coordinating activities. Moreover, the major port operator in PONZ is a state-owned enterprise, so the probability of internal worker strikes happening is very low (Interview with Mengda Tong, 2015).

(3) Engineering and information technology

The PONZG puts a high value on engineering and information technology. The requirements of equipment are strict in all sections, from production to use, then to repairs and maintenance. The status of equipment is not only related to engineering operations, but also influences the transmission of information. For example, the base station of each terminal is responsible for commanding all operations within the specific terminal. In PONZ when equipment in the base station needs to be repaired, they will use the old but effective equipment to replace it temporarily. This old equipment uses an analog signal which is not as advanced as a digital signal, but it can still play a role in the short-term without any extra costs being incurred.

(4) Leakage of liquid chemical products and oil

As we mentioned above, there is a large amount of liquid chemical products and crude oil in the port of Ningbo, which could have catastrophic consequences under a UEE. This kind of event can potentially lead to a chain reaction or even an explosion. To guard against this kind of risk, the new Production Safety Law requires that the legal representatives of an enterprise have to take security exams and take part in emergency drills. Moreover, the port authority also strengthens the relevant security regulation. Besides the supervision of hazardous goods themselves, the supervision of facilities is also important. Certificates need to be replaced by new ones every three years, and reports about the aging of equipment should be done at the same time. Both random and regular checks will be applied to ensure a highly reliable management system. At the same time, an enterprise should turn to self-evaluation from passive acceptance (Interview with Mingsheng Hang, 2015).

These measures above are always used to solve some specific UEE, but there are also some other practices or strategies whose original purposes were not for risk management, or risk management is not the main purpose, but they indirectly influence the performance of risk management. For example, PONZG has developed its own truck fleets (Interview with Yahui Teng, 2016). There is no doubt that their main purpose is to seize a market share of highway transport, but we should also admit that when strikes happen in inland operators, the own fleets will become effective. What's more, in the interview with Yahui Teng, he puts a strong emphasis on the development of railway, and their determination to enhance this. The main purpose of this target is to extend the hinterland to central regions and reduce the transport cost. However, it is actually a kind of risk diversification to reduce risk exposure, because about 75% of containers are transited by highway nowadays (Interview with Yahui Teng, 2016).

4.3 Summaries and Suggestions

After summarizing the existing problems and measures of PONZ, it is very clear that port operators, inland operators and port authorities are involved in risk management under a UEE. Problems relating to risk management not only exist in the port, but also have a strong connection with its hinterland. When facing different types of UEE, the same port operator/inland operator/port authority plays a different role, sometimes in a leading position and sometimes in a supporting position. All of them need to seek cooperation with other players. No matter what is the nature of an unconventional event, the measures comprise three parts chronologically: preventing pre-disaster, control during the disaster and remedy post-disaster. Moreover, there is a huge gap between theory and practice. In addition, security should be a part of strategy construction, in order to have a long-term systematic development plan or target. The structure of existing practice is summarized in figure 11.

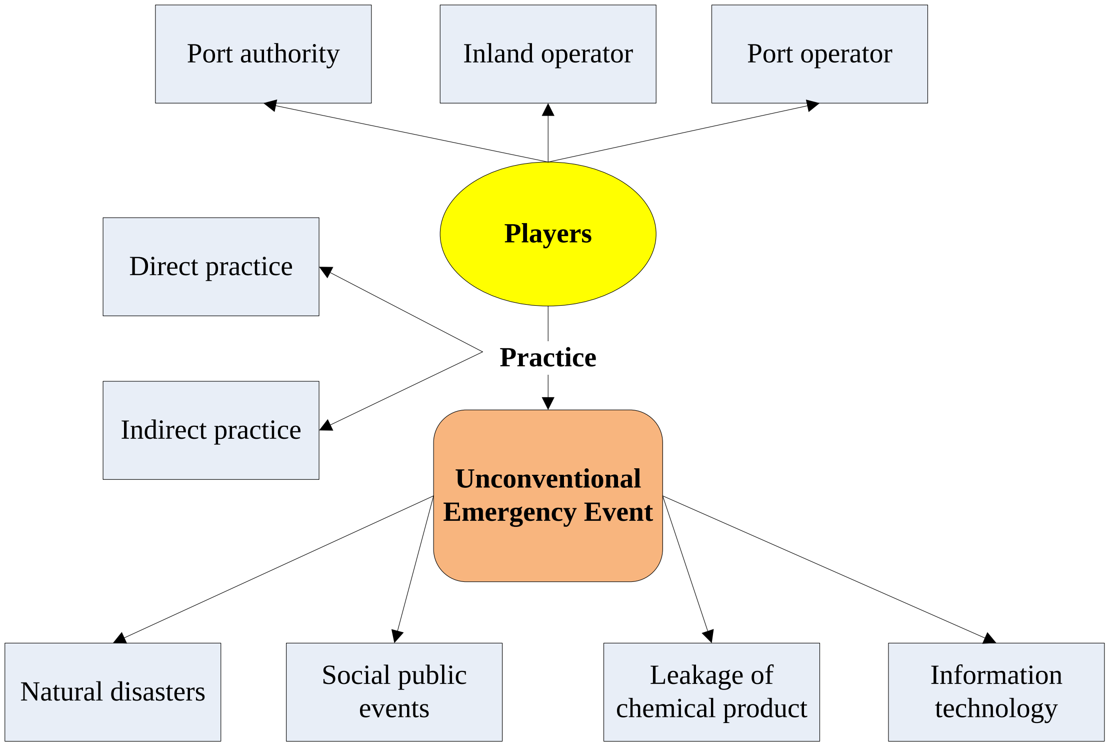

Figure 11: The structure of existing practice in PONZ

In this chapter, we analyze the existing practice adopted by the players in coping with a UEE. Although there are many specific measures, policies or rules for different types of UEE, the implementation of most of them involves three kinds of players – the port operator, inland transport operator and port authority. It is clear that it is the important to strengthen the relationship of different players in this transportation network. To further discuss this possibility, a coalition model with a suitable cooperation mechanism is proposed in the next chapter

5. A COALITION MODEL AMONG FREIGHT CARRIERS

From the analysis of the PONZ, it is clear to see that the importance of involving different players in the PHTN is emphasized. Thus in this chapter, we propose a coalition model by sharing their distribution centers among freight carriers. Within the context of cooperation, more logistics resource is provided and the reliability of the transportation network is increased. Specifically, we quantify the reliability of the transportation network by adopting the concept of 'resilience'. Then we analyze the issue of allocating the payoffs, taking the form of long term reductions in the cost of risk management. By referring to Game Theory, the allocation mechanism is established with the application of a Shapley value, based on the contribution of each carrier to network reliability, i.e. the player with more contribution will be allocated more payoff.

5.1Model Description

5.1.1 Notation and explanation

To describe the upcoming model, we firstly introduce the notation in table 5.

G	Represents the coalition
N	number of players in a coalition,N $= \|G\|$
V	set of nodes or distribution centers in the transportation network
E	set of edges or links connecting the nodes in the transportation network
n	number of nodes, n $= \|V\|$
m	number of links, m $= \|E\|$
$u_i, i = 1 \dots n$	capacity of node i
$v_i, i = 1 \dots n$	self-exhausted weight of node i
$w_i, i = 1 \dots n$	weight of node i
$d_i, i = 1 \dots n$	degree of node i
$q_k, k = 1 \dots$ m	reliability of link k
$L_k(i, j)$	k-th passageway between node i and j
$P_k(i, j)$	reliability of passageway $L_k(i, j)$
$R_i, i = 1 \dots n$	resilience of node i
R(G)	resilience of coalition G

Table 5: Notation in the coalition model

Explanation of the notation
We consider the coalition as a transportation network composed of nodes and links. In this case, the nodes represent the distribution center, which is owned by several different freight carriers. Without cooperation, the fright carrier can only get access to its own distribution center. Within the context of cooperation, one freight carrier will be able to use all the distribution centers among the coalition. The links are the roads, railways or waterways connecting these distribution centers. The capabilities of cargo handling are different across these distribution centers and we use ton per hour as the unit to measure the amount of handled cargo. The distribution center with a higher capability will be considered more important in the transportation network. The weight and self-exhausted weight of a node are adopted to quantify the importance of each node. Degree of a node is the number of links connected with this node. The node with a larger degree means it has more connected links. The reliability of a link is an inner attribute of a road (railway or waterway), standing for the quality of the facility. For example, in some developing countries, the road is very fragile and easily broken under a UEE. Then the reliability of this link will be considered very low. The passageway between node i and j is a notation adopted in calculating the resilience (see Appendix A for detailed definition). The reliability of a passageway is related to all the links within this passageway. The resilience of a node and the coalition is adopted to quantify the reliability of this network. The theoretical definition of resilience is introduced in section 5.1.3 and an example of calculating the resilience of a transportation network is provided in Appendix A.

5.1.2Theoretical basis

Port regionalization theory (Notteboom and Rodrigue, 2007) pointed out the importance of hinterland. Logistics efficiency is highly related to the development of inland transport. An improvement in logistics efficiency, lowering the total cost of transporting cargos, is largely derived from inland distribution. Global integration brings pressure on not only port operation and maritime haul, but also on inland freight distribution. The level of inland accessibility has become a key fact in port competition (CEMT, 2001). Meanwhile, the risk management measures taken within a port-hinterland network are often combined with strategic measures (see chapter4). Thus, to increase the internal reliability of this logistics system in dealing with a UEE, it is crucial to involve inland logistic players. By combining the logistics resources of all the freight carriers, the decision makers are able to generate risk management related strategy more comprehensively. It is essential, therefore, to form a coalition that enables the carriers to cooperate with each other.

In fact, it is a common approach to risk management to provide more redundant resources to increase the reliability of a transportation system (Ip and Wang, 2009). As illustrated in chapter 4, a transport operator will often try to find a similar solution when the original configuration is interrupted by a UEE. For example, if one distribution center is damaged because of a hurricane, the forwarders will tend to use the adjacent distribution centers to finish the given transport mission.

The coalition here is defined as a group of carriers sharing their distribution center in order to achieve better logistics performance. The purpose in forming a coalition like this may not be simply explained as mitigating the damage from a UEE. In fact, more strategic factors are considered by the decision makers, like reducing the cost by sharing resources (Kopfer and Pankratz, 1999; Ergun et al., 2007). But the reality that more redundant transportation resources are provided does not change. Thus it is considered as an effective practice in coping with a UEE, although the motivation to form a coalition may not be limited to risk management. To be clear, we only consider the advantage of this coalition from the perspective of mitigating the damage from a UEE in the model, i.e. the numerical increase of resilience of the transportation network.

A coalition like this will never be achieved, however, without a suitable profit sharing mechanism if the individual carriers are profitable. Here, the profit takes the form of long-term reductions in the cost of risk management. While this type of profit is often considered in the collation level, it is crucial to calculate the payoff that each carrier should receive. In this model, we allocate the payoff based on the contribution to the reliability of the transportation network of each carrier. The concept of resilience is adopted here to quantify reliability. To develop a fair allocation mechanism that would be accepted by all the carriers, we use a Shapley value to accurately predict the amount that each player should receive under certain circumstances. A summary of the theoretical basis of the model is shown in figure 12.

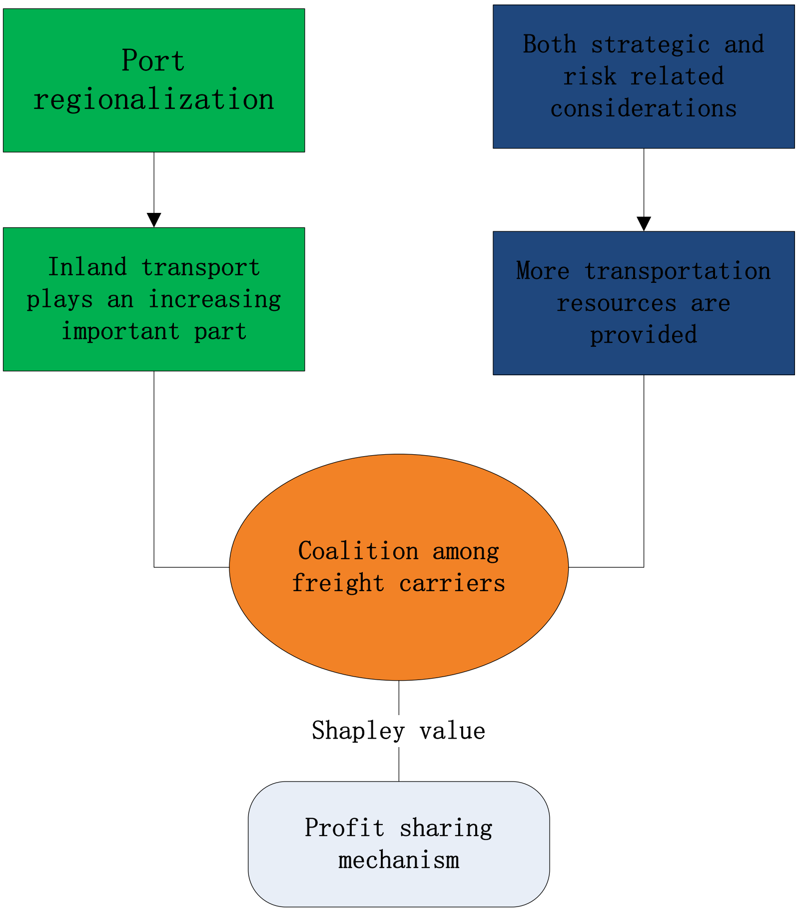

Figure 12: A summary of the model description

In previous chapters, we have discussed the complexity and uncertainty of the PHTN. It is not feasible to establish a general model that is suitable for all different types of PHTN. In order to implement the coalition model, some related issues need to be simplified and re-clarified based on the theoretical basis and the information collected. First, all the different players in the PHTN are considered to be of the same 'type', i.e. a freight carrier providing logistic resources. The definition and role of these players in a PHTN needs to be re-clarified in this case. There are several major players in the PHTN: the port authority, port operators, inland transport operators and logistics service providers. Sometimes the functions of these players could overlap. For example, in some cases, there is no clear distinction between port authority and port operator (see section 2.5). Inland operators may also act as logistic service providers. Sometimes the port operator covers the inland transport part with its own fleet. The role and function of each player are diversified across different countries and regions. In this case, the major concern is the logistics process instead of operational process. We only focus on how many transportation nodes (distribution centers) one player can provide and the contribution to network resilience of each player. Thus, all the players in the PHTN have the same 'type', regardless of whether it is a port operator or inland transport operator.

5.1.3 Resilience of a transportation network

As mentioned above, we will use the concept of resilience to quantify the reliability of a transportation network. This numerical value will be considered as the value of a characteristic function of a certain coalition. The resilience of a transportation network has been defined by many researchers (Murray-Tuite, 2006; Freckleton et al., 2012; Chen & Miller-Hooks, 2012; Janic, 2015) and a comprehensive review in this area can be found in Chen (2015). As Freckleton et al. (2012) pointed out that the resilience of a transportation network stands for the ability ofthis network to absorb disruptive events gracefully and return itself to a pre-disruption level of service. Thus, it is considered a suitable variable in this case to measure the value of the coalition, i.e. the characteristic function of this coalition. The marginal contribution of a player can be interpreted as the increment of resilience when this player joins the transportation network.

In this case, we calculated the numerical value of resilience by adopting the formula proposed by Ip and Wang (2011), in which three factors are considered: redundant resource, distributed supplies and reliable delivery lines. The calculation formula is

$$\mathrm{R(G)} = \sum_{i=1}^{n} w_i \sum_{j=1, j\neq i}^{n} v_j \sum_{\forall k\ link(i,j)} \prod_{l\in L_K(i,j)} q_l$$

The definition of all the notation can be found in section 5.1.1 and an example of calculating the resilience of a transportation network is provided in Appendix A.

5.2 A profit Sharing Mechanism with the Application of Shapley Value

In this chapter, we define a typical cooperative game with N players. For each possible coalition of players $\mathrm{S}(\mathrm{S} \subseteq \mathrm{N})$, there is a unique characteristic function $\mathrm{v}(S)$, representing its 'power' in this cooperative game (In this case, we take the numerical value of resilience as the value of the characteristic function of a possible coalition). $\mathrm{x} = (x_1, x_2, \dots x_N)$ is a feasible payoff vector for the N players. Then some properties need to be satisfied to make this cooperative game stable:

$$\mathrm{v}(\emptyset) = 0$$

$$\mathrm{v}(\mathrm{S} \cup \mathrm{T}) \geq \mathrm{v}(S) + \mathrm{v}(\mathrm{T}), \quad \forall \mathrm{S}, \mathrm{T} \subseteq \mathrm{N}, \mathrm{S} \cap \mathrm{T} = \emptyset$$

$$\sum\nolimits_{i\in S} x_i \geq v(S), \forall S \subseteq N$$

$$\sum\nolimits_{i\in N} x_i = v(N)$$

The first property means that a void coalition does not have any power in the cooperative game. The second property is called super-additivity, making sure that any two coalitions among all these players join together. They can achieve at least the same power when acting separately (A very simple example: Three workers A, B, C, if they work separately, they can produce 2, 3, 4 units of goods a day respectively. If A and B work together, they can only produce 4 units, less than 5 a day, then the super-additivity is not satisfied and the cooperation is meaningless). The third property means that the payoff of any coalition should at least equal its characteristic function (A,B work together, they can produce 6, A, C work together, they can produce 7, B C work together, they can produce 8, A,B,C work together, they can produce 20. If A,B, C work together, but when allocating the payoff, A and C only achieve 6 in total, then the cooperative game will not exist because A and C could leave this coalition and achieve a higher payoff). The last formula means that the value created by the coalition is fully allocated to the members in this cooperative game (If A,B , C work together and produce 20 units, then the final payoff of these three players will be 20 in total.).

The above mentioned constraints only provide a feasible plan to allocate the value measured by a characteristic function. But the final result often predicted with different objects pursued by the decision maker. Many concepts could be involved under different situations, including the 'core', the 'kernel', the 'stable set', the 'bargaining set' and the 'Shapley value' (Osborne and Rubinstein, 1994; Myerson, 1991). The major concern when choosing the solution process is always connected with the environment of the specific issue (e.g. Select a unique imputation or not). Here we choose the Shapley value as the mechanism of profit allocation in the cooperation game. The Shapley value provides a N-vector solution denoted $\varphi(v) = (\varphi_1(v), \dots \varphi_N(v))$. It is calculated by,

$$\varphi_i(v) = \sum_{i \in S} \frac{(N-s)!\,(s-1)!}{N!}\big(v(S) - v(S\backslash\{i\})\big), \qquad \forall i \in N$$

Where s stands for the number of players in coalition S, $v(S) - v(S\backslash\{i\})$ means the marginal contribution of player i.

The reason why we choose a Shapley value here is that it has some excellent properties. We summarize three properties that make it suitable for this study based on previous research (Osborne and Rubinstein, 1994; Myerson, 1991; Krajewska et al., 2008):

Fairness

As in the formula, the Shapley value is dependent on the marginal contribution of players. It is claimed by all the players in the cooperative game. A relatively fair profit allocation mechanism where the player with more contribution achieves more payoffs lies behind this formula.

Efficiency
The Shapley value satisfies $\sum_{i=1}^{N} \varphi_i(v) = v(N)$, meaning that the total gain in the cooperative game is fully shared by the players. Thus, there is no 'waste' and it is an efficient plan.

Uniqueness
By adopting the Shapley value, only one imputation is selected. An endless bargaining process is avoided and there is no room for any player to deviate to another allocation. Thus, it is easy to implement.

There is another potential problem, the Shapley value may not lie in the *core*, i.e. there exists no coalition that can potentially improve the existing imputation to each of the members. To make sure of this situation, we will examine if the following formula (standing for individual and group rationality) is satisfied in the numerical example.

$$\mathrm{v}(\mathrm{S} \cup \mathrm{T}) \geq \mathrm{v}(\mathrm{S}) + \mathrm{v}(\mathrm{T}), \quad \forall \mathrm{S}, \mathrm{T} \subseteq \mathrm{N}, \mathrm{S} \cap \mathrm{T} = \emptyset$$

$$\sum_{i \in S} x_i \geq v(S), \forall S \subseteq N$$

5.3 Numerical Example

In this section, a numerical example applying this present model is provided. Firstly, we will introduce the data input and the procedure for applying this model in section 5.3.1. Also, this section allows the reader to reapply the model and obtain the same result. In section 5.3.2, we list and analyze the results of this numerical example. Then a sensitivity analysis is performed at the end of this chapter.

5.3.1 Data input and procedure

To implement this model, three basic data or items of information need to be provided or generated: A transportation network with distribution centers owned by several freight carriers, the reliability of the links and the capacity of each distribution center. We discuss them separately.

First, a structure of the transportation network needs to be provided. The location of the distribution centers and the links are shown in this network. These distribution centers belong to different freight carriers. In this numerical example, we considered a PHTN with 20 distribution centers (coded as 1-20) owned by four different carriers (coded as ABCD). The network is shown in figure 13 (the different colors of the nodes mean they are owned by different carriers).

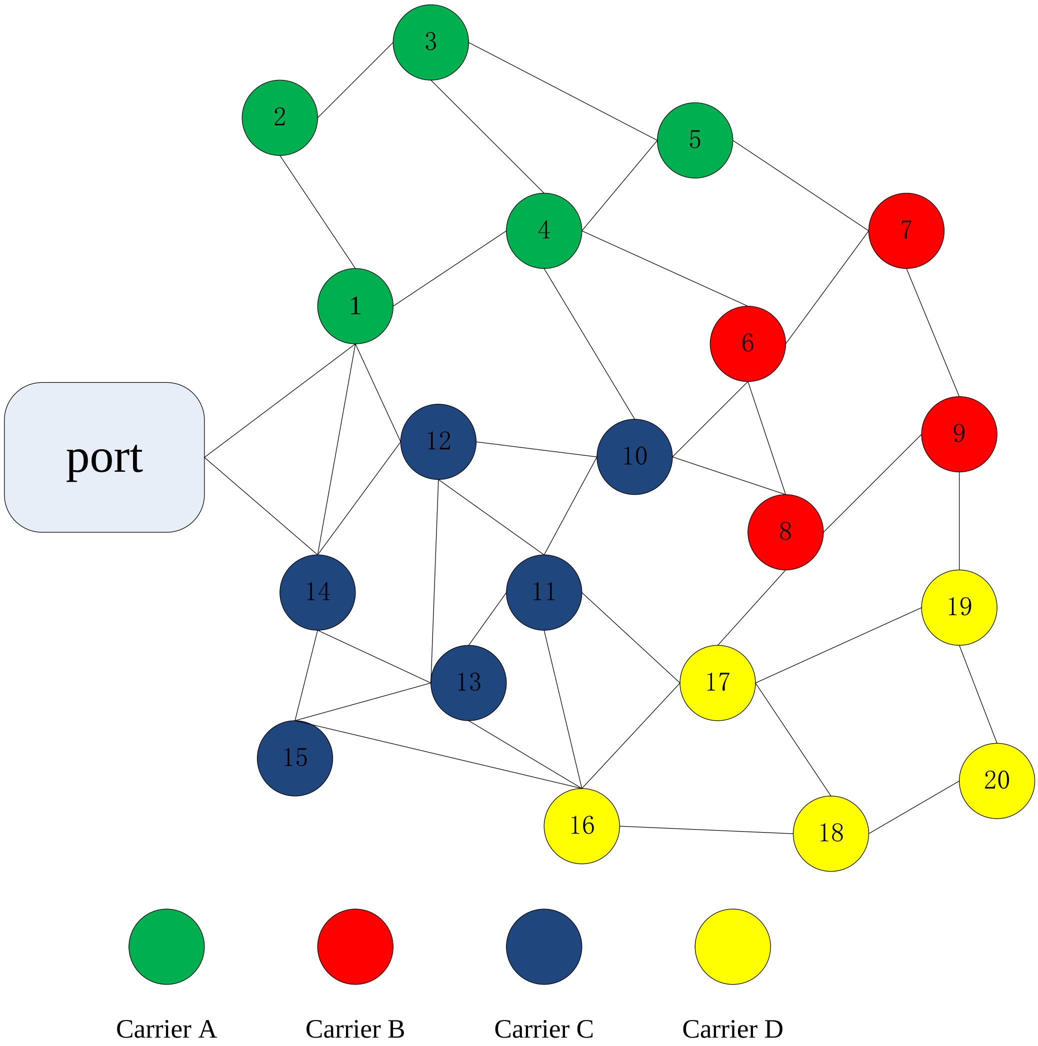

Figure 13: A transportation network with nodes and links

The second parameter that needs to be generated before running the model is the reliability of the links (road, railway or waterway). It is a value between 0-1, standing for the internal quality of the facility. With a value closer to 1, the quality of the links is considered higher. The third parameter is the capability of each node (distribution center). It is connected with the self-exhausted weight and weight of each node.

A procedure to apply this model is introduced below:
Step 1: Identify all the possible coalitions and the corresponding transportation network (with links and nodes).
Step 2: Calculate the resilience of all the possible transportation networks (an example of calculating the resilience is provided in appendix A).
Step 3: Use the resilience of each possible transportation network to represent the 'power' of the corresponding coalition i.e. let V(s)=R(s), and set V(s)=0.
Step 4: Calculate the Shapley value by using the equation below,

$$\varphi_i(v) = \sum_{i \in S} \frac{(N-s)!\,(s-1)!}{N!}\big(v(S) - v(S\backslash\{i\})\big), \qquad \forall i \in N$$

Step 5: Output the results.

In this case, the numerical example includes four different carriers. Thus, there are 15 possible coalitions. Accordingly, there are 15 different transportation networks. The results and the sensitivity analysis are generated by using Microsoft Excel 2010.

5.3.2 Results and analysis

With the transportation network presented in figure 13, we will firstly set the reliability of the links as 0.8 and set all the distribution centers to have equal capacity of 100. A preliminary result is obtained and analyzed in this section and a sensitivity analysis is conducted based on these two parameters in section 5.3.3.

The results are list in table 6.

Coalition A
r_1=0.2659, r_2=0.2659, r_3=0.3148, r_4=0.3148, r_5=0.2727
R(A)=0.0717
Coalition B
R_6=0.2054, r_7=0.2054, r_8=0.2054, r_9=2054
R(B)=0.0410
Coalition C
r_{10}=0.3333, r_{11}=0.4276, r_{12}=0.4592, r_{13}=0.4592, r_{14}=0.4276, r_{15}=0.3333
R(C)=0.1220
Coalition D
r_{16}=0.2727, r_{17}=0.3148, r_{18}=0.3148, r_{19}=0.2659, r_{20}=0.2659
R(D)=0.0717
Coalition AB
r_1=0.4414, r_2=0.4405, r_3=0.5467, r_4=0.5871, r_5=0.5450, r_6=0.5219, r_7=0.5208, r_8=0.4424, r_9=0.4458
R(AB)=0.2245
Coalition AC
r_1=0.9084, r_2=0.5592, r_3=0.6930, r_4=0.7746, r_5=0.5302, r_{10}=0.7805, r_{11}=0.7660, r_{12}=0.9301, r_{13}=0.7800, r_{14}=0.8629, r_{15}=0.5483
R(AC)=0.4067

Coalition AD

r_1=0.2659, r_2=0.2659, r_3=0.3148, r_4=0.3148, r_5=0.2727, r_{16}=0.2727, r_{17}=0.3148, r_{18}=0.3148, r_{19}=0.2659, r_{20}=0.2659

R(AD)=0.1434

Coalition BC

r_6=0.5566, r_7=0.4594, r_8=0.5566, r_9=0.4594, r_{10}=0.6060, r_{11}=0.6264, r_{12}=0.6424, r_{13}=0.6270, r_{14}=0.5778, r_{15}=0.4662

R(BC)=0.2789

Coalition BD

r_6=0.4424, r_7=0.4316, r_8=0.5286, r_9=0.5262, r_{16}=0.4516, r_{17}=0.5871, r_{18}=0.5283, r_{19}=0.5555, r_{20}=0.4623

R(BD)=0.2257

Coalition CD

r_{10}=0.5727, r_{11}=0.9215, r_{12}=0.8185, r_{13}=0.9066, r_{14}=0.7276, r_{15}=0.7373, r_{16}=0.8565, r_{17}=0.6377, r_{18}=6383, r_{19}=5262, r_{20}=0.5234

R(CD)=0.3933

Coalition ABC

r_1=1.2385, r_2=0.7381, r_3=0.9790, r_4=1.2816, r_5=0.9872,r_6=1.1726, r_7=0.9664, r_8=0.9857, r_9=0.7023, r_{10}=1.2614, r_{11}=1.0102, r_{12}=1.2700, r_{13}=1.1286, r_{14}=1.1842, r_{15}=0.6968

R(ABC)=0.7801

Coalition ABD

r_1=0.5836, r_2=0.5748, r_3=0.7320, r_4=0.7767, r_5=0.7503, r_6=0.7656, r_7=0.7613, r_8=0.7656, r_9=0.7613, r_{16}=0.6021, r_{17}=0.7702, r_{18}=0.7024, r_{19}=0.7374, r_{20}=0.6122

R(ABD)=0.4948

Coalition ACD

r_1=1.2163, r_2=0.7153, r_3=0.8969, r_4=1.0130, r_5=0.6757, r_{10}=1.0643, r_{11}=1.3672, r_{12}=1.3706, r_{13}=1.3599, r_{14}=1.2771, r_{15}=1.0626, r_{16}=1.2536, r_{17}=1.0408, r_{18}=0.9107, r_{19}=0.6788, r_{20}=0.7210

R(ACD)=0.8312

Coalition BCD

r_6=0.9898, r_7=0.7023, r_8=1.2079, r_9=0.9787, r_{10}=1.1920, r_{11}=1.3809, r_{12}=1.2129, r_{13}=1.2878, r_{14}=1.0124, r_{15}=1.0199, r_{16}=1.3284, r_{17}=13468, r_{18}=1.0155, r_{19}=0.9910, r_{20}=0.7337

R(BCD)=0.8200

Coalition ABCD
r_1=1.6558, r_2=0.9165, r_3=1.2341, r_4=1.7283, r_5=1.2594, r_6=1.6158, r_7=1.2641, r_8=1.6299, r_9=1.2707, r_{10}=1.8635, r_{11}=1.8774, r_{12}=1.8282, r_{13}=1.7700, r_{14}=1.7011, r_{15}=1.3085, r_{16}=1.7245, r_{17}=1.7731, r_{18}=1.2542, r_{19}=1.2519, r_{20}=0.8958
R(ABCD)=1.4911
Shapley value
A=0.4771, B=0.4445, C=0.7349, D=0.4896

Table 6: Results for a numerical example

Analysis

From the table of results, we can see that the reliability of the network (measured by resilience) is always increasing with the participation of each player, i.e. $R(s+i) > R(s)$, for $\forall\, s, i \in N$. This means that all the carriers have a positive effect on the network reliability. The resilience of coalition ABCD is the highest, which means the optimal situation is to involve all four players in the coalition.

As for the profit sharing, we look at the Shapley value of each carrier. Carrier C will be allocated with most payoffs as it has the largest Shapley value and carrier B will be allocated with the least payoffs because of similar reason. From figure 13, it is clear to see that carrier C has more nodes (distribution centers) than other players and these nodes are connected better with more links in this area. In other words, carrier C contributes the most to the increase of the network reliability. The results indicate that more profit should be allocated to it and with only four distribution centers provided by carrier B, this model gives it the least profit. The fairness of using the Shapley is shown here.

5.3.3 Sensitivity analysis

In this section, we will conduct two sensitivity analyses based on the reliability of the links and the capacity of each node. First, the capacity of each node will be tight as it is equal to 100 and we then change the reliability of the links to see the change of the Shapley value. Second, the reliability of the links will remain unchanged and the capacity of the distribution centers will be changed.

In the first case, the reliability of the links takes different values (0.70, 0.75, 0.8, 0.85, 0.9 and 0.95). We examine the Shapley value of all the different cases respectively. The result is shown in table 7.

Reliability of links	Shapley value
0.70	A=0.3192, B=0.2891, C=0.4936, D=0.3294
0.75	A=0.3907, B=0.3596, C=0.6037, D=0.4021
0.8	A=0.4771, B=0.4445, C=0.7349, D=0.4896

0.85	A=0.5814, B=0.5463, C=0.8912, D=0.5948
0.9	A=0.7072, B=0.6682, C=1.0771, D=0.7212
0.95	A=0.8588, B=0.8140, C=1.2981, D=0.8728

Table 7: Sensitivity analysis of the reliability of links

Analysis

From table 7, it is clear that the Shapley value of all the players is increasing with increased reliability of the links. The reason is that the increase of the network resilience causes an increase of the 'value' of the entire coalition. However, it is more meaningful to focus on the comparative value of the Shapley value rather than the absolute value. We can see that the percentage of carrier C in the Shapley value is increasing with the improvement of the links, which means C is getting more 'power' in the coalition and will be allocated with more payoff. Thus, the higher reliability of the links is a benefit to the bigger players (who contribute more to the network reliability).

In the second case, we set the reliability as 0.8 and adjust the capacity of the distribution centers. As the major purpose is to investigate the change of the capacity to the Shapley value, so we change the capacity of distribution centers 1-5 and keep the others unchanged to see the Shapley value of Carrier A (distribution centers 1-5 belong to carrier A). Specifically, we take the capacity of nodes 1-5 as values of 50,100,150, 200 and 250 respectively. The results are shown in table 8.

Capacity of node 1-5	Shapley value
50	A=0.2495, B=0.4737, C=0.9379, D=0.5920
100	A=0.4771, B=0.4445, C=0.7349, D=0.4896
150	A=0.8809, B=0.5597, C=0.9334, D=0.5813
200	A=1.1593, B=0.5607, C=0.9353, D=0.5406
250	A=1.3717, B=0.5176, C=0.9783, D=0.4600

Table 8: Sensitivity analysis of the capacity of the distribution center

Analysis

Here, we focus on the change of the Shapley value of carrier A. With the increase of the capacity of nodes 1-5, the Shapley value of carrier A is increasing. With more contribution provided by A, it is assigned with more power in the coalition game. That is a reflection of the fairness of the Shapley value. With an equal increase of the capacity, the Shapley value is increasing faster and faster. This means that for the carrier with more advanced distribution center(s), it is easier to increase their power in the coalition game by developing their center(s) to a more advanced level.

6. CONCLUSIONS

The purpose of this chapter is to summarize the results of this research and systemize the information into several practical insights. The limitations of the research and its potential extension into future research are provided in sections 6.2 and 6.3

6.1 Answers to Research Questions

By conducting the case study of PONZ in chapter 4 and establishing the coalition model in chapter 5, the two research questions proposed in this thesis are answered. A summary of the respective answers are provided below.

Research question 1:
In a port-hinterland transportation network, what are the existing practices adopted by players to cope with the damage from unconventional emergency event?

- The existing practice for risk management under UEEs needs cooperation between three kinds of players: the port authority, inland operators and port operators. When facing different types of UEE, the same individual player can play a different role.
- Natural disaster, social or public events, leakage of chemical product, IT are four major areas in port-hinterland risk management under UEEs.
- Forecasts are the key factor for natural disaster risk management.
- The Chinese government plays a leading role in social or public events risk management, with other players responsible for coordinating activities.
- Supervision and the availability of backup equipment are common ways to keep engineering and information technology safe.
- Leakage of liquid chemical products and oil is always a big challenge for every port. Measures for this kind of risk are more complex. Both port authorities and port operators need to make a lot of effort in this respect, with random and regular checks being necessary.
- Although the original purpose of som practices are not for risk management, they exert an indirect influence over the performance of risk management.

No matter what the nature of a UEE, risk management practices can be concluded as comprising three elements in chronological order: prevent, control and remedy. Moreover, a port has its own emphases in risk management under a UEE due to its own particular situation, so the conclusions here are not absolutely suitable for all kinds of ports. In addition, risk management under a UEE should be a part of the construction of a strategy, in order to have a long-term systematic development plan or target.

Research question 2:
How can a coalition model be established to properly allocate the payoffs from investing in risk management among all the freight carriers?

- To answer this question, we propose a coalition model based on the application of a Shapley value, as it is a widely used tool with the characteristic of fairness. To conclude, the player with more 'power' will be allocated with more payoffs.
- As the topic is to deal with the damage from a UEE, we choose the reliability of the transportation network to describe the 'power' in a cooperation game. Generally, the player who contributes more to increasing network reliability is considered to possess more 'power'.
- To quantify the reliability of a transportation network, we adopted the concept of 'resilience', which is used in numerous previous publications to measure the reliability of a transportation network.
- The result of the model provides a crucial guideline, and a direct solution, for allocating the payoff from investing in risk management to different players.

6.2 Limitations

The limitations of this research can be summarized as follows:

- tTe research in this thesis has been conducted from a static point of view while the PHTN has a dynamic nature in order to adapt to the variations in the global economy. When talking about dealing with a UEE, the mechanism is to keep changing and to use more and better technologies that will help develop system performance. Thus, this research needs to be improved continuously. For example, Miller-hooks (2012) applies a quantitative approach for analyzing prevention pre-disaster, control during the disaster and remedy after the disaster from a dynamic perspective. This paper also includes these three stages, but more from a static point of view.
- Because of the availability of data, the reliability of the results remains to be improved. For example, because of some uncontrollable reasons, we were only able to conduct three interviews. Although the interviewees are all professionals with a relative comprehensive understanding in this area, we still believe it will be better if we can conduct more interviews. What's more, instead of a real context with real data, only a theoretical numerical example is provided in chapter 5. This is because it has proved simply not possible to have all the parameters in the model assigned using real world data. This also limits the realistic significance of this research.

6.3 Future Research

During the process of performing this research, we found several potential related avenues that could be explored in future research. Due to the limitation of time and other resources, we briefly list some of them here.

- As mentioned above, the structure of a PHTN varies across different countries and regions. In this research, we propose a case study based on the background of a Chinese port. Some topics are suitable to investigate from a more general level, such as the role of IT in increasing the reliability of a PHTN.
- Different types of UEE would cause damage to a PHTN in different ways. In this study, we did not discuss and compare these different types of consequence. It would be a very suitable academic topic to just focus on one type of UEE, for example to investigate how the PHTN would be affected by an earthquake.
- In this research, the structure of the PHTN is focused on one port but, in fact, both cooperation and competition between ports is becoming more common. For example, the Port of Shanghai (POS) and the PONZ have connected more closely and they combine together to form a PHTN with a larger area. There are some differences compared to the single port structure when it comes to dealing with the damage from UEE.

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APPENDIX A

An example of calculating the resilience of the transportation network (Ip and Wang, 2011)

We considered a transportation network as follows (figure 14). The notations can be found in section 5.1.2.

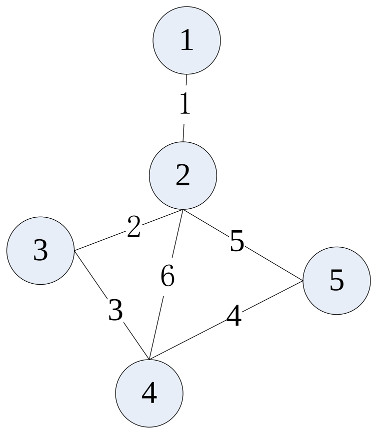

Figure 14: Example of a transportation network

Define passageway: A path set includes the paths connected nodes i and j without any common links. For example, there are three passageways between node 2 and 4. They are {6}, {2, 3} and {4, 5}. The passageway between node 1 and 4 is unique, which is {1, 6}. {1, 2, 3} is not a passageway because it shares a common link {1} with {1, 6}.
The procedure of searching the passageways is described as follows:
Step1: Set the lengths of all links are equal value.
Step2: For a node pair of (i, j), find the shortest path from i to j by applying Dijkstra algorithm. Label the path as path k and delete all links in this passageway.
Step3: Find all the passageways until there is no connection between i and j.
Step4: For all the node pair (i,j), i=1,2…n, j=1,2…n, i≠j, repeat step 2 and step 3.
Step5: When all node pairs are done, stop and output result.

The reliability of a passage way connecting node i and j is calculated as follows:

$$P_k(i,j) = \prod_{l \in L_k(i,j)} q_l$$

The reliability between a node pair i and j is calculated as the sum of the reliability of all the passage ways:

$$\mathrm{NP(i,j)} = \sum_{\forall k\ link(i,j)} \prod_{l \in L_k(i,j)} q_l$$

We use the capacity of the nodes here to measure the weight of all the nodes:

$$w_i = \frac{u_i}{\sum_{j=1}^{n} u_j}, i = 1, 2, \dots, n$$

The self-exhausted weight of a node is calculated as follows:

$$v_i = \frac{u_i}{\sum_{j=1}^{n} u_j - u_i}, i = 1, 2, \dots, n$$

The resilience of a node is calculated as follows:

$$R_i = \sum_{j=1, j\neq i}^{n} v_j NP(i,j)$$

The resilience of a coalition is defined as the resilience of corresponding transportation network, calculated as the weighted sum of the resilience of all nodes:

$$\mathrm{R(G)} = \sum_{i=1}^{n} w_i R_i = \sum_{i=1}^{n} w_i \sum_{j=1, j\neq i}^{n} v_j \sum_{\forall k\ link(i,j)} \prod_{l\in L_K(i,j)} q_l\,, \quad i = 1,2, \dots n$$

We set the reliability of all the links in figure 13 as 0.8 and the capacity of all the nods are equal. The numerical value of resilience of this presented transportation network is 1.184. The related results are summarized in table 7

Node i	1	2	3	4	5
weight w_i	0.2	0.2	0.2	0.2	0.2
s.e.w v_i	0.25	0.25	0.25	0.25	0.25
resilience R_i	0.68	1.44	1.2	1.4	1.2

Table 9: Resilience of a transportation network

APPENDIX B

Interview summaries (The original interview is performed in Chinese, the summaries provided here has been translated into English by authors)

Data: 27th May, 2015
Place: Port of Ningbo-Zhoushan Authority
Interviewee: Mengda Tong, Chief Engineer of Ningbo Port Company Limited

Q: What do you think of the issue of the safety of the port-hinterland transportation network?

We think it's a very crucial issue and need to be paid more attention to. We have a relatively advanced mechanism about coping with the emergency event. Normally, we address this issue from different types of emergency events. First, due to the geographically location of PONZ, some nature disasters such as earthquake are less likely to happen and it is very difficult to prevent or mitigate the damage from nature disaster like this. Second, because the location of PONZ is closed to the ocean, there are several typhoons every year. The modern technology will provide a very precise prediction of these typhoons. Thus our stuffs have a relatively long lead time to prepare for the potential consequence of typhoon. Normally, typhoon doesn't affect the normal operation of the port so much. Third, the safety of engineering is very important including the maintenance of the equipment and the effective connection between all these facilities. Last but not least, the emergency event that I worried most is about the safety of the liquid chemical product. The improper operation of this type of product could lead to a chain reaction even cause explosion in the adjacent area. For example, there are similar incidents happened in the port of Dalian. The major reason that leads to such accidents is the poor management and improper operation.

Q: Is there any example of how PONZ dealing with the UEE before?

Strike of the truck drivers happened sometimes because of the improper freight rates. The major actor when dealing such kind of issue is the government, involving the active cooperation of the port authority. Normally, it is not a big issue because there are enough truck drivers waiting for the job so it is always handled appropriately with the coordination of government. The port is a public platform with very large area. Different actors are responsible for different segments. For example, the railway and the road transportation both have its own operation system and the administrative principal is different. The artificial event like a strike is usually handled by the government. The strong power of government in China allows it to address this issue by integrating resource from all aspects.

Q: Does the company have any specific program that is designed for coping with the damage from UEE?

Right now, we don't have any specific program that is designed for this purpose. It is more combined with the strategic plan, for example, improving our management system by information technology. Although the motivation of IT implementation may not limited in coping with UEE, but it does help increase the reliability of the transportation system.

Q: Could you give us some examples about how you use IT to improve the system performance?

For now, our stuffs are able to monitor and control all the links of logistics process. There are many examples of IT implementation such as every truck of the company is equipped with GPS and we have sensor in every place to monitoring the leak of dangerous cargo.

Q: Do you think the existing practice is enough to cope with UEE?

We believe we are able to deal with most of the UEE with our existing system. But as I said before, PHTN is a very complex system with a lot of actors. To increase the reliability of the system, it is necessary to bring all the actors together.

Data: 27th May, 2015
Place: Transport Committee of Ningbo Municipality, Ningbo Municipal Port Administration Bureau
Interviewee: Mingsheng Hang, Director of Transport Committee of Ningbo Municipality, Ningbo Municipal Port Administration Bureau

Q: From the perspective of government, can you talk about how you dealing with UEE?

It is very common that the UEE happens in the PHTN, but the related administration department has not given a very systematic consideration and there is no formal processing mechanism. The major practice in coping with such event is focused on the post-disaster remedy. Besides the government department, the Ningbo-Zhoushan port company also has a responsibility to participate in the post-disaster re-construction.

Q: According to your experience, what are the challenges in safety management?

First, PONZ is a very large area with 114 berths. There are a lot of pipelines and dangerous chemical cargo. Because of the policy from national level, the amount of crude oil in PONZ is also very large. All these factors increase complexity of port management. To address this issue, we've proposed several policies. For example, the directors of every department need to learn the lessons about safety management and pass the test. The equipment in port need to refresh the related permissions every three years, all the equipment need to be evaluated by professionals in order to be put in use.

Q: Can you give us some specific example about dealing with UEE?

I'll talk about the strike happened in last year. The cutthroat competition within the industry leading to a low freight rate and finally result in a strike. We cope with this event from several aspects. First, we boost police presence to keep order in the port area in case of any incidents. Second, we rearrange the resource and make sure the port is under normal situation. Third, we negotiate with related departments to keep the freight rate fluctuate in a reasonable range. We solve this event by cooperating with the Ningbo-Zhoushan port company and they contribute a lot that time.

Q: Do you think there are any weaknesses in the existing safety management system?

The entire PHTN is so complex that both big-sized players and small sized players are involved. These small sized players are very difficult to manage and monitor, but it is not possible to increase the system reliability without these small sized players. Thus I think to establish a mechanism or system to bring all the players together is very important. It is benefit to the standardization of the operation process.

Q: How do you improve the current situation?

From the perspective of government, besides involving all the players, I think we need to strengthen guiding the companies. Improve our information system so that we can strengthen the connection with the companies. Increase the investment on the pre-disaster prevention so that the reliability of the transportation system will be increased.

Data: 22nd April, 2016

Place: Handelshögskolan (by Wechat)

Interviewee: Yahui Teng, Vice president, business apartment, Ningbo-Zhoushan Port Group

Q: How much management area of the whole port is covered by Ningbo-Zhoushan Group?

It's hard to give some precise data about the management area. After the merger of Ningbo Port and Zhoushan Port, we have 19 terminals in total, and all of them are directly controlled by our group.

Q: What is the percentage of business that PONZG directly involved in?

Wharfs can be divided into two types-public wharfs and cargo owner's wharfs that include private wharfs, foreign investment wharfs and state-owned wharfs. When comes to port throughput, public wharfs account for 60% while the rest 40% are cargo owner's wharfs. For certain special cargo like container, more than 99% is operated by PONZ. Cargo owner's wharfs are served for their own companies and almost never take part in some public issues, there is also no relationships of management between them and us.

Q: Is there any investment from the local government or your group to support the infrastructure construction of cargo owner's wharfs?

No. All investments are from themselves, and so do we.

Q: Then we want to learn something about supervising. Who is in charge of the rules of daily operation like security rules?

This is the duty of port authority, including administration and security management. Port authority is a governmental institute.

Q: Can we say that port authority is responsible for the whole port, no matter public or cargo owner's wharfs?

Of course!

Q: What's the role of PONZG in the daily operation of this port?

I think we are more like a port operator and become more and more comprehensive, many perspectives we are involved.

Q: How about the investment of security construction? The amount is decided by the port authority or yourselves?

We decide it but our decisions must meet the requirements that formulated by the port authority. For examples, the construction of dangerous chemicals yard and the Closed Circuit Television (CCTV) systems are invested by us.

Q: How can you make the cooperation between your group and inland operators? The port authority will coordinate it or you two discuss it face to face?

Usually, we and inland operators discuss directly. In this phase, our cooperation exists in three ways: railway, highway and waterway. For railway, we have been cooperated with Shanghai Railway Bureau and China Railway Corporation.

Q: Is it convenient for you to tell us some specific data about railway transport?

Railway is one of our strategic develop target, but the transport amount of it does not account for a large percentage because we are still in the initial phase. The total amount transported by railway is 170,000 TEU, accounting for 1% of all, and we hope that this number can increase to 20,000 even 25,000. Railway is our major transport way yet, and we have relationships with a lot of logistics companies.

Q: Are all these logistics companies private?

Yes. We have two own logistics companies, but the percentage of the whole market is less than 10%. In inland river part, the total business amount is a small percentage, local containers and water transit containers account for 23%-24%. Except for this 24% and the 1% of railway, the rest 75% all belong to highway.

Q: What are existing measures of PONZ for risk management under unconventional events?

For existing practices, we keep doing security work and follow the International Convention for the Safety of Life at Sea (SOLAS). What's more, we have independent waterway that means we have our own transit capacity under conventional events. For the same reason, this is why we also regard railway transport as our strategic target in the future. Now we have some under-construction projects cooperated with China Railway Corporation that can make the rail direct access to our main terminals. It is equivalent to using intermodal to reduce risks. E. g., when there is a heave accident occurs in highway, time-critical cargo can be transited first through railway, inland river wharfs and other coastal wharfs. We cooperate with some important large port in the coast. In the current phase, investment of railway accounts for a large part of all investment. We predict that the target 1,000,000TEU will achieved in 2020 and which is 5 times as much as nowadays.

Q: As we know that there are some unconventional events happened before in PONZ, such as the strike of truckers. Are there any specific measures for solving this kind of event?

For some key customers, we will use our own truck fleet or other modes to transit as soon as possible. For these customers who are not time-critical, they will wait for more time. Therefore, the construction of railway is also a suitable measure.

Q: Do you have a budget particularly for security or risk management?

No, usually we will not do that. If we do this separately, the response rate is very low and can be accepted. We always do these works combined with other perspectives' works. E. g., we have a large investment in information safety, but it is also used to meet other requirements of data analysis. The demand of customers, advantages of logistics et al. are factors that we will consider about. Still take railway as an example, what we do now is not only helpful for risk management, but also extend our port-hinterland to farther inland central region.

Q: Can we say that the construction of security is combined with the construction of strategy?

Yes. Because of the large amount of investment, it is hard to do them separately, for example, the strike in Hong Kong's port. Some policies will be done to improve, but there is no specific fund for it.

Q: The investment of transport corridor construction is only from PONZG or will be shared with both PONZG and inland operators?

All these investments are results of cooperation. Like the construction of railway, this is an infrastructure construction with large investment but low rate of return. Obviously, we cannot afford it by ourselves. China Railway Corporation (CRC) is our partner in this area, the specific investment amount of us and they will come out after a long negotiation.