An Approach to the Assessment of Resilience in Indonesian Fertiliser Industry Supply Networks

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The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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Abstract

The fertiliser industry is a significant contributor to the Indonesian economy. Given the need to distribute its products to customers on the 17,000 islands making up the Indonesian archipelago, capacity and availability of ports is a major factor in managing fertiliser product lifecycles and the supply networks. Fluctuations in the availability of infrastructure influence levels of risk in the supply networks. Supply network resilience is important to maintain the performance of the Indonesian fertiliser industry. Currently, decision makers in the Indonesian fertiliser industry use risk assessment reports to assess resilience. Discussions with Indonesian fertiliser industry managers highlighted a second, port management, report that is used to evaluate the availability of infrastructure. An opportunity was identified to use both reports in assessing resilience.

This thesis is based on the premise that the risk assessment report can be used as an information resource for resilience assessment. A theoretical framework, based on a synthesis of literature and interviews with industry practitioners, is proposed. Results from interviews concluded that the supply network is a system consisting of social and technical factors. Thus, the approach needed to include both factors. Secondary data collected from risk assessment reports and primary data from brainstorming with key people in the industry were used to validate the approach. The theoretical framework was used to inform the construction of a conceptual model that was populated with data from a real-world case study. A simulation model was then built to translate the conceptual model into a practical application. The simulation model was used to investigate the results of the resilience assessment in different scenarios and predict levels of risk. Early feedback from Indonesian fertiliser industry practitioners indicated that the model could be valuable in the assessment of resilience.

This research provides a new approach for managers to predict the level of risk in supply networks. Since the Indonesian fertiliser industry is owned and governed by the Indonesian state, the approach could be used by policy makers as a prototype to assess the current condition of the supply network in Indonesian industries and the output could be used to underpin the planning of supply networks in the future. For academia, the approach provides a new theoretical framework for research on supply network resilience and presents a real example of how agent-based modelling might be used as a tool to support the assessment of resilience.

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Chapter 1
Introduction

The Indonesian fertiliser industry produces and distributes subsidized fertiliser to maintain food security and sustainable economic development in Indonesia. The main product of the Indonesian fertiliser industry is subsidized fertilisers that are distributed to small and medium income farmers in various parts of Indonesia. The key raw materials are chemical substances imported from Jordan and delivered from Aceh, Kalimantan, and Surabaya. Infrastructure is important because it is needed as a main facility to deliver raw material from the supplier and to distribute fertiliser to consumers. However, the fertiliser industry supply network in Indonesia is at risk due to changes in infrastructure availability. Indonesia has experienced several large scale natural disasters (for example: tsunami, landslides and floods) in recent years, and these disasters have had a major impact on the availability of infrastructure facilities (road, railroad, bridges and ports) and influenced supply network performance (Vanany and Zailani, 2010). With the geographic make up of Indonesia consisting of thousands of islands, this makes the port a major infrastructure facility in the distribution of goods, including fertiliser, throughout Indonesia.

The resilience of supply networks is closely related to the continuity of the process flow through the networks. Disruptions occurring in flow or infrastructure affect the whole process. In this era of globalization, ports are a very important infrastructure to support resilience of products and information flow in the supply network (Muhammad et al., 2011). Ports tend to be vulnerable to the risks that occur in the process flow of the network. For example, disruptions in the process of moving the product and the flow of information in the port can result in delays in the overall flow processes in the network (Klibi et al., 2010). Thus, research is required on the effect of changes in the availability of ports on the resilience of the supply flow in the network.

This research proposes an approach for assessing the resilience of supply networks to changes in infrastructure availability. The approach aims to aid decision makers in assessing resilience in their supply networks. The approach was validated using a case study taken from a port in the Indonesian fertiliser industry.

This chapter begins by providing a background to the research and an overview of Indonesian supply networks in Section 1.1. The Problem Statement and Research Question are presented in Section 1.2. Section 1.3 provides the research aim and objectives, while Section 1.4 presents the Outline of the Thesis.

1.1 Indonesian fertiliser supply network

As an archipelago and developing country, Indonesia is particularly vulnerable to changes in infrastructure of transportation and distribution, which can significantly destabilise the Indonesian supply networks. Indonesia consists of 17,000 (seventeen thousand) islands, as shown in Figure 1.1, with various geographical characteristics leading to problems for Indonesian industry in managing these characteristics, coupled with factors such as the various infrastructure facilities (roads, bridges, ports and rail roads) in the supply networks (The Ministry of Trade of the Republic of Indonesia, 2012).

Figure 1.1 The Indonesian Map

Source:http.nationsonline.org/oneworld/map/indonesia

The government of Indonesia has made numerous efforts to improve the domestic supply network performance, but global competition increased significantly which, in turn, influenced national logistics performance. One indicator that shows the performance of a country's logistics is the Logistics Performance Index (LPI) issued by the World Bank, which assesses the performance of the logistics sector in countries based on business perception. Table 1.1 shows that the ranking logistics performance of Indonesia decreased dramatically from 43 in 2007 to 75 in 2010.

Table 1.1 Indonesian Logistic Performance Index

Country	LPI		Custom		Infrastructure		International Shipment		Competence		Tracking & Tracing		Domestic Logistics		Timelines	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score
2007																
Singapore	1	4.19	3	3.90	2	2.47	2	4.04	2	4.21	1	4.25	113	2.70	1	4.53
Malaysia	27	3.28	23	3.36	25	3.44	24	3.44	26	3.40	28	3.51	36	3.13	26	3.95
Thailand	31	3.31	32	3.03	32	3.16	32	3.24	29	3.31	36	3.25	25	3.21	28	3.91
Indonesia	43	3.01	44	2.73	45	2.83	44	3.05	50	2.90	33	3.30	92	2.84	58	3.28
Vietnam	53	2.89	37	2.89	60	2.50	47	3.00	56	2.80	53	2.94	17	3.30	65	3.22
Philippines	65	2.69	53	2.64	86	2.26	63	2.77	55	2.83	50	2.92	58	3.00	67	3.17
2010																
Singapore	2	4.09	2	4.02	4	4.22	1	3.86	6	4.12	6	4.15			14	4.23
Malaysia	29	3.44	36	3.11	28	3.50	13	3.50	31	3.34	41	3.32			37	3.86
Thailand	35	3.29	39	3.02	36	3.16	30	3.27	39	3.16	37	3.41			48	3.73
Philippines	44	3.14	54	2.67	64	2.57	20	3.40	47	2.95	44	3.29			42	3.83
Vietnam	53	2.96	53	3.26	66	2.56	58	3.04	51	2.89	55	3.10			76	3.44
Indonesia	75	2.76	72	2.43	69	2.54	80	2.83	62	2.47	80	2.77			69	3.46
Growth	↓ -32		↓ -28		↓ -24		↓ -36		↓ -42		↓ -47				↓ -11	

Source: Report of the Indonesian Ministry of Trade, 2012

As a developing country, Indonesia continues to construct infrastructure facilities to support economic development and increase prosperity. However, dynamic changes in infrastructure will affect the flow of information and products in the supply network. Regulation 26, 2012 of the Government of Indonesia has established the Blue Print of Logistical National Planning as part of the national supply network management strategy. This Blue Print is a road map that will be used to implement and improve the performance of supply network systems in Indonesia.

The National Logistical System is a government programme to achieve long term national objectives and realize Indonesian economic vision to 2025. The vision is, “to achieve an independent, developed, fair and prosperous Indonesian society” so that a per capita Gross Domestic Product will reach the target of $14,250-15,500 in 2025, as shown in Figure 1.2 (The Ministry of Trade of the Republic of Indonesia, 2012).

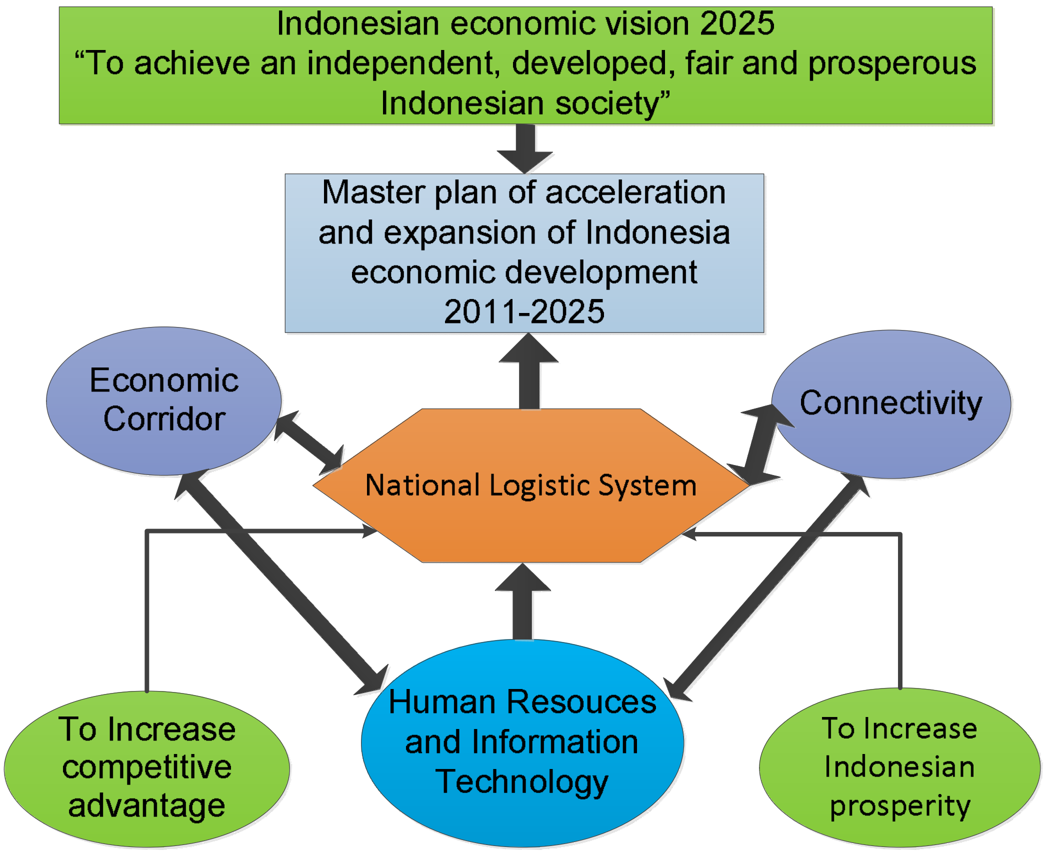

Figure 1.2 Road Map of the Indonesian National Logistic System
Source: The Ministry of Trade, 2012

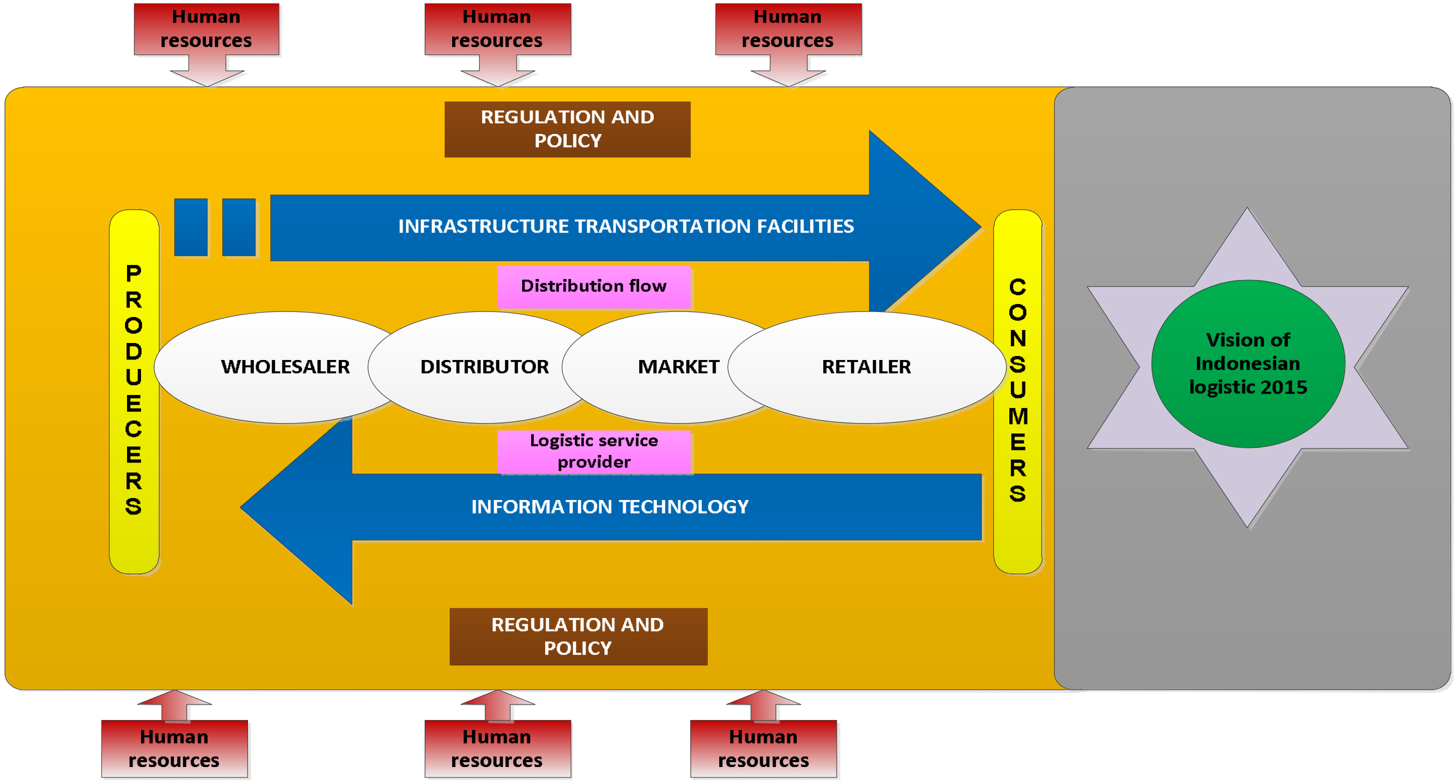

Figure 1.3 Six key-drivers of Indonesian supply networks

Source: The Ministry of Trade, 2012

In the blue print, The Ministry of Trade (2012) defines six key drivers of Indonesian supply networks: infrastructure of transportation and distribution, information technology, human resources, regulation and policy, institutional issues and logistic service providers, as illustrated in Figure 1.3. The Indonesian government identified the most important key driver is infrastructure facilities since infrastructures have a significant function to link and integrate the other five key drivers (The Ministry of Trade of the Republic of Indonesia, 2012).

As an agrarian country, the fertiliser industry is an important industry to support agricultural development. The Ministry of Industry of The Republic of Indonesia reported that the fertiliser industry contributes 2.63% to the Indonesian gross domestic product (GDP) (The Ministry of Industry of the Republic Indonesia, 2011). Figure 1.4 illustrates the composition of contributions of Indonesian industry to the gross domestic product.

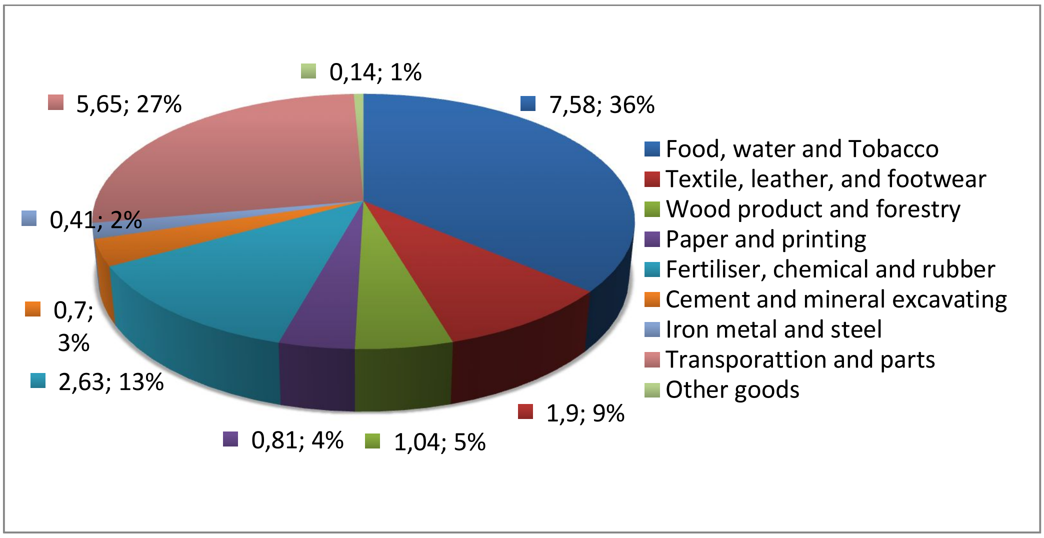

Figure 1.4 Composition of contribution of the Manufacturing Sector to the Indonesian Gross Domestic Product

The supply network in the fertiliser industry is a special case because overall supply network elements are governed by the Indonesian state. The elements of the fertiliser supply networks are the fertiliser industry, distribution centres, distributors, with retailers and farmers as the end consumers. In order to support supply network flow, the fertiliser industry has its own port, presented in Figure 1.5, located 3.7 km from the fertiliser manufacturing plan. The decision makers in the fertiliser industry understand that port availability has a significant influence on the resilience of the supply networks. The Risk Assessment Department of the industry reported that strategic risks related to the supply network were: busy activity of loading and unloading at the dock, congestion or long queues of loading and unloading at the port and the delay in shipping product, as reported in the sustainability report of the fertiliser industry. This report provides evidence that the infrastructure availability, especially the port, causes a major impact on the resilience of supply networks. In addition, it demonstrates that risk assessment needs to consider the issues of infrastructure and supply network resilience.

Figure 1.5 T-Port (Source: The Indonesian fertiliser industry)

During the last decade, the paradigm of competitive advantage has changed. Industries are not only concerned with production improvement but they also consider reducing risks as an essential strategy for increasing performance. Risks in the supply network affect not only an organisation's internal operating system but also customer satisfaction. The risk in a supply network is caused by numerous potential disruptions. For example, the World Economic Forum reports that transportation infrastructure failures triggered 6% of supply chain and transport network disruptions (Industry Agenda, 2012). Furthermore, the Indonesian fertiliser industry reported an issue of subsidised fertiliser not being available for farmers during planting time in 2011 due to delays in distribution of fertiliser from industry to distributors (The Fertiliser Industry, 2011). Hence, there is a crucial need to review risk management practice in supporting strategic decision making (Agenda Industry, 2011). Many companies realise that profitability could be achieved by preventative actions and this concept has developed dramatically as competitiveness increases (Savage and Gibson, 2013). The delivery and transportation system influences the quality of the product and problems of logistics and inventories influence the production process considerably (Chaharsooghi and Heydari, 2010; Boone et al., 2013). Resilience, the ability to respond and control is important when considering the interconnectedness in supply networks, where risk and disruption can have a significant impact globally. Therefore, to survive, supply networks must be resilient (Carvalho et al., 2012a) and assess their resilience periodically.

Research on resilience has been carried out in various fields of science and focused on areas such as; ecological, individual, community, organizational, and supply chain. However, research is still needed on resilience from the system engineering perspective, especially to investigate the collaboration between the network and infrastructure in the context of systems and operations (Bhamra et al., 2011) because infrastructures are critical to the operation of supply chains (Gong et al., 2014). In the current era of global markets, ports are important infrastructure facilities for the sustainability of supply networks (Esmer S., 2010; Muhammad et al., 2011; Loh and Thai, 2014). Thus, this thesis presents an approach for the information generated from the risk assessment as data to measure resilience in the supply networks by considering the effect of changes in infrastructure facilities. The port is used as a case study to illustrate and evaluate the approach.

The case study method was applied to investigate a real world case from the Indonesian fertiliser industry supply network in order to support generating of the resilience assessment approach. By examining the approach in a real world case, it was expected that the approach could then be applied in the real world supply network system.

This research was conducted to aid Indonesian industry to identify risk and develop a strategic plan to increase the resilience of supply networks. Fieldwork was carried out in the Indonesian fertiliser supply network that was chosen as the case study for this research. As approved by the Head of Education and Training Management of the fertiliser industry, fieldwork was carried out for four months in the Department of Risk Assessment. For further meetings and data collection, the researcher was allowed to visit and arrange the next meeting with the key person in the fertiliser industry until this research was completed. Ten key people from the Indonesian fertiliser industry agreed to participate in this research.

The Risk Assessment Department has responsibility for collecting, identifying and managing risk in all the departments of the fertiliser industry. This research focused on the supply network resilience assessment in the fertiliser industry. The supply network system consists of the Department of Sales Management Region I and Region II, the Department of Harbour Management, and the Department of Procurement. However, the observation carried out during fieldwork covered all departments in order to gain broader perspectives on activities in the internal and external supply networks process in the fertiliser industry.

1.2 Problem statement and research question

Indonesian supply networks are vulnerable to changes in infrastructure availability. There is a need for an approach to improve and maintain the competitiveness of the Indonesian industry by helping decision makers to assess and thereby improve the resilience of their supply networks to potential infrastructure changes. This leads to the research question:

"How can the Indonesian fertiliser industry assess the resilience of its supply network to changes in infrastructure availability?"

1.3 Research aim and objectives

The aim of this research was to propose and evaluate an approach for assessing the resilience of Indonesian fertiliser supply networks to changes in infrastructure availability.

The following objectives were pursued:

1. To characterise key dimensions of resilience based on the literature.
2. To define a case study of the Indonesian fertiliser industry for use in the assessment of the resilience approach proposed.
3. To identify key requirements for an approach for assessing the resilience of Indonesian fertiliser industry supply networks to infrastructure changes.

4. To propose an approach for assessing the resilience of Indonesian fertiliser industry supply networks to infrastructure changes.
5. To evaluate the proposed approach using the case study and a prototype software implementation.

1.4 Thesis Outline

This thesis is organised in eight chapters. Chapter 2 provides a review of current literature on the assessment of resilience in supply networks. Most literature focuses on designing and assessing supply chain resilience in internal processes and provides little consideration of infrastructure availability. In addition, some of the research did not validate their framework into a practical case study. This stimulated research in assessing supply network resilience with respect to changes in infrastructure availability. Methods for assessing risk are reviewed and dimensions of resilience assessment are identified. Agent-based simulation modelling was identified as a suitable approach that can aid process flow analysis and explore key performance indicators of resilience assessment.

Chapter 3 introduces the methodology used in this research. Chapter 4 highlights data collected in the Indonesian fertiliser supply network and what the researcher learnt about the types of problems that the industry encounters and analyses the steps the decision makers have taken to plan and correct specific problems and concerns in terms of supply network resilience. Chapter 5 presents the theoretical framework modelled by adapting an enterprise engineering framework to analyse the case study. Furthermore, decision maker requirements are identified to build an approach for resilience assessment.

Chapter 6 provides a conceptual model developed for resilience assessment in supply networks in relation to infrastructure availability by implementing the approach and using data or information from case study analysis. The chapter also highlights validation of the model and improvements identified as a result of model validation.

Chapter 7 provides the simulation model built based on the conceptual model. The simulation model is used to explore the resilience of supply networks under different scenarios of infrastructure availability. This chapter also presents the validation of the simulation model and how scenarios have explored the influence of mitigation plans on port availability and risk level. Finally, Chapter 8 presents the summary and outcome of this research. This chapter also provides the implications and the limitations of the research, and the future work needed to take the research forward.

Chapter 2
Literature Review

This chapter provides a review of the current literature on the assessment of resilience in supply networks in order to understand and critically analyse the previous research relating to resilience assessment of supply networks. Methods for assessing risk are discussed and dimensions of resilience assessment are identified.

The aim of this chapter is to review the literature on resilience and use it to provide a definition of resilience for this thesis. This chapter consists of four sections. Section 2.1 reviews the literature on risk and resilience in the supply network and provides the definition of resilience that was used in this research. Section 2.2 presents system thinking and its application to the supply networks. Section 2.3 introduces previous work on simulation of supply networks. Section 2.4 provides summary of this chapter.

2.1 Risk and resilience in supply networks

This section provides a review of the literature on risk and resilience in supply networks and analyses the link between them as part of the resilience assessment process in order to obtain the key characteristics of resilience assessment. It concludes with a definition of resilience used throughout this thesis.

2.1.1 Risk in supply networks

A supply network is a group of supply chains which are linked together by “connection” in order to achieve the same purposes of creating products or services (Hearnshaw and Wilson, 2011). Figure 2.1 illustrates supply chains and Figure 2.2 illustrates supply network. The circles represent the elements of a supply chain, for example; organisation or departments. The arrows symbolise the connection between the elements. The connections between the elements of a supply network represent material or information flow. Material flow refers to the transfer of physical product, and the information flow refers to the transfer of co-ordinating data.

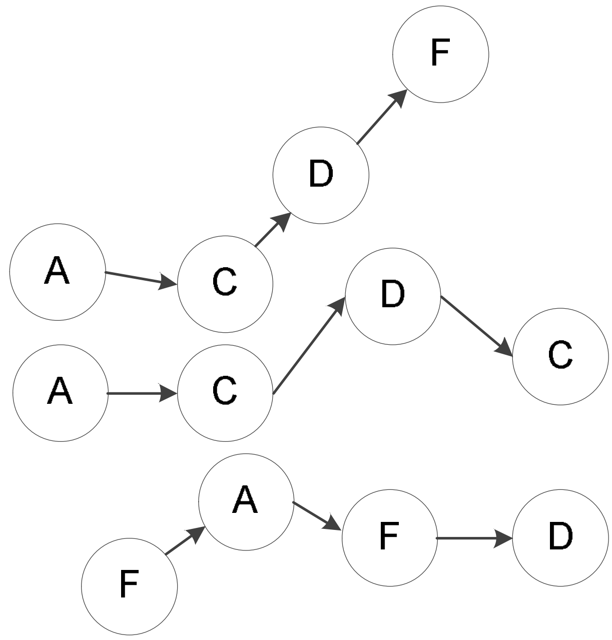

Figure 2.1 Supply chains (Peck et al., 2014)

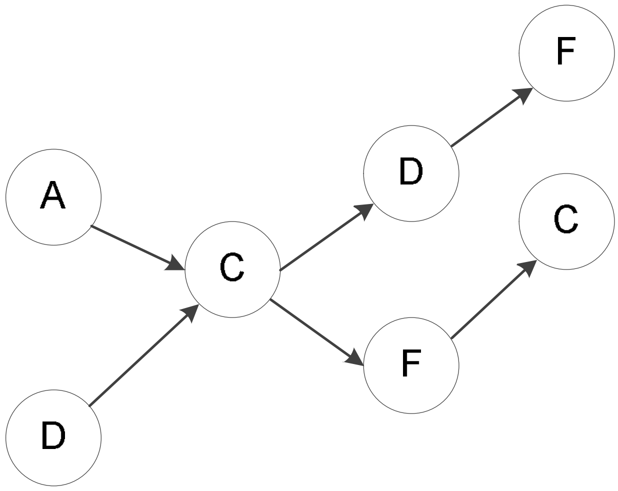

Figure 2.2 Supply network (Peck et al., 2014)

Disruptions in the supply network affect not only an organization's operational system but also all supply network components, such as distributors, agents and the consumers. Therefore, identification of elements in a supply network that cause major risk and impact on the whole network is essential (Mizgier et al., 2013). Visualization of supply networks can be used to identify and analyse risks properly (Vilko and Hallikas, 2012b).

Supply network practices are different in developed and developing countries because supply network management derived from experiences in developed countries cannot easily be applied in developing countries without understanding the differences in the nature of the industries in both types of countries. The differences are caused by factors such as: culture, system and regulation (Chopra and Meindl, 2007; Sanberg, 2007; Soroor et al., 2009). For example, in developed countries industries have large networks of retailers and this causes an increase in transaction costs, meanwhile in developing countries industries have outlets, e.g. one stop shops (Chopra and Meindl, 2007). In terms of information sharing, the supply network participants in developing countries share forecasting production and selling information. This culture is different from the phenomenon in developing countries where there is a lack of information sharing between industries and their stakeholders, and this situation causes problems in the transactions of raw materials and finished product (Sanberg, 2007). The most common way to plan logistics in supply networks in developed countries is by joint planning on an operational level, however, the degree of joint strategic planning can be considered as low. In developing countries the companies have several problems such as unfocused strategic planning, decision making and lack of direction to improve the creativity and innovativeness to increase the quality of business partnership (Soroor et al., 2009).

The risk assessment is important information to design and maintain robust networks and increase product flow management efficiency (Farahani et al., 2014). Tuncel and Alpan (2010) define risk assessment as the assignment of probabilities to risk bearing events in the system and identifying the consequences of these risk events. Manuj and Mentzer (2008) formulate the quantitative definition of supply-chain risk as: Risk = (PLoss × ILoss), where risk is the function of the probability (P) of loss and the significance of its consequences (I). Losses include both quantitative and qualitative losses. For supply chain risk, for example, the quantitative losses may be lost sales due to stock outs, and the qualitative losses may be loss of brand equity or termination of a business relationship (Manuj and Mentzer, 2008; Vilko and Hallikas, 2012b). In managing the flow of supply in the network, the management team should be able to discover the disruptions that occurred in the network so that the recovery strategy can be determined in order to design a resilient supply chain (Blackhurst et al., 2005; Glickman and White, 2006).

2.1.2 Resilience in supply networks

Research on resilience in the supply network can be divided into two groups; supply network design for resilience and assessment of resilience in the supply network. The former research group aims to build supply network resilience to disasters, changes in demand or changes in the components of the network. Researches in supply network design for resilience are presented in Table 2.1. Research on resilience assessment in the supply network, are shown in Table 2.2.

Table 2.1 Research in supply network design for resilience

Authors	Focus	Approach/ Model	Case Study	Implication
Gong et al. (2014)	Identifying and modelling the inter-dependencies between the supply chain network and infrastructures, and using the model to develop supply chain restoration plans that can improve the company's resilience to disasters.	Inter-dependent layered network model.	Virtual scenario of supply chain and disaster in the eastern part of the United States.	The model proposes a co-operation model between the managers of infrastructure and the managers of supply chain in dealing with disruptions and extreme events.
Kristianto et al. (2014)	Optimizing inventory allocation and transportation routing.	Two stage programming with the fuzzy shortest path.	HP printer supply chain.	Minimizing computational time and CPU memory consumption.
Carvalho et al. (2012a)	To evaluate alternative supply chain scenarios for improving supply chain resilience to a disturbance and understanding how mitigation strategies affect each supply chain entity’s performance.	Discrete event simulation model: Arena software interacted with Microsoft Excel using Visual Basic for Applications (VBA).	The Portuguese automotive supply chain.	The simulation model allows comparison of two scenarios of resilience supply chain design to reduce the negative effect of disturbance.

Table 2.2 Research on resilience assessment of supply network

Authors	Focus	Approach/ Model	Case study	Implication
Soni et al. (2014)	Deterministic modelling approach to measure supply chain resilience.	Resilience index is measured by applying the graph theory. Digraph theory is used to measure inter-relationships between variables of resilience.	Firms in India	A new methodology to aid managers in analysing how a partner's expertise influences resilience improvement.
Azevedo et al. (2013)	Greenness and resilience assessment in the up-stream automotive supply chain.	Case study approach and The Delphi technique are used to obtain the weight of the supply chain resilience index.	Link of supplier/ manufacturer in the automotive supply chain.	Generating sources strategies by allowing switching of suppliers to create supply chain visibility.
Carvalho et al. (2012b)	Framework for assessing resilience in supply chain.	Supply chain mapping is applied to analyse supply chain resilience in demand and lead time changes.	Wine industry in Portugal.	Information from value mapping of resilience aid the management in deciding changes in supply chain configuration if disruption occurred in the supply chain.
Spiegler et al. (2012)	A control engineering approach to the assessment of supply chain resilience based on synthesising literature.	Integral Time Absolute Error (ITAE) is applied to measure resilience by using data from inventory level and shipment rates, and applying system dynamics to design a resilient supply chain.	-	A robust supply chain is not the solution for designing supply chain resilience. Meanwhile, resilience supply chain will change drastically when lead-time changes.

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Table 2.2 *Continued*

Authors	Focus	Approach/ Model	Case study	Implication
Jüttner and Maklan (2011)	Empirical study to investigate supply chain resilience in a disruptive global event in financial crisis.	A review of the literature of the conceptual domain of supply chain resilience and longitudinal case study with three supply chains.	A cabling supplier (Cable Co [1]), a global supplier of specialty chemical products (Chemical Co) and a wood/timber wholesaler (Timber Co)	The paper identifies which supply chain capabilities can support the containment of disruptions and how these capabilities can be supported by effective supply chain risk management.
Ponomarov and Holcomb (2009)	A conceptual framework of the relationship between logistic capabilities and supply chain resilience.	A review of the literature in supply chain resilience.	-	The key elements of supply chain resilience and the relationships among them, the links between risks and implications for supply chain management, and the methodologies for managing these key issues are poorly understood.
Falasca et al. (2008)	Quantitative approach for assessing supply chain resilience to disasters.	Simulation Arena and Visual Basic Application (VBA) are applied to assess the effect of disaster to supply chain configuration.	-	Investigating the effect of different supply chain configurations on the expected resilience behaviour of the system.

There are still few studies on measuring supply network resilience. Some empirical frameworks were proposed to evaluate supply chain resilience, but these have not been implemented in a practical case study. For example; Guoping and Xinqiu (2010b) introduce a framework to evaluate resilience supply networks by using the black box method and an evaluation index. They state that the black box method is suitable to evaluate the performance of a system, in which the internal component of the system is complex and difficult to observe. Performance of the system could be assessed based on the input and output of the system without investigating the internal process of the system. They argue that the supply network system is a complex system, so the black box method is suitable to assess resilience in the supply network by analysing the input and output of the supply network without analysing the inner process in the supply network.

Then, Guoping and Xinqiu (2010a) develop a resilience framework by using Hooke's law. They illustrate the connection of elements in a supply network, such as the series connection between the enterprise or business organisation as springs. Changing in a node would influence all of the springs. The resilience of a supply network is measured by multiplying the resilience coefficient of the node and the number of nodes. The resilience coefficient was measured as: $1/k = 1/k_1 + 1/k_n$ where, k is the number of nodes or the supply network elements.

The other studies employ the mapping method to propose stages in supply chain resilience. For example, Carvalho et al. (2012c) develop a framework to assess supply chain resilience based on the failure mode in the supply chain process. They found that the most frequent failure was transportation problems, and this failure caused a very negative impact on the supply chain. However, the link between the failure and resilience in the supply chain was not discussed.

Carvalho et al. (2012b) implement mapping risk to a specific disturbance and implement the mapping framework in the automotive industry. The framework was developed to understand the current operation of the supply chain and to identify critical activities in it. The key characteristics of the supply chain, such as, entities, relational links between the entities, material flows, information flows, management policies, and lead times are identified in order to investigate vulnerabilities in the supply chain processes.

Barroso et al. (2011b) apply value stream mapping to assess resilience in the automotive industry. They state that the value stream mapping helped to visualise the connection between the elements of the network and allowed identification of the problem and supported the decision making process. They found that the resilience of supply chain could be achieved by re-designing the supply chain to mitigate adverse impact and speed recovery.

Research in supply network resilience by considering the link between infrastructure changes and control of risk has still not been considered. Meanwhile, risk in supply networks caused by changes in the availability of infrastructure generates a crucial impact on the resilience of the supply network. Balancing infrastructure availability is a substantial issue when managing industrial supply networks. Benefits will not be accrued from the excess if the availability of the infrastructure is over and above that required. On the other hand, if there is inadequate key infrastructure availability, this can cause delays in operation or even failure in the process (Grieves, 2006). Considering the role of infrastructure in supply networks is essential in developing decision-making, so that an approach that results in more resilient supply networks is needed.

In global product distribution systems such as the Indonesian fertiliser supply network, physical infrastructure such as ports is important as these affect the supply network's performance. Inefficiencies in loading or unloading of material in ports cause negative effects, which have a detrimental impact through the product lifecycle, from the production process to consumer satisfaction. For this reason, port availability needs to be managed in order to maintain continuity and increase performance of key supply network processes, such as logistic operations and manufacturing.

2.1.3 Definition of resilience

Resilience is recognized as an important dimension of the sustainability in engineering systems (Maliszewski and Perrings, 2012), since supply chains are facing numerous changes, for instance: supply and demand uncertainty and lead time re-scheduling that are contributing to their complexity and vulnerability to disturbances. Therefore, to survive, supply chains must be resilient (Klibi and Martel, 2012). This section reviews the definitions and methods of assessing resilience presented in the literature.

Resilience is a concept that has had many definitions, depending on the area of application such as; infrastructure resilience, organisation resilience, personal resilience and supply network resilience. For example; Vugrin and Camphouse (2011); Turnquist and Vugrin (2012) define resilience as the ability of infrastructure systems to absorb, adapt, and rapidly recover from the effects of a disruptive event. McManus et al. (2007) define the resilience of an organisation as a function of the overall situation awareness, keystone vulnerabilities and adaptive capacity of an organisation in a complex, dynamic and inter-related environment. Robinson (2010) defines personal resilience as the capacity to remain productive and true to core purpose and identity whilst absorbing disturbance and adapting with integrity in response to changing circumstances, and Klibi and Martel (2012) define resilience as the ability to recover from the disturbance through the development of responsiveness, capabilities, redundancy and flexibility. In terms of the supply chain, Carvalho et al. (2012b) define supply chain resilience as the system's ability to return to its original state or to a new, more desirable, one, after experiencing a disturbance, and avoid failure modes. Ponomarov and Holcomb (2009) define resilience as the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function.

The definition of resilience used in this research aligns with the definition of resilience by Ponomarov and Holcomb (2009). The following definition of resilience was used in this research, "*resilience is the ability of a network to respond to disturbance by maintaining social and technical resources to reduce and control risk."* Resilience of the supply network could be achieved by functioning optimal organization resources, such as: human resources, tools or technology, transportation facilities, and warehouses. Assessment of resilience will enable organisations to identify how resilient their supply networks are and what the supply networks can do to improve their resilience.

2.1.4 Assessing resilience in supply networks

Disturbances in organization or supply network are inevitable and they could be caused by several factors, such as people, technology, and physical infrastructure. In some areas with specific geographical conditions, the physical infrastructure performance is a major element that influences supply networks resilience. Thus, it is important to address some literature that discussed the relationship between physical infrastructure and resilience.

Several studies propose the concept of resilience and its measurement in physical infrastructure facilities (Murray-Tuite, 2006; McDaniels et al., 2008; Berle et al., 2011; Maliszewski and Perrings, 2012; Erdoğan and Miller-Hooks, 2012). The resilience of physical infrastructure is important and most visible during and after a natural disaster (earthquake, flood, or drought), which disturbs the performance of these facilities.

Organisations also have to manage risks (for example: supply network failures) in order to deal with competitiveness and maintain customer satisfaction (McManus, 2008). Organization resilience is less visible and is manifested through an organisation’s culture (Stephenson et al., 2010). Organizations recognize that they need to become resilient rather than just robust. Snowden (2012) propose that moving from a system designed for robustness to one that supports resilience represents a significant strategic shift. Systems have commonly been designed to be robust, and are designed to prevent failure. Increasing of complexity and difficulty has made a shift to a resilience system an imperative strategy. Ivanov and Sokolov (2013) argue that in some cases it is impossible to avoid disturbance. Hence, decision makers and researchers must be concerned with development of system resilience as the fundamental strategy and research in complex systems (McDaniels et al., 2008).

A resilient system accepts that failure is inevitable and focuses instead on early discovery and fast recovery from failure. Robustness is an important dimension in supply networks that aids systems in dealing with high frequency and low and middle impact disruption. On the other hand, resilience aids the supply networks to deal with complex events and high impact, low frequency disruption. Zolli and Healy (2012) argue that in global and natural world changes, organisations should have core competencies to reorganise and restructure themselves, especially in high impact low frequency disruption (for example: earthquake, financial crisis and terrorism) by being resilient.

Robustness is the extent to which, under pre-specified circumstances, a network is able to maintain the function for which it was originally designed, while resilience creates an adaptive organization by using its capability to deal with risks (Snelder, 2012). Klibi et al. (2010) define the differences between robustness, responsiveness and resilience. Robustness is the quality of a Supply Chain Network to remain effective for all plausible future events, responsiveness is the capability of a supply chain network to respond positively to variations in business conditions, and resilience is the capability of a supply chain network to avoid disruptions or quickly recover from failures. There is increasing demand for the supply networks to exhibit high reliability, the consistency to result in targeted performance, in the face of adversity where decision makers must address not only the risk that they know will happen by using the robustness method, but also the risk that they cannot foresee by using the resilience method.

Supply networks should be resilient to vulnerabilities and the negative effect of risk. Resilience assessment and identification need to be addressed from the decision makers' perspective in supply networks because they are users of the resilience assessment report and their decisions determine the level of resilience. In addition, they can define critical criteria in resilience assessment based on historical data and experiences by considering that supply network resilience affects supply network entity performance (Carvalho et al., 2012a).

Supply networks could be represented as an integral value chain (Massow and Canbolat, 2014). Configuration of a value chain in the supply chain aids understanding of the supply process (Melnyk et al., 2014). For example: Carvalho et al. (2012b) propose a framework for supply chain resilience mapping which contained four elements: mapping dimension (supply chain entities, relational links, material flow, information flow, management policies and lead times), state variables, resilience attributes (diversity, adaptability and cohesion) and failure modes (raw material shortages, labour and capacity shortages, scrap/re-work, and finished products completed but not delivered). They suggested that in order to assess supply chain resilience, the focus should be on the failure modes caused by disturbances and analyse potential failures by using a preventive and predictive approach.

For another example, Barroso et al. (2011b) use value-stream mapping to aid companies in minimizing and removing waste. The process mapping aid represented product, material and information flow in the supply networks. Value stream mapping can be used to identify three types of activity in the internal manufacturing process: Non-value Adding Activity, Necessary but Non-Value Adding Activity and Value adding Activity (Monden, 1993). Non-Value Adding Activity is activity considered as waste and unnecessary activities that must be eliminated, for example: waiting time, excessive inventory of work in process products and double handling. Necessary but Non-Value Adding Activity is an activity containing waste but necessary in the operating process procedures, for example: the replacement of equipment or the operator. Value adding Activity is an activity that transforms raw materials or work in processing products through the production process, for example: assembling parts, forging of raw materials, automobile body painting.

There are still few studies on measuring supply network resilience by considering physical infrastructure effects. Supply chain resilience studies were initiated in the United Kingdom while there was a disruption in transportation due to fuel protests in 2000 and the spread of Foot and Mouth Disease in early 2001 (Pettit et al., 2010).

In contrast to the well-established supply network design, where the research issues and types of problems have been established during the last two decades, research in supply network resilience by considering dynamic analysis and control of risk have so far received little systematic consideration (Ivanov and Sokolov, 2013). Hence, this research proposes an approach for assessing the resilience of supply networks to changes in infrastructure availability by considering the risk and mitigation plan established by the industry.

2.1.5 Dimensions of resilience assessment

Research in resilience infrastructure concludes that the important dimension of resilience assessment of the physical infrastructure is flexibility of network management to adapt to dynamic changes. For example; Milman and Short (2008) find that two indicators of water system infrastructure resilience are the absorption capacity and the ability to adapt to dynamic conditions. McDaniels et al. (2008) develop a conceptual flow diagram to identify specific system failures and develop planning and implementation to enhance the resilience of hospital infrastructure after an extreme event, for example, an earthquake. The framework addressed two dimensions: robustness (the extent of system function that is maintained) and rapidity (the time required to return to full system operations and productivity).

Maliszewski and Perrings (2012) suggest that resilience depends on physical characteristics, responsiveness of the company and the performance of network management. Further, they found that infrastructure resilience was influenced by the immediate biophysical surroundings. They stated that resilience is a good way to handle risks by understanding system disruptions before failures occur. Erdoğan and

Miller-Hooks (2012) proposed resilience preparedness options to measure and maximize the network resilience of intermodal freight under budget and level of service constraints. The capability of managers to measure and manage risks in supply networks could reduce the impact of risks and aid decision makers in formulating appropriate mitigation strategies (Wagner and Neshat, 2010).

Woxenius (2012) propose the directness as key performance indicators in the transport chain. The directness of transport services depends on factors such as geography, available infrastructure, temporary conditions, shippers' qualitative preferences, the economy of and practical possibilities for consolidation and access to return flows. However, most of the studies proposed resilience indicator identification and resilience assessment in physical infrastructure by adopting various disciplines. In today's business change and competitiveness organizations, in particular supply networks, should assess supply network resilience that is influenced by the physical infrastructure availability and changes.

Resilience is important when considering the interconnectedness of stakeholders in supply networks, where risk and disruption can have significant impact globally. In order for resilience assessment to aid supply networks in being successful, they need to deal with risk by making resilience part of the supply network in day-to-day operations (McManus et al., 2007). Thus, risk assessment is commonly viewed as being closely related to resilience. For example; Vilko and Hallikas (2012a) propose quantitative process planning to measure catastrophic risks in supply chains by using simulation modelling to quantify the risks in multiple catastrophic events to design supply network resilience. Guoping and Xinqiu (2010b) study supply chain resilience evaluation based on a system approach and compared four supply chain resilience methods to measure the resilience index: The Constraint method, Addition, Multiplication and Black Box methods. They concluded that the Black Box method was the simplest and most objective because the three previous methods only calculate resilience index from the sub-system as a whole supply chain index, while the black box method calculates resilience from the mean value of the resilience index. However, none of the research validated the method using a real case study.

Dimensions of resilience in some literature are presented in Table 2.3 and Table 2.4 presents the dimension of supply chain resilience. Some terms and definitions dimension of resilience in the tables could be suitable for this research. However, further analysis from case study is needed to ensure that the dimensions are appropriate for the purposes of resilience assessment in this research. Further dimensions of resilience used in this research are discussed in Chapter 5.

Table 2.3 Dimension of resilience from the literature

Dimension	Definition	Authors
	Organisational Resilience	
Situation Awareness	Level of awareness of the organisation to threats from internal and external sources.	McManus et al. (2007)
Management of Keystone vulnerability	Potential vulnerability from component of system that cause negative impact.	
Adaptive capacity	The ability of organisation to social adaptive culture during crisis and using strength to use opportunity.	
Human resources	Human resources are managed strategically in order to build competencies of employees for creating resilience culture.	Lengnick-Hall et al. (2011)
	Infrastructure Resilience	
The nature of external shocks	Disruption from the external environment influences damage and repair time of the infrastructure.	Maliszewski and Perrings (2012)
Prevailing environmental	Weather conditions create a vulnerable environment.	
Land use	Congestion in dense areas.	
Infrastructural characteristics	Characteristics or age of the infrastructure.	
The number of customers affected	The large number of customers affected by the disruption.	
Type of customers affected	The key customers affected.	
Access of utility repair trucks to outage location	Locations of trucks to maintenance department.	

Table 2.4 Dimension of supply chain resilience from the literature

Dimension	Definition	Authors
Supply chain Resilience		
Key location	Location of supply chain element influences flow of material.	Knemeyer et al. (2009)
Adaptability	Adaptability to type of transportation facilities, infrastructure and demand changes.	Murray-Tuite (2006)
Safety	The number of traffic incidents that occur in infrastructure.	
Mobility	Responsive to travel changes from one zone to another.	
Recovery	The amount of time, money, and services required to restore connectivity at a standard level of service.	
Diversity	The employment and availability of entities with alternative products, suppliers, processes, facilities and resources.	Carvalho et al. (2012b)
Adaptability	The ability to adapt effectively to entities by restructuring operations and aligning strategies between supply chain entities.	
Cohesion	The unifying relationships among supply chain entities without disturbing network structures.	
Availability (supply availability rate)	The percentage of demand nodes that have access to supplies.	Zhao et al. (2011)
Connectivity	The number of nodes in the LFSN (largest functional sub-network.	
Accessibility	Average and maximum supply path length in the LFSN.	
Green behaviour (BG).	A set of SCM practices to achieve corporate profit and market-share objectives by reducing environmental risks and impacts while improving the company's ecological efficiency.	Azevedo et al. (2013)
Resilient behaviour (BR)	A set of SCM practices reflecting the company's ability to cope with unexpected disturbances.	
Flexibility	Response to unpredictable demand change, optimizing capacity utilization and shifting to cost-effectiveness.	Jüttner and Maklan (2011)
Velocity	Quick response to unpredictable demand change.	
Visibility	Lower sourcing costs and counteractive.	
Collaboration	The relative importance of entities within a supply chain.	Falasca et al. (2008)
Complexity	The interconnections between entities in a supply chain.	
Density	The quantity and geographical spacing of entities within a supply chain.	

Continues on next page

Table 2.4 *Continued*

Dimension	Definition	Authors
Supply chain Resilience		
Vulnerabilities	Factors that makes an enterprise susceptible to disruptions.	Pettit et al. (2010); Pettit et al. (2013)
Capability	Attributes that enable an enterprise to anticipate and overcome disruptions.	
Coherence	The enhanced meaning, direction and understanding that result from disruptive events or potential threats.	Ponomarov and Holcomb (2009)
Control	The direction and regulation of strategic and tactical actions within the supply chain network.	
Connectedness	The behaviour of people to crowd together during times of disaster.	
Agility	"The ability of a supply chain to rapidly respond to change by adapting its initial stable configuration."	Wieland and Wallenburg (2012); Wieland and Wallenburg (2013)
Robustness	"The ability of a supply chain to resist change without adapting its initial stable configuration."	

Table 2.5 Summary of the dimensions of resilience in some literature

Dimensions / Authors	Coherence in internal management	Adaptability	Human resources	The nature of external shocks	Prevailing environment	Land use	Infrastructural characteristics	The number of customers affected	Mobility	Safety	Recovery	Diversity	Availability	Connectivity	Agility	Control	Robustness
(McManus et al., 2007)	√	√															
(Lengnick-Hall et al., 2011)			√														
(Maliszewski and Perrings, 2012)				√	√	√	√	√	√	√							
(Knemeyer et al., 2009)							√										
(Murray-Tuite, 2006)							√		√	√	√						
(Carvalho et al., 2012b)	√	√										√					
(Zhao et al., 2011)							√						√	√	√		
(Azevedo et al., 2013)				√	√			√	√	√	√						
(Jüttner and Maklan, 2011)		√						√					√				
(Falasca et al., 2008)	√					√								√			
(Pettit et al., 2010; Pettit et al., 2013)	√	√								√	√			√			
(Ponomarov and Holcomb, 2009)	√													√		√	
(Wieland and Wallenburg, 2012; Wieland and Wallenburg, 2013)															√	√	√

2.2 System thinking in supply networks

System thinking is an approach to analyse the components of systems and their environment comprehensively in order to conduct conceptual models based on reality. Since systems are composed of sub-systems, co-ordination within the sub-systems helps to improve system performance. Supply networks are complex systems. Considering the system composed of smaller, more manageable sub-systems interacting among themselves can reduce complexity of the system. Therefore, the modelling supply networks as an integrated modular system comprised of nodes with simpler modelling complexity can help in the exploration of the effects of supply network initiatives on performance (Mishra and Chan, 2011).

A socio-technical system approach provides an opportunity to analyse systems from social and technical perspectives. Meanwhile, the enterprise engineering framework offers several elements to examine a system from the organisational, process and operation perspectives. More explanation of the two methods is presented in Section 2.3.1 and Section 2.3.2.

2.2.1 Socio-technical system approaches

The modelling of supply networks as an integrated modular system comprised of nodes with simpler modelling complexity supports the exploration of the effects of supply network initiatives on performance (Mishra and Chan, 2011). Parallel consideration of social and technical issues is needed in system design to deliver optimal whole system performance including people, processes and technology (Ropohl, 1999). The idea of socio-technical systems was designed in response to theoretical and practical problems of working conditions in industry. The concept of the socio-technical system was established to focus on the inter-relationship between humans and machines in order to increase efficiency by considering the technical and the social conditions of work (Clegg, 2000). Challenger and Clegg (2011) propose a socio-technical framework that identifies six components in an organization, as presented in Figure 2.3. Those six perspectives are: goals, people, culture, process and procedures, buildings and infrastructure, and technologies.

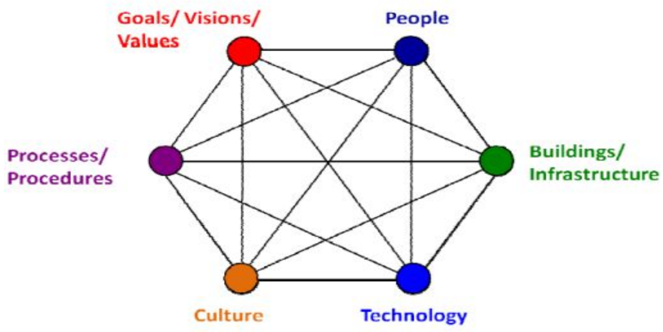

Figure 2.3 A socio-technical system perspective (Challenger and Clegg, 2011)

The socio-technical framework can be used to identify potential threats in systems so the system can be made more resilient. The framework also aids organisations in identifying flow of function and improvement opportunities (HM Treasury, 2014). For example, Worton (2012) proposes collaboration of socio-technical and resilience engineering frameworks to prevent and anticipate threats in terrorist scenarios and poisoning the UK's water supply. Worton's collaboration framework is illustrated in Figure 2.4. The framework was adapted from four characteristics of the resilience engineering stated by Hollnagel (2012). The four characteristics are: learning (knowing what has happened), responding (knowing what to do), monitoring (knowing what to look for), and anticipating (knowing what to expect).

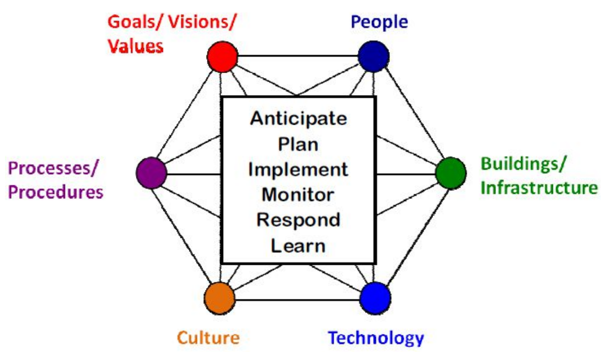

Figure 2.4 The socio-technical resilience framework (Worton, 2012)

A socio-technical perspective could be extended to supply network systems by considering the interconnection and involvement of people or organisations (end-users, managers, technologists, human factor specialists, trade unionists, suppliers, government) in the system design process (Clegg, 2000). Researchers need to consider users' knowledge, ideas and methods in design, re-design and implementation of continuous improvement of socio-technical systems (Carayon, 2006). The involvement of the user in socio-technical system adaptation and improvement could involve several actions: participation, interaction, design, adapt, learn and make sense (Caldwell, 2008). Johnson et al. (2013) find that the dimension (cognitive, structural and relational) of social capital can play a powerful role in assisting the resilience supply chain. Application of the socio-technical framework to configure resilience assessment in supply networks could be applied in a resilience assessment life cycle. Every stage of the resilience assessment framework could take into account six components of the socio-technical framework. The socio-technical framework is also of significant importance in the decision making process.

In recent years, socio-technical system approaches have been applied to a range of complex systems. However, complex socio-technical systems are difficult to analyse. Stanton and Bessell (2014) develop Cognitive Work Analysis that offers an integrated way of analysing complex systems in multiple interpretations. The effects of knowledge sharing, training, team co-ordination and human interactions have been an interesting focus of research into the socio-technical approach. Siemieniuch and Sinclair (2014) propose the socio-technical approach as an effective way to entrain information communication technology as global drivers. In human interdisciplinary interaction, McGowan et al. (2013) suggest that socio-technical approaches might be a critical need in the interaction of humans and organizations in interdisciplinary systems.

This research presents a new application of the socio-technical system approach by applying it to a resilience assessment and material flow system in the context of the broader supply network system. Identification of key elements in the material flow system used the six perspectives of Challenger and Clegg's framework.

2.2.2 Enterprise engineering framework

The enterprise engineering framework aids the supply networks in representing alignment between the network elements. Table 2.6 describes components of the enterprise engineering framework. The framework contains three steps: Define, Develop, and Deploy, and contains three aspects: Purpose, Agency, and Product and Services

(McKay et al., 2009). Enterprise operating systems are socio-technical systems. By visualizing the structure of the supply network strategy, the improvement process can be conducted. The enterprise engineering framework is flexible and can be applied in industries based on their function. There are several applications of the enterprise engineering framework. For instance, the application of the enterprise engineering framework in the aerospace sector to improve a questionnaire in identifying requirements for an interface between the quality of system and strategy (McKay et al., 2009). This research has applied the enterprise engineering framework to address generation of the resilience assessment approach.

Table 2.6 Enterprise engineering framework (McKay et al., 2009)

	Define	**Develop**	**Deploy**
Purpose	*Mission definition strategy*	*Action programmes*	*Direction*
Agency	*Enterprise architecture*	*Enterprise operating system*	*Operation*
Products and services	*Product & service architecture*	*Product & services*	*Solutions*

2.3 Simulation of supply network operations

Simulation is a tool used to represent the behaviour of systems in the real world by using computer programming. This section discusses the benefit of using a simulation tool to reduce risks in the supply network. Simulation makes it possible to determine the influence of control policies on the performance of multi-site enterprise and also to quantify this impact. For example: Petrovic (2001) develop supply network integrated modelling, a simulation tool that can be used for various supply network analyses to gain a better understanding of supply network behaviour and performance in the presence of uncertainty and to enhance decision making on operational control parameters. Carvalho et al. (2012c) evaluated supply networks through six scenarios by using discrete event simulation, Arena software to identify and mitigate disturbance to increase the resilience level of the supply networks. Baç and Erkan (2011) develop a model for an integrated supply network flexibility system. Allesina et al. (2010) propose a new quantitative measurement of complexity for a supply network based on network analysis, which focused on the particular concept of entropy of information. The research presented eight levels of complexity in the whole supply network mapping and recommended possible scenarios as simple evaluation tools. Mishra and Chan (2011) present a simulation platform to undertake studies with an industrial supply network scenario based on the building block approach using Arena. Further research is needed to observe the influence of the behaviour of entities on supply network design and resilience.

2.3.1 Agent based modelling software for supply networks

Siebers et al. (2010b) define agent-based simulation by adapting the definition of what constitutes a simulation by Shannon (1975):

"Agent-based simulation *is the process of designing agent-based modelling of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system*."

In Agent-based simulation, a complex system is represented by a collection of agents that are programmed to follow some (often very simple) behaviour rules. Agents are discrete entities that are designed to mimic the behaviour of their real-world counterparts. Table 2.7 describes the differences between discrete event simulation and agent-based simulation. Agents have their own set of goals and behaviour and their own thread of control. Unlike objects, agents are capable of making autonomous decisions (i.e. they are able to take flexible action in reaction to their environment) and agents are capable of showing proactive behaviour (i.e. actions depend on motivations generated from their internal state). By using an agent-based model, the model developer can reproduce key notions or modules that suit their system requirements and purposes (Jennings, 2001).

Table 2.7 Differences between discrete event simulation and agent based modelling (Siebers et al., 2010b)

Discrete event simulation	**Agent based simulation**
Process oriented (top-down modelling approach); focus is on modelling the system in detail, not the entities.	Individual based (bottom-up modelling approach); focus is on modelling the entities and interactions between them.
Top-down modelling approach.	Bottom-up modelling approach.
One thread of control (centralised).	Each agent has its own thread of control (decentralised).
Passive entities, that is something is done to the entities while they move through the system; intelligence (e.g., decision making) is modelled as part in the system.	Active entities, that is the entities themselves can take on the initiative to do something; intelligence is represented within each individual entity.
Queues are a key element.	No concept of queues.
Flow of entities through a system; macro behaviour is modelled.	No concept of flows; macro behaviour is not modelled, it emerges from the micro decisions of the individual agents.
Input distributions are often based on collect/measured (objective) data	Input distributions are often based on theories or subjective data.

Agent-based simulation has been applied in studies that considered the effect of human roles and behaviour on system performance and decision-making. For example, Siebers et al. (2010a) report an application of agent-based simulation on assessing the effect of human resource management practices on customer satisfaction through observing changes in customer behaviour in a service-oriented organization. Crowder et al. (2012) propose an agent-based modelling framework to facilitate the decision making process in managing the impacts of team composition and working process on product development. Forkmann et al. (2012) employ agent-based simulation to investigate the effect of strategy changes in business relationships on the performance. Mizgier et al. (2012) used Agent-Based Modelling to visualize the supply networks, investigate the behaviour of agents in the supply network in order to analyse the influence of local events on global performance. Agent-based modelling is ideal to perform and analyse supply chains (Julka et al., 2002; Labarthe et al., 2007).

2.3.2 Discrete-event simulation software for supply networks

Discrete-event simulation represents modelling, simulating, and analysing systems utilizing computational and mathematical techniques, while creating a model constructed of a conceptual framework that describes a system (Babulak and Wang, 2010). The discrete event simulation software Arena is often used in academia due to the extensive documentation that comes with the software (Siebers et al., 2010b). The main reason to use discrete event simulation for system analysis in supply network management is the possibility to include dynamics and simplicity of modelling. Discrete-event simulation represents modelling, simulating, and analysing systems utilizing the computational and mathematical techniques, while creating a model constructed of a conceptual framework that describes a system. The system performed a computer implementation model and analysis to present conclusions from the output that assisted in the decision-making process in considering the categories of application rather than on the nature of the underlying research questions that drive the applications (Babulak and Wang, 2010).

Discrete event simulation is useful for problems that consist of queuing simulations or a complex network of queues, in which the processes can be well defined and their emphasis is on representing uncertainty through stochastic distributions. Many of these applications occur in the manufacturing and service industries as well as queueing situations (Siebers et al., 2010b). Persson and Araldi (2009) describe a simulation toolbox based on the Supply Network Operation Reference model which integrates the model and discrete event simulation tool. This integration tool provides the supply network analyst with a comprehensive and dynamic tool in order to solve various scenarios in supply network problem solutions.

2.3.3 Verification and validation of conceptual and simulation models

A model should be developed for a specific purpose or application and its validity determined with respect to that purpose (Sargent, 2010). Verification and validation of a model is necessary to ensure that the model and its output can be trusted (Cook and Skinner, 2005).

A conceptual model is an abstract model of reality that is platform independent. A simulation model is a computerized version of a conceptual model which is platform dependent, and the same conceptual model can be implemented by multiple simulation models (Liu et al., 2012). Sargent (2010) defines validation of a conceptual model as determining that the theories and assumptions underlying the conceptual model are correct and that the model representation of the problem entity is “reasonable” for the intended purpose of the model. Computerized model verification is defined as assuming that the computer programming and implementation of the conceptual model is correct (Sargent, 2010).

There is no standard procedure for developing a conceptual model. Heath et al. (2012) design the Conceptual Model for Simulation (CM4S) Diagram to develop and document the conceptual model of a simulation while capturing appropriate validation criteria in agent-based modelling. Ragheb et al. (2010) present a validation relationship between the model inputs and model outputs in a seaport simulation model and the output of the study can be used by management to improve the decision-making process by using a statistical approach. Conceptual model verification and validation is necessary to assure that the conceptual model is internally complete, consistent, coherent, correct, and does not consist of conflicting elements, entities and processes. Liu et al. (2012) suggest that the assessment criteria for conceptual model validation and verification are the capability of the conceptual model to satisfy the requirements specified by the developer and user for the simulation in general and to support a particular application of the simulation. Four approaches to the validation process are:

- **Individual approach**: the model is validated solely by the designer;
- **Subjective approach**: the model is validated by a team comprised of the model designer, suppliers, customers or people with multiple disciplines in the organization;

- **Independent verification and validation:** the model is validated by an independent reviewer; and
- **Scoring model:** the model is validated on the basis of some pre-defined scoring criteria.

If the size of the simulation team developing the model is small, a better approach than the one above is to have the user(s) of the model heavily involved with the model development team in deciding the validity of the simulation model. With this approach the focus of determining the validity of the simulation model moves from the model developers to the model users. Also, this approach aids the model's credibility.

Heath et al. (2012) find that the qualitative method was mainly used to validate an agent-based model. This might be because many agent-based models require the finer level of model detail in which data at that level of detail may be difficult to obtain. This research implemented a qualitative method to validate the conceptual and the simulation model.

Another important technique of model validation is sensitivity analysis or what-if analysis, that is defined as the systematic investigation of the reaction of model outputs to drastic changes in model inputs and model structure (Kleijnen, 1995). Sensitivity analysis is useful to assess the consistency of the model and to determine the best parameters to achieve optimal goals. Parameter variability sensitivity analysis (Sargent, 2010; Xiang et al., 2005; Law and Kelton, 2000; Clemen, 1991) is a validation technique where one changes the value of the input and internal parameters of a model to determine the effect upon the model and its output. The same relationship should occur in the model as in the real system. Those parameters that are sensitive, i.e. which cause significant changes in the model's behaviour, should be made sufficiently accurate prior to using the model.

At the level of components, Bharathy and Silverman (2010) apply internal validity to assess the completeness, clarity, coherence, and robustness of the agent-based model. The internal validation process provided multiple levels of correspondence. Montanola-Sales et al. (2011) use structured walkthrough (Law and Kelton, 2000) of the programme technique to verify the agent-based model. This technique has divided the model into smaller components and tested the correctness of each component. It is started with the simplest possible behaviour so that simulation output can be easily understood and errors can be easily recognized. The method is especially effective, since it provides many possible combinations of interactions between agents in the model. The White Box validation method focuses on the correctness of the interaction between components by assuming that the components inside the model are identified. Hence, the white box method was applied by comparing the input and the output of the model.

Sargent (2010) defines face validity as asking the domain experts whether the conceptual model, simulation model and its behaviour are reasonable. The technique can aid the experts in making subjective judgments on whether a model is sufficiently accurate and the model input-output relationships are reasonable. There are two ways to allow the experts to give the correct judgments easily (Xiang et al., 2005):

1. Animation is the graphical display of the behaviour of the model over time.
2. Graphical representation is representing the model's output data (mean, distribution, and time series of a variable) with various graphs. The graphs can help in making subjective judgments.

Face validity by using graphical representations is proposed in this research, since the simulation model is built to help the decision maker's to assess resilience practically. By observing the visualisation of the simulation model, the decision makers are expected to provide an accurate review of the model.

2.4 Summary

This chapter provides a review of the literature on supply network resilience from a number of authors who argue that resilience has a strong links with risk assessment. When organisations, industry, or supply networks attempt to be resilient, they must have the ability to deal with risks occurring in their system. The literature also argues that risks occurring in the infrastructure tend to disturb processes in the supply network. Figure 2.5 provides a chronological summary of literature. It can be seen there has been little in-depth consideration of ways in which resilience might be assessed in supply network contexts. This research addressed this aspect.

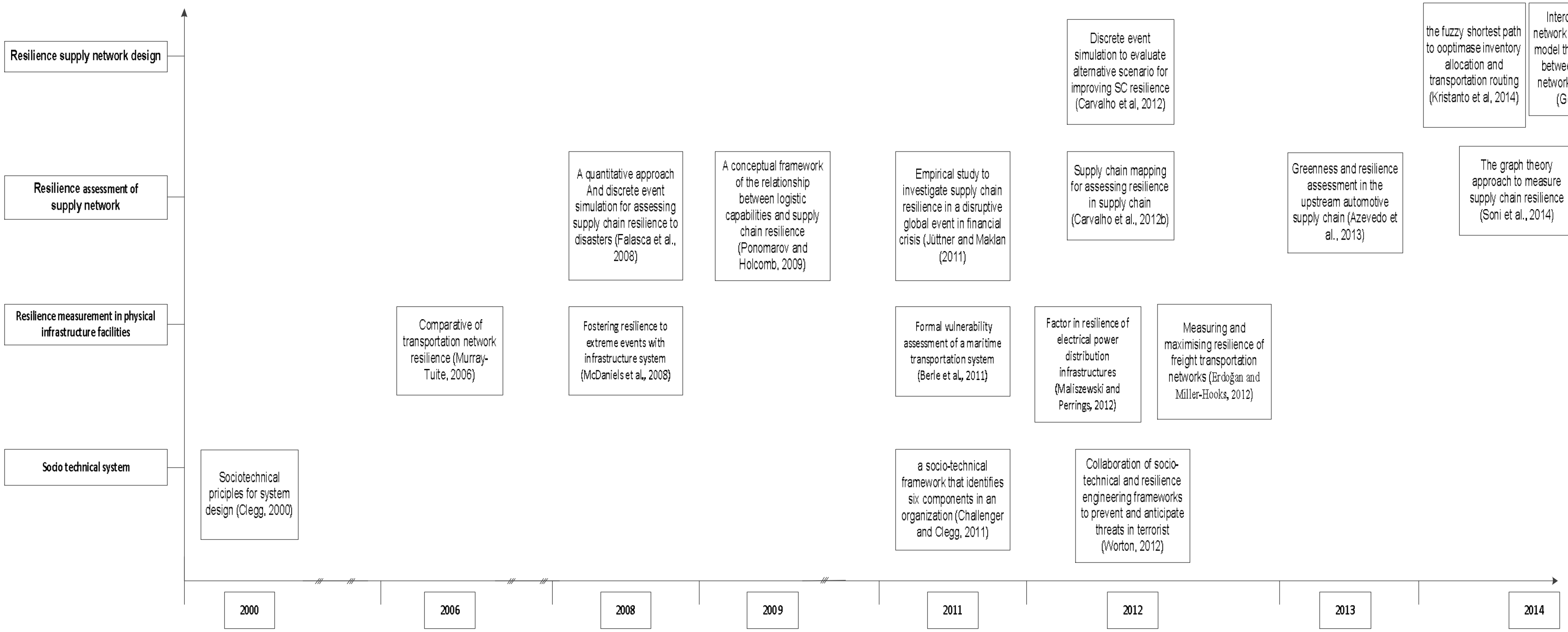

Figure 2.5 Literature review in diagram

This research was based on the proposition that risk assessment report can be used as information in the resilience assessment process. For the purpose of this research, the definition of resilience is the ability of a network to respond to risk by maintaining social and technical resources to reduce and control risk. Information generated from resilience assessment is important in identifying the level of resilience of a supply network. Further, resilience assessment results can be used as information resources to select mitigation strategy and reduce risk.

Literature reviewed in this chapter was used to inform the establishment of the theoretical framework in Chapter 5. By compiling the framework with data from the case study in Chapter 4, the conceptual model in Chapter 6 was built to enable the implementation of the framework for the case study. A simulation model was then constructed to demonstrate the conceptual model and its practical application; this is reported in Chapter 7.

Chapter 3
Research Methodology

This chapter explains the methodology and research process that were used. Section 3.1 introduces the methodological framework and describes the research in terms of the epistemological approach that was adopted. Section 3.2 outlines the research design and includes the reasons for choosing case study as the research method, the data collection process, and types of data that were collected, how the data was analysed, and criteria for interpreting the findings. Section 3.3 provides a summary of this chapter.

3.1 Methodological Framework

The methodological framework introduced in this section was created to provide guidance in conducting research. In order to answer the research question, this research aimed to establish new knowledge or a theoretical framework in accordance with the epistemological approach (Butte College, 2008). There are three methods in the process of generating new knowledge: deductive, inductive, and abductive approaches. The deductive approach involves forming new knowledge based on a general idea or interest in some study, then a specific theory is built and tested with a specific case that subsequently leads to the conclusion. Conversely, the inductive method starts from the observation of a specific problem, then forms a hypothesis as a guide to form a new theory that can be generalized (Trochim, 2006). The abductive method starts from observation of the real world problem and then makes a decision based on existing data that drives into a conclusion whether the theory is true or not (Butte College, 2008).

This research combined the abductive and inductive approaches. Figure 3.1 illustrates the research process undertaken in this study. Abductive phases are outlined in red lines, while inductive phases are outlined in blue lines. The abductive phase followed the research through observation of specific cases that occurred in the Indonesian fertiliser industry and geographical conditions of Indonesia as an archipelago country, as described in Section 1.1. Moreover, results of interviews with decision makers found that the Indonesian fertiliser industry has historical data, in the form of the risk assessments and the port management reports. These reports could be used as information to assess the resilience in the supply network. This research used House of Quality matrix to identify decision makers' requirements on the resilience assessment approach and link between the requirements with the resilience dimension as illustrated in Section 5.3.

The inductive phase results from the literature review highlighted an industry need for an approach that connects supply network resilience with infrastructure availability. The definition of resilience used in this research[1] is given in Chapter 2, Section 2.3. A combination of the abductive approach and inductive approach were applied to identify key dimensions of resilience[2] in this research based on case study analysis.

The theoretical framework in Chapter 5 was generated by linking data collected through the Indonesian fertiliser industry case study in Chapter 4 and results from the literature review in Chapter 2. The theoretical framework was translated into a conceptual model in Chapter 6, so the theory could be implemented practically through the use of historical data from the Indonesian fertiliser industry. Then, the simulation model in Chapter 7 was established to apply the model in computer language to facilitate decision makers in operating results of the new approach and produce output that can be used to analyze the level of risk and resilience. The translation from theoretical framework to conceptual model and simulation models was described in Table 7.10. These processes were described in Figure 3.2 The new approach generated can be generalised and implemented to other industries with the same geographical condition as the Indonesian fertiliser industry.

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[1] Resilience is the ability of a network to respond to disturbance by maintaining social and technical resources to reduce and control risk.

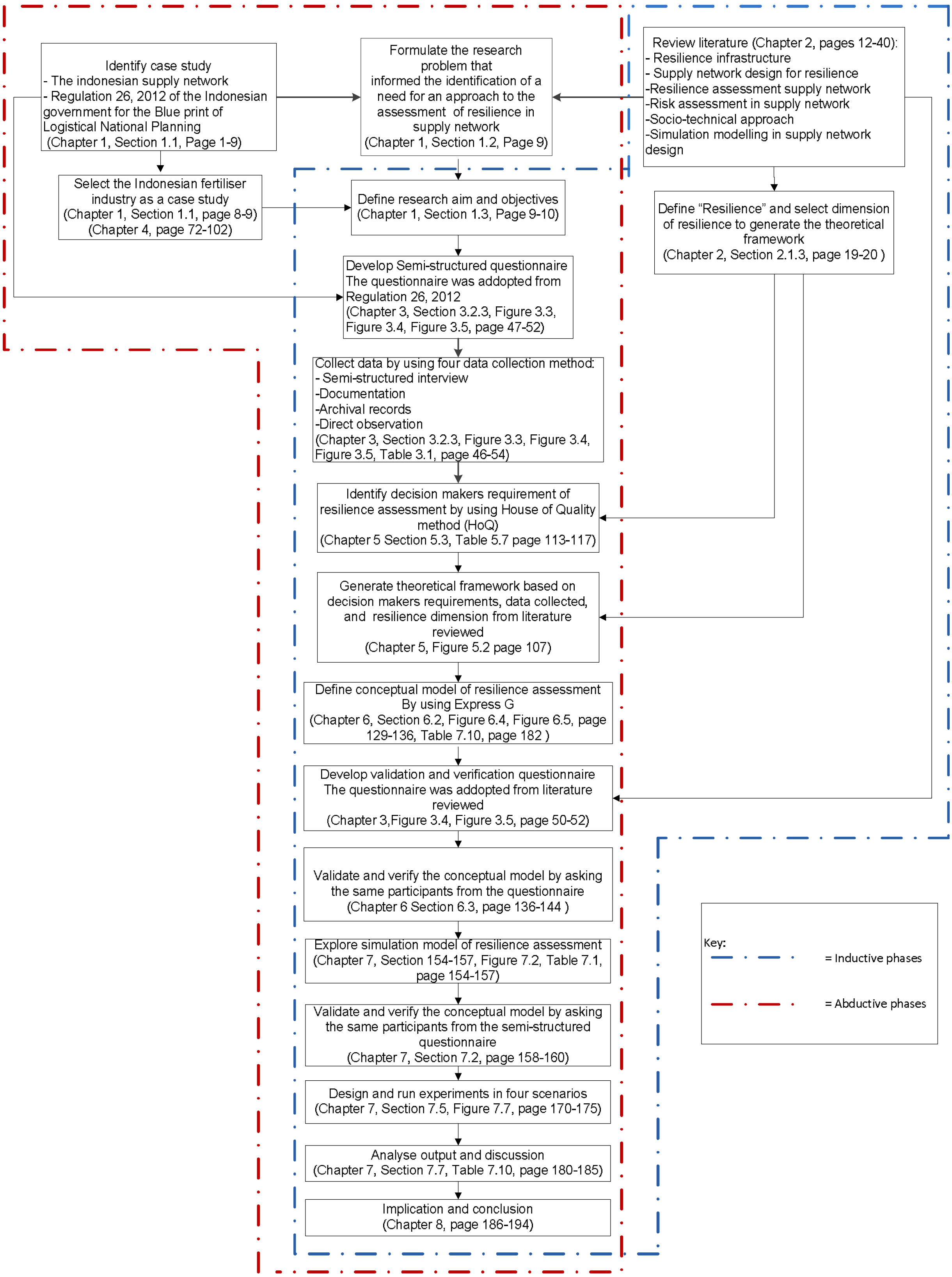


Figure 3.1 Research process diagram

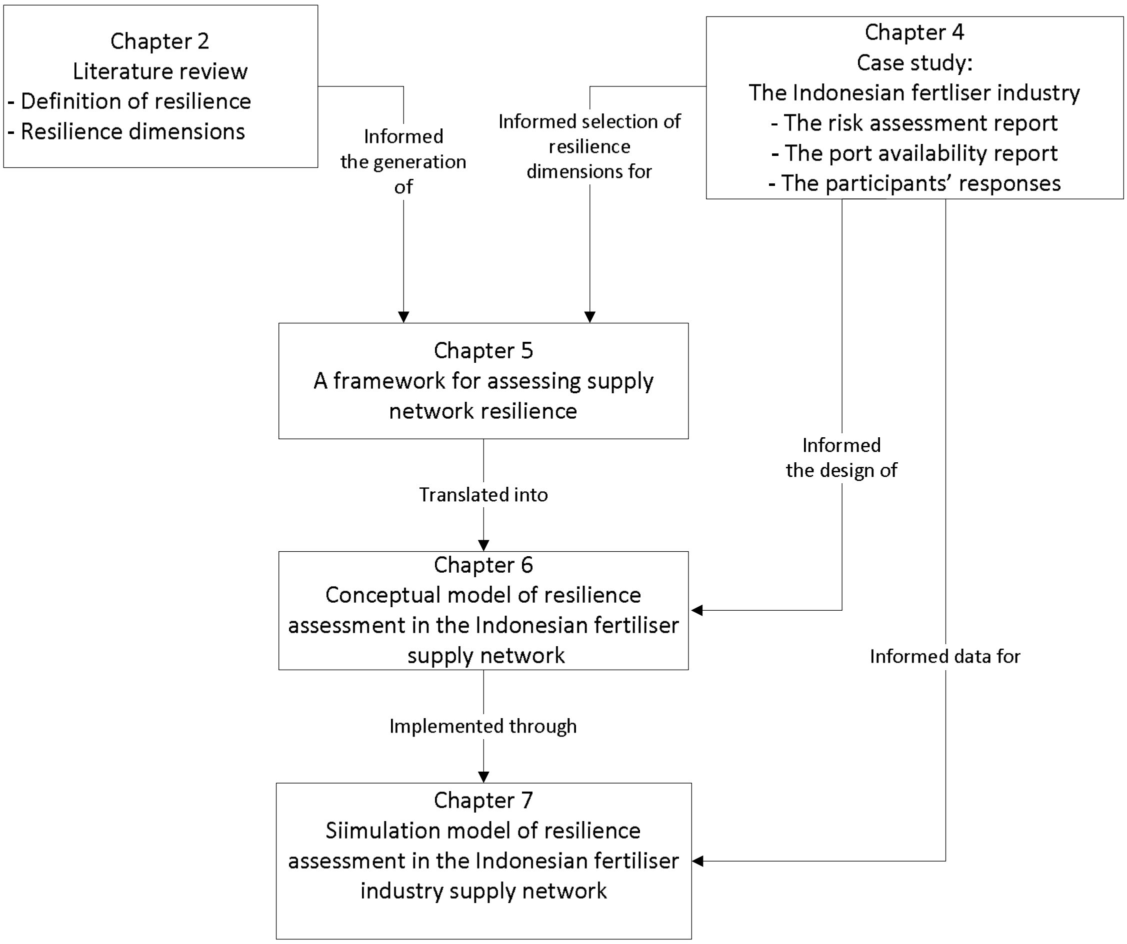


Figure 3.2 Diagram linking the theoretical framework, the conceptual model and the simulation model.

3.2 Research Design

The methodological framework was used to inform the design of the research. Yin (2009) defines research design as a logical plan for getting from the initial questions to be answered to some conclusions about the questions. Five components of case study research design (Shuai et al., 2011; Yin, 2009) were adapted to develop the research design in this research. The method of data collection has beed included in Section 3.2.3.

This research proposed to answer the research question from a real life system in the Indonesian fertiliser supply network. A supply network is an important system that should be resilient in order to maintain the availability of subsidised fertiliser in Indonesia. Further, the port as the major infrastructure in the Indonesian supply network system, should be considered in assessing the supply of network resilience. Due to the complexity of supply infrastructure networks, a holistic case study was conducted as an in depth case study of one particular industry. The Indonesian fertiliser supply network has been chosen as the case study due to the contribution of the industry to the Indonesian economy and the complexity of supply infrastructure networks in an archipelago country.

3.2.1 Research question

The case study method investigates a contemporary phenomenon in depth and within real life (Yin, 2009). In addition, the case study method allows researchers to retain holistic and meaningful characteristics of real life events, such as the maturation of industries (Yin, 2009). The case study method provides an opportunity to examine a crucial phenomenon that occurs in real conditions. Further, the case study method bridges the gap between empirical and theoretical science analysis by engaging authentic evidence of the event and literature review. The method also provides an opportunity to collect multiple data resources; qualitative and quantitative. The approach built, based on case study, provides greater opportunity to be implemented in the real world.

The case study method was suggested as a suitable methodology in this research. The research question was, *“How can the Indonesian fertiliser industry assess the resilience of its supply network to changes in infrastructure availability?”* which indicates the requirement to discuss and analyse thoroughly and deeply using a real case from industry. The word "*how*" was used in the research question because this study analyses the process of assessment of resilience in the case study. Questioning words like "*how*" assisted the researcher in defining the purpose and objectives of the research. In addition, the question “*how*” was also selected based on the real conditions and available data in the Indonesian supply network, where "*how*" can be answered by data collected from key persons and historical data available to analyse in the case study.

Primary and secondary data, quantitative and qualitative, was needed to answer the research question. The research question opens an opportunity to generate a new approach associated with empirical and practical research in supply networks. For this reason, the case study method was chosen as the research method in this thesis.

3.2.2 Research propositions

Propositions are an important factor in the case study method. They guide the researcher to decide on the scope of the research and sources of data or evidence to use in answering the research question. By reflecting on information from the research question and the literature review, the propositions for this research were as follows.

a. Changing the availability of infrastructures has an impact on the resilience of supply networks.

b. Resilience assessment can be accommodated within existing risk assessment processes.

c. The success of achieving a resilience target relies on Indonesian supply networks being able to reduce their vulnerability to changes in the availability of infrastructures.

3.2.3 Data Collection

The unit of analysis was the case studied in the research. It can be an individual, organization or system (Yin, 2009). The unit of analysis of this research was the Indonesian fertiliser industry. The Indonesian fertiliser industry supply network is managed by four departments within the Indonesian goverment; Department of Risk Management, Department of Purchasing, Department of Sales Region I and Department of Sales Region II.

Data collected in this research was particularly on the supply networks and the port as a major infrastructure in the Indonesian supply network. Yin (2009) identifies six sources from which to collect data evidence: documentation, archival records, interviews, direct observations, participants' observations and physical artefacts. The data collected in this research was the historical data that could support the response of key persons and the data available in the Indonesian fertiliser supply network. Four sources of the data used are explained as follows:

a. Interviews

A semi-structured questionnaire (Appendix A) was developed and used as a tool for data collection. The Indonesian industry report (The Ministry of Industry of the Republic of Indonesia, 2011) and Regulation 26, 2012 were used to inform the design of the semi-structured questionnaire. The report includes the characteristics of products, suppliers, consumers, locations, and the infrastructure facilities required for industries in Indonesia. The reports were integrated with six perspectives of the socio-technical system (goal, culture, people, process or procedure, technology, and building). The six factors were used as key performance indicators in resilience assessment. Questions in the semi-structured questionnaire helped to define the main factors in resilience assessment. Figure 3.3 highlights relationships in the reports, six perspectives of the socio-technical system and questions in the questionnaire (Appendix A). The following relationships can be seen from Figure 3.3.

- Question (A), question (B), question (C), question (D), question (11), question (12) helped to analyse the general profile of the Indonesian fertiliser industry supply network. Information collected from the questions addressed the goals of the Indonesian fertiliser industry.
- Question (1), question (8), and question (11) were used to define the relationship of supply network elements, and the influence of government on supply network operation. These relationships described the culture of the Indonesian fertiliser industry operation.
- Question (2), question (3), and question (4), defined elements of the supply network and performance of the supply network.
- Question (5), question (9), question (10), and question (11) defined the transportation and infrastructure used in the supply network operation. Responses to these questions addressed technology used in the Indonesian fertiliser industry supply network.
- Question (6), question (7), and question (14) helped to address process or procedure and the contribution of the researcher's institution in the improvement of supply network operation.
- Question (9), question (10), and question (13) defined buildings used in the Indonesian fertiliser industry supply network.

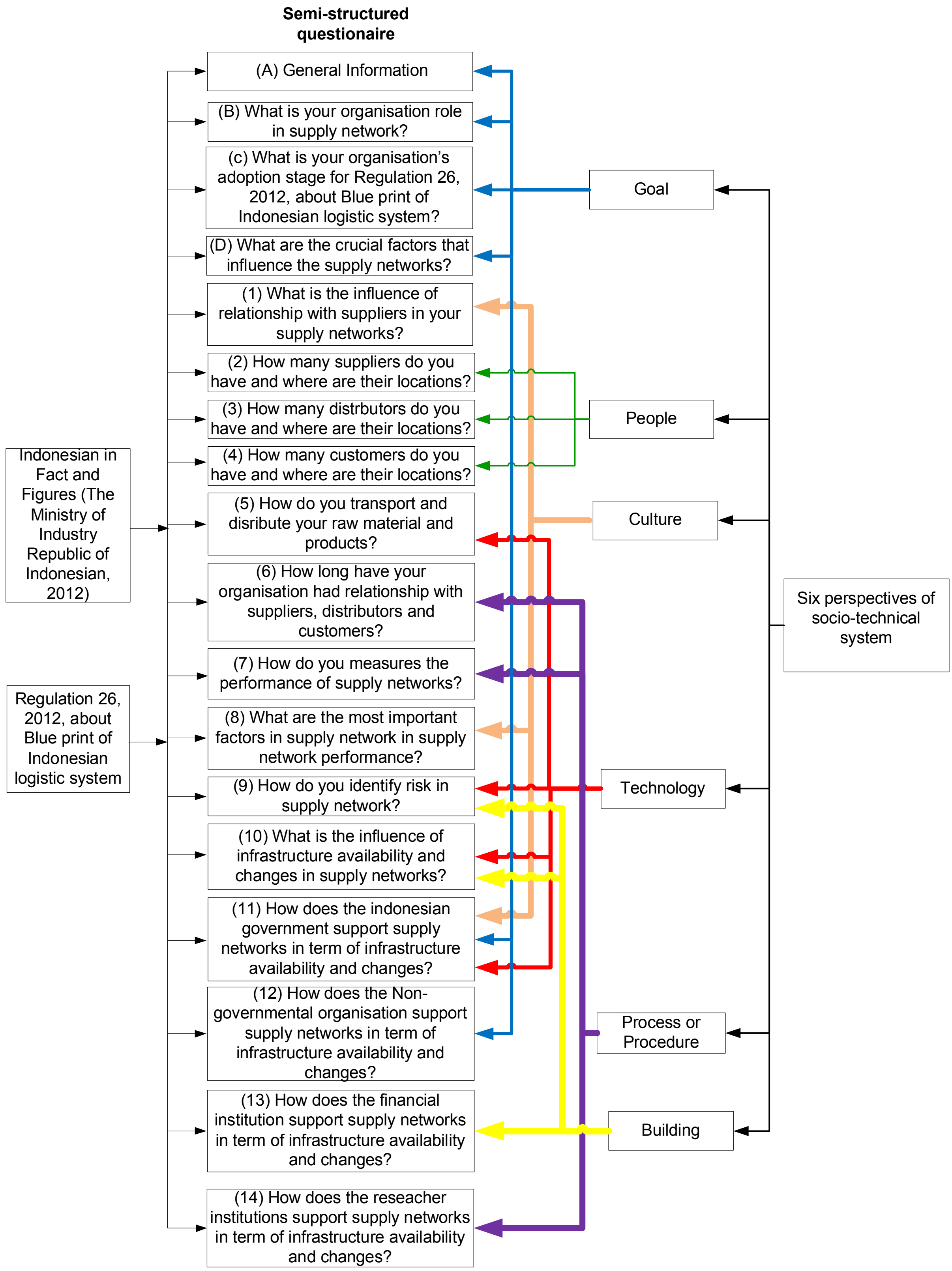


Figure 3.3 Sources of semi-structured questionnaire

The semi-structured questionnaire was used because it provides an opportunity for the researcher to explain verbally and directly the main focus of the questions to key people. This could assist key people in understanding the questions and answer them correctly based on the purposes. A qualitative approach was used to gain perceptions and judgement of the key person based on their experience and background. Semi-structured interviews were used to obtain information from decision makers regarding risk assessments and resilience measurement in supply networks, as the methodology to estimate the risk based on expert estimation (Knemeyer et al., 2009). Further, a semi-structured questionnaire was used to identify product and information flow in supply networks. The questionnaire consisted of questions with tick boxes as one way of recording answers in order to help the decision maker answer the questions quickly and efficiently. This research applied a purposely random sampling technique (Sekaran, 2003) to determine the number of participants in the fertiliser supply network. The potential participants were chosen based on their job description, experience, and recommendation from the manager. Ten potential participants were contacted at the beginning of the fieldwork and a meeting schedule was arranged. Brainstorming with the manager was conducted on the first day of fieldwork to discuss the research topic, potential participants, and schedule of interviews. The detailed nature of job roles, average experience levels and countries, in which the participants are based, were described in Table 3.1. This thesis used two questionnaires. The first questionnaire was the semi-structured questionnaire as a tool to collect data and information from the participants. It was used in the first fieldwork from September - December 2012. The second questionnaire was a validation and verification questionnaire used as a tool to validate and verify conceptual and simulation models. It was also used during the second fieldwork session from September - October 2013. The same participants took part in the two questionnaires, except one participant who retired in February 2013. The retired participant was replaced by the new participant who filled the same position in the department.

Direct interviews were held between the researcher and the participants. Before conducting interviews, the researcher explained to the participants the definitions of the variables and clarified information that addressed the answers. The researcher recorded the answers and available data that had been given by participants to support the information. The participants were managers or key persons who have the task and responsibility for supply network management. While conducting interviews, the participants were asked to complete questionnaires as well as to provide information needed by the researcher. To complement the interviews, the managers were also contacted via telephone and e-mail to answer any questions that had been overlooked during the interview.

A validation and verification questionnaire (Appendix C) was also compiled as a tool to obtain the participants' feedback on the conceptual and simulation model built. This design of this questionnaire was based on previous literature. Figure 3.4 and Figure 3.5 describes sources of validation and verification questionnaire. In Figure 3.4, representation of conceptual model was validated using six parameters: model is complete, model is correct, model minimal, model is understandable, model is extendable, and overall representation. Model process flow was validated from four parameters: entities, variables, entities relationship, and overall representation. Level validation was scaled in three categories: low, medium, and high. In Figure 3.5, the interface of the simulation was validated from seven parameters: monitor display, colour, variable layout, plot and diagram, running appearance, and overall representation. Variables of model were: lead time, delivery time, and infrastructure facilities. Level of validation was scaled in three scales: low, medium, and high. This research applied four scenarios: scenario A (reducing risk), scenario B (transferring risk to third party), scenario C (exploiting risk), and scenario D (avoiding risk).

The participants who answered the semi-structured questionnaire (Appendix A) were also asked to respond to the validation and verification questionnaire. The ten participants were asked to respond to the second questionnaire. Their answers were used as the main data to build the theoretical framework through identification of their requirement by using House of Quality.

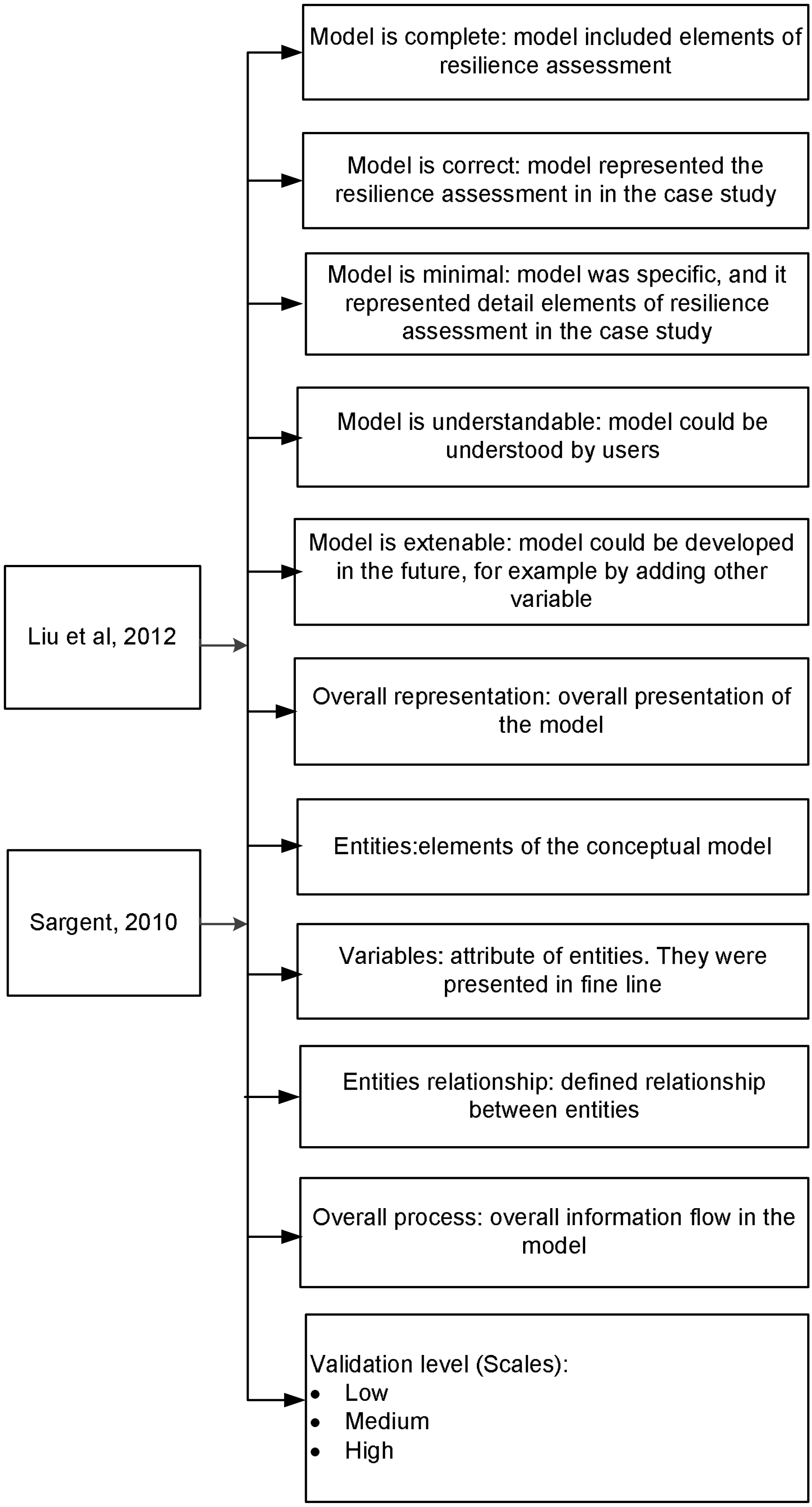


Figure 3.4 Sources of questionnaire for validation and verification of conceptual model

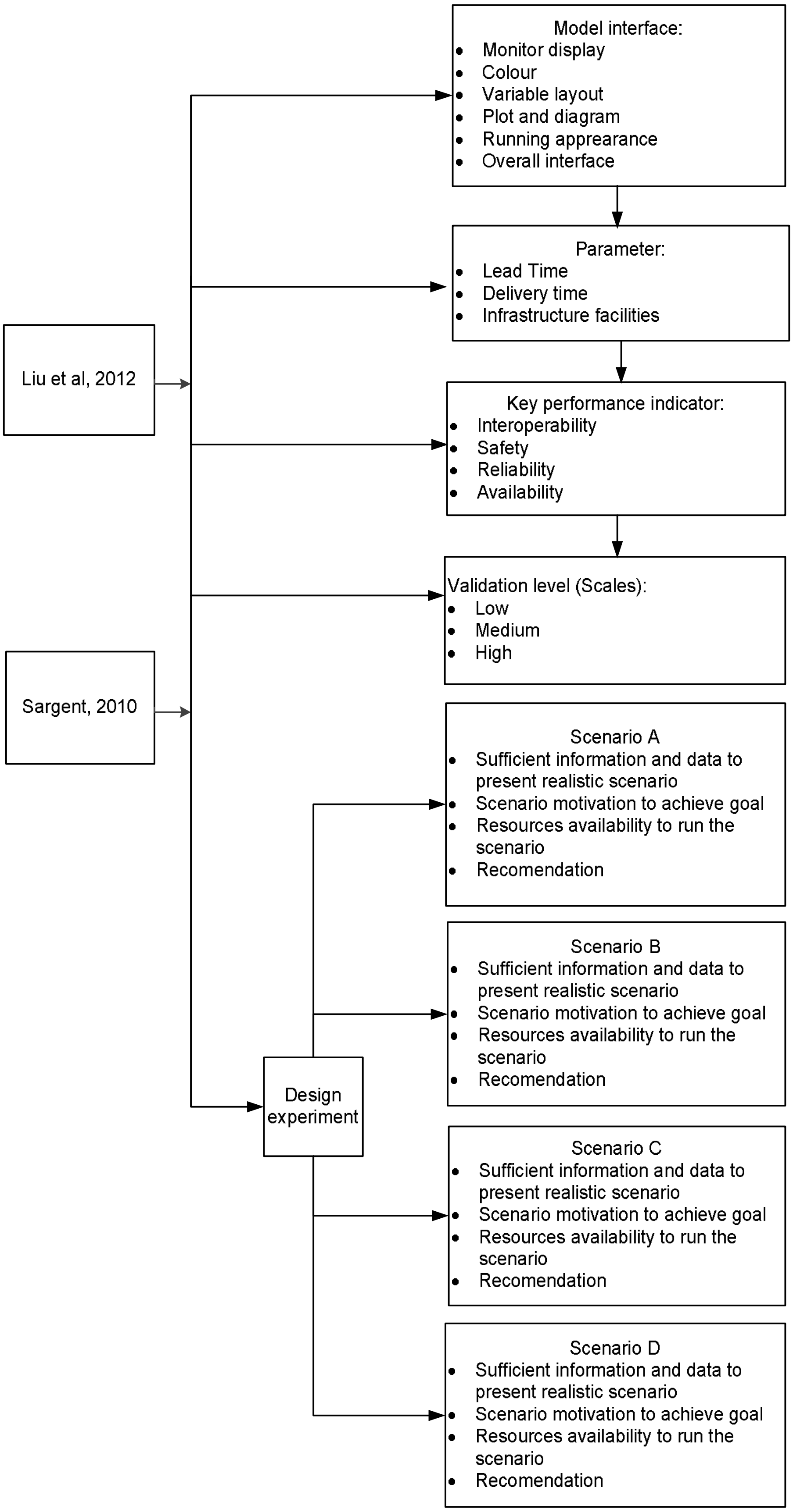


Figure 3.5 Source of questionnaire for validation and verification of simulation model

Table 3.1 Detail of participants

No	Participants	Based in	Job nature	Level of working experiences in the Indonesian fertiliser industry	Took part in semi structure interviewed questionnaire	Took part in validation and verification model questionnaire
1	Risk assessment manager	Indonesia	The manager has responsibility to analyse potential risk from all of departments and formulate respective risk mitigation based on risk standard in the Indonesian fertiliser industry. The risk assessment report is established annually after approved by the risk assessment manager.	> 30 years	Yes	Yes
2	Senior staff in the risk assessment department	Indonesia	Analysing the influence of risk on the customer complaint. His role is very important since the main goal of the Indonesian fertiliser industry is to achieve customer's satisfaction by providing sufficient subsidised fertiliser for Indonesian small and medium farmers.	> 30 years	Yes	Yes
3	Senior staff in the risk assessment department.	Indonesia	Collecting and analysing the risk assessment report from departments in the fertilizer industry.	> 35 years	Yes	No (Retired in February 2013)
4	Middle staff in the risk assessment department	Indonesia	Help the senior staff (Participants No. 3) to prepare the risk assessment report.	> 5 years	Yes	Yes
5	Senior staff in the procurement department	Indonesia	Managing relationship with the suppliers and controlling raw material delivery timetable from supplier.	> 30 years	Yes	Yes
6	Middle staff in the procurement department	Indonesia	Preparing the procurement department report.	> 7 years	Yes	Yes
7	Senior staff in the sales department region I	Indonesia	Managing and controlling fertiliser delivery to customers in Region I.	> 30 years	Yes	Yes
8	Senior staff in the sales department region II	Indonesia	Managing and controlling fertiliser delivery to customers in Region II.	> 30 years	Yes	Yes
9	Senior staff in the port department	Indonesia	Managing and controlling port utility.	> 30 years	Yes	Yes
10	Middle staff in the port department	Indonesia	Preparing the port management report.	> 5 five years	Yes	Yes
11	New staff in the risk assessment department (Replace retired staff/participants no. 3 to fulfill validation and verification conceptual and simulation model)	Indonesia	Preparing the risk assessment report.	> 6 month	No (Replace participant No. 3 to fulfill validation and verification questionnaire	Yes

b. Documentation

Documentation that can be used to meet the emerging information needs is collected if documents provide appropriate and effective information for answering the questionnaire. The researcher ensured that confidential data were protected and was used only for academic purposes and publications. Data collected from the documentation was the industry's profile, location and number of key suppliers, the schedule of delivery time from suppliers, the schedule of delivery of product to distributors and retailer, transportation facilities for distributions, and the risk management profile.

c. Archival records

Archival records are data that take the form of computer files and records (Yin, 2009). The fertiliser industry provides information and data on the industry's web sites. The data include the industry's sustainability reports (www.petrokimia-gresik.com), number and location of distribution centres, number and location of distributors and coverage area of supply networks in 33 (thirty-three) provinces of Indonesia. Data were also collected from the Indonesian government web site: Blue prints of Indonesian supply chain management 2012, regulations of the Ministry of Agriculture, regulations of the Ministry of Industry, and regulations of Ministry of the Trade which relate to fertiliser industry supply networks.

d. Direct observations

Reseacher observed material flow of fertliser from warehouses in the Indonesian fertiliser industry to T-port. Observation was conducted to support answers and information from participants.

3.2.4 Data Analysis

As explained above, the research question is determined based on data available in the case study, thus the data collection process is also based on the information to answer the research question. Logically, the analysis process could only be carried out based on the data available at that time, otherwise, the analysis would only have been carried out based on guesswork (Holt, 2005). Therefore, the research used a semi-structured questionnaire (Appendix A) and was supported by historical data. The most important historical data in this study is the risk assessment reports that are produced each year by the Risk Assessment Department. This research used the reports that were issued in 2012 and 2013.

A detailed description of the process flow in a system is needed to identify the problems that occurred. Two methods that are often used to map the business process are rich mapping and value stream mapping. Rich picture mapping configures details of the overall process from input to output of the process, while value stream mapping can be used to identify priority areas of improvement (Stroud, 2010). Thus, the research carried out for this thesis applied value stream mapping to map the supply network and identify the cause of the risk area.

The researcher adopted value-stream mapping to explore stages in supply network activities in a case study. The researcher argues that risk in the supply network system is similar to waste in lean manufacturing. Thus by adopting value stream mapping, risks in supply networks could be identified and minimized. Value-stream mapping focuses on streams and connections between activities (Womack and Jones, 1994) and it has both qualitative and quantitative aspects. Value-stream mapping provides a clear picture of how things are going now and through time so that no change was applied to the system, as it is reliable. However, it has weaknesses where two or more value-streams meet. The other weakness of the method is that the nature of the information collected in many cases is subjective, informal or based on observation (Delbridge and Kirkpatrick, 1994) while some data may be missed or be inappropriately highlighted.

In the case study analysis (Section 4.4) a matrix in House of Quality was adopted to assist the translation of decision maker requirements into a set of resilience dimensions in the theoretical framework. The matrix in this research, as shown in Figure 3.3 is called the expression of purpose dimensions matrix. The application of the level of purpose matrix in this study is similar to the needs-metrics matrix (Ulrich and Eppinger, 2012) in terms of the structure of the matrix, which uses two main tables; requirements and metrics, or dimensions. However, the matrix in this study is quite different from the needs-metrics matrix. The expression of the purpose dimensions matrix uses three scales, which are: strong, medium, and weak relationships to measure the relationship between the purposes and dimensions of the key performance indicators. Meanwhile, the needs-metrics matrix does not use a certain scale to identify the relationship between needs and metrics.

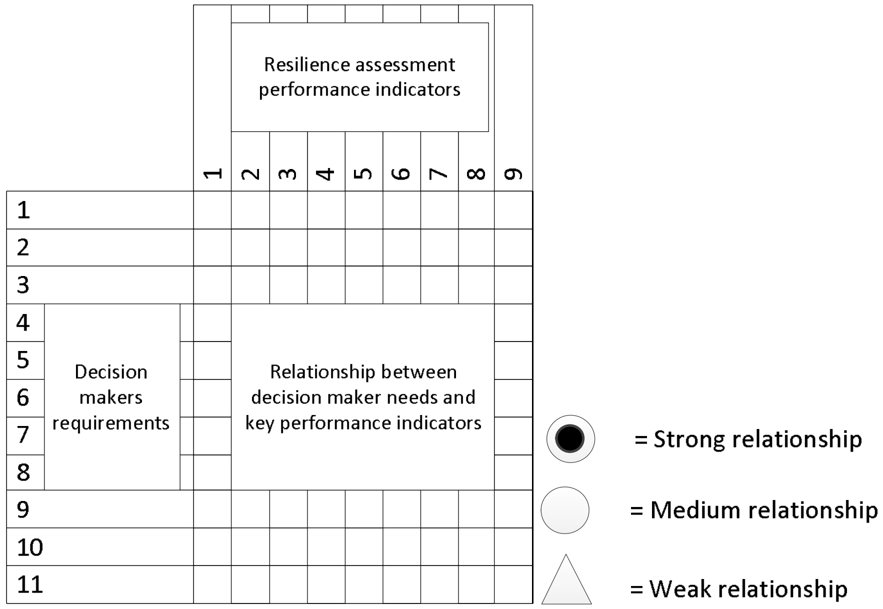


Figure 3.6 The expression of purpose dimensions matrix

3.2.4.1 Configuring the theoretical framework

This research used influence diagrams (Clemen, 1991) to configure a systematic structure of the resilience assessment approach in the theoretical framework. The influence diagram provides a simple graphical representation of a decision problem, such as decision, uncertainty, value, relevance link and information flow. Detail of the theoretical framework configuration is presented in Chapter 5.

Methods to help in transforming a complex real world into systems are: soft system methodology, socio-technical system approach and enterprise engineering framework. Soft system methodology provides several stages which are the situation defined, using rich pictures to express the richness of the situation (Structure, Processes, Climate, People, Issues expressed by people, and Conflicts), root definitions of relevant systems by applying CATWOE (Customers, Actors, Transformation, Weltanschauung, Owner, and Environment), developing the model, and back in the real world (William, 2005). Six perspectives in the socio-technical system covered two important factors in supply network operation. The factors were social and technical. This thesis focused on supply networks in the Indonesian fertiliser industry that had specific characteristics. The main technical factor in this thesis was infrastructure changes that suggested influence in the resilience of supply network. Most supply network operations in the Indonesian fertiliser industry are operated manually. For this reason, the researcher suggested that balancing analysis of technical and social factor was needed in order to assess resilience in the supply network.

Considering the problem defined in this thesis that assesses resilience in supply network infrastructure changes influence, this thesis applied a socio-technical approach and developed stages analysis by using the enterprise engineering framework. Infrastructure in supply network is not only influenced by technical factors (for example: machines, tools and vehicles), but it is also affected by social factors (for example: managers, operators and administration staff performance). Moreover, detailed analysis to prioritise the problem, departments involved, supply network process and strategy planning are needed to help find an optimum solution to the research problem. Therefore, this thesis develops the application of the enterprise engineering framework to investigate case study in Section 5.2.

3.2.4.2 Developing the conceptual model

The theoretical framework then translated into a conceptual model. A conceptual model was built to represent implementation of the resilience assessment approach against real supply network in the fertiliser industry. In order to generate conceptual modelling, the scale of key performance indicators of resilience supply networks are determined by quantifying resilience dimensions.

Next, the conceptual model will be designed to gradually translate the theoretical framework into a more detailed conceptual model. The development of conceptual modelling will apply a disciplined approach to the development of a decision support tool. This research applies the conceptual model development cycle as follows:

1. Conceptual model planning: in the early stages of conceptual model design, functional analysis development is necessary to describe model requirements as defined through the system process, elements or entities, key performance indicators, risk assessment, related material and information on flow in the model. The functional analysis is an iterative process of breaking down requirements from the system level, to the sub-system, and as far down the hierarchical structure as necessary to identify input design criteria and/or constraints for the various elements of the system (Blanchard, 2004). The functional analysis is generated by comprehensive flow diagrams that enabled the completion of the definition process in a logical manner from the top system level down to the detailed design. Chapter 4 conveyed that resilience assessment in

the Indonesian fertiliser supply network was developed in this research based on the information from case study analysis and quantitative data collected during fieldwork. IDEF 3 will be applied to represent the system process and requirements.

2. Requirement analysis: the significant requirement of conceptual model building is that the model can represent the real world and be understood and readable by users or decision makers alike. In addition, the conceptual model should be flexible, so the configuration can be improved easily without significant changes. The model must be traceable from the top down of system level functions and address desired goals.
3. Conceptual model design: representation of correlation and interplay between elements of the resilience assessment system were established by using the Express data modelling language. The design sequence detailed was based on application of the theoretical framework in the case study analysis in Chapter 5.
4. Conceptual model drawing: the Express G data modelling graphic was applied to draw the conceptual model. The model was structured gradually from five stages of theoretical framework, in Chapter 5.
5. Conceptual modelling validation test: a validation of conceptual modelling was accomplished to ensure that the model achieved its desired goals. The key people were asked to review the model and give suggestions to improve model validation. This research applied a formal validation model in a systems engineering approach. The formal validation model is a structured series of formal design reviews conducted at specific times in the overall system development process (Blanchard, 2004).
6. Conceptual model improvement: the reviews from key people were used as the basis for improving the reliability of the model.

3.2.4.3 Verification and validation of the conceptual model

Verification and validation of models is an important activity to ensure that the model is correct and fulfils the goal. Definition and differences between verification and validation are described in Section 2.3.3 of Chapter 2. Verification of a model involves determining whether the structure of the model is correct; this is achieved by testing the model through examining the outputs resulting from the model under a given set of inputs. Models will be constructed gradually and compared with the real conditions of the system in the supply networks. The Manager's perspective and judgment will be sought to confirm the verification process of the conceptual model, as one method is the decision maker judgment (Carvalho et al., 2012a). In validating a model, the model's output resulting from known inputs is compared to realisations of the reality (Fellows and Liu, 2008). This research applied internal validity, external validity and constructed validity to validate the conceptual and simulation model.

The validation and verification questionnaire (Appendix C) was formed as a tool to obtain the participants' view on the conceptual model. Scales used in the questionnaire were adopted from the risk assessment report of the Indonesian fertiliser industry. These levels of scale were used to aid the participants in order to comprehend the interpretation of the model compared with the real conditions in the case study.

3.2.4.4 Building the simulation model

Two methods used to help solve problems in a complex system are the simulation model and the statistical analysis method. Simulation models are suitable to be used to help solve problems in the system that has a large space state and can be used to predict the output by changing the value of variables in the model. Simulation is able to help solve generic problems by presenting a series of steps in the sub-system (Schneidewind, 2009). Statistical method analysis is a powerful method to analyse data in supply chain research. However, the application of statistics dependens on the data type, sample, and data collection time (Helmuth et al., 2015). On the other hand, the simulation method is a more flexible method and the model built could be matched with data available in the case study. As data available in this research is the annual risk assessment report, thus this research focuses on simulation.

The research problem addressed in this thesis is a complex system and needed a model that was capable of predicting the level of risk and resilience. For this reason, the simulation model was considered the most appropriate model to help solve the problem outline in this thesis.

The use of simulation in Chapter 7 was proposed as a part of the resilience assessment approach to assist the measurement of risks and resilience levels. The simulation tool will support the identification of gaps between the actual and the desired state of the supply networks and achieve the desired objectives from the proposed scenarios. The simulation model is used to demonstrate the conceptual model into a practical approach for decision making. The simulation approach permits observation of the dynamic behaviour of a system and is useful for understanding future conditions. Simulation generates quantitative results and permits a, “What if?” scenario investigation that will support decision makers. The output is expected to result in a comprehensive and more in-depth finding to answer the research question. Some considerations in selecting an appropriate simulation modelling tool are: modelling flexibility and execution speed, available to and accessible by to users.

Modelling of supply networks, risk and resilience measurement is constructed in order to represent real supply network systems. A model must capture and represent the reality being modelled as closely as is practical, it must include the essential features of reality, in respect of the purpose of constructing the model, whilst being reasonably cheap to construct and operate and easy to use (Fellows and Liu, 2008). Further, simulation is used to examine how the behaviour in the reality is likely to change upon a change in the values of input variables in the representative model. Simulation is used to assist prediction of the behaviour of a real system and to revise a model to enhance its predictive accuracy or predictive capability. Realizing that simulation is a complex sequential process, Law and Kelton (2000) develop ten steps in a simulation study: formulate the problem, collect data and define a conceptual model, validate the conceptual model, construct a language programme, pilot runs, validation simulation modelling, design experiment, running model, analyse output data, and present results.

An agent-based simulation approach was used in this research to create a prototype of the influence the port availability changes have on the level of risk and key performance indicators. An agent-based simulation model was also needed to provide an example of the application of strategy planning to reduce risk by managing material flow and determine the influence of variable changes in the material flow system in the port area on the duration of the loading process and percentage of berth occupancy ratio. Moreover, the agent-based model was also used when considering the availability of data in this research, such as the risk assessment report and the port availability, which was available once a year.

There are five agent-based model software packages often used to help problem solving in complex systems, these are; NetLogo, Java Swarm, MASON, Objective-C Swarm, and Repast. Table 3.2 describes comparison of advantage and disadvantage of the five agent-based software. Among these five, NetLogo is the highest-level agent-based software. NetLogo provides a simple yet powerful programming language, has comprehensive documentation and presents output in graphical interfaces, and NetLogo is highly recommended, even for prototyping complex models (Railsback et al., 2013).

Table 3.2 Comparison of advantage and disadvantage of agent-based modes

Agent Based Model Software	Advantage	Disadvantage
NetLogo	- Suitable for academia. - Compatible for building model which observe local agents interactions in short term and a parallel structure. - Not extremely complicated. - Provide an error checker that help model builder to develop and try in a small step.	- NetLogo language programming could be too simple for experienced programmer. - Classified code in some module could be disadvantage for a large model. - Model built with NetLogo could be very specific and not easy to replicate.
Java Swarm	Java Swarm certainly met its design objective of providing Swarm for Java users.	- Slow execution speed. - Incompatibility some feature. - The difficulty of debugging run-time errors.
MASON	- Having many agents or long run times. - Currently offers relatively few tools but supports computationally intensive models. - The fastest platform and quite clever, especially including all of the drawing methods in the user interface class.	- Nonstandard and sometimes confusing terminology. - Incompatible collection classes.
Objective-C Swarm	- The father of the framework and library platforms. - Stable (new versions and even bug discoveries are rare). - Relatively small and well-organized while providing a fairly complete set of tools. - Having a clear conceptual basis and a clever design. - Allows clear separation of graphical interfaces and the model.	- A lack of novice-friendly development tools. - Weak error handling. - The lack of “garbage collection”. - Lower availability of documentation and tutorial materials than for other platforms.

Continues on next page

Table 3.2 *Continued*

Repast	- Certainly the most complete Java platform. - Having the ability to reset and restart models from the graphical interface and the “Multi-run” experiment manager. - Having a good execution speed compared to the other platforms. - Includes many classes for geographical and network functions.	Some of its basic elements seem incomplete or not very carefully designed.

Vensim is software to build simulation for dynamic systems. This software provides a simple and flexible model to structure inter-relationship among the variables (Qiaolun and Tiegang, 2012). However, Vensim does not integrate with the agent-based model, which was necessary in this thesis. Thus, this thesis used NetLogo that provides broader and more flexible language programming, including the agent-based model. This research uses the NetLogo 5.0.4 software. The benefit of using this computer language programming is the software can be developed by researchers to suit the system components and behaviour.

Similarly with validation and verification of conceptual modelling, the questionnaire in Appendix C was used to validate and verify the simulation model. The simulation model will be constructed gradually and compared with real conditions of the system in supply networks. The simulation model will be validated using face validity. The key personnel were asked to review the simulation model. This thesis applied face validity by using graphical representations of the interface and the conceptual and simulation model. NetLogo 5.0.4 software provides the feature of plots to build graphs in the simulation model interface. The plot displays the score of risk in supply networks and infrastructure facilities over a period.

3.2.4.5 Design experiments

Design experiments are demonstrated based on the mitigation plan in the risk assessment of the fertiliser industry. The Indonesian fertiliser industry established four mitigation plans; reducing risk, transferring risk to third party organizations, exploiting risk, and avoiding risk. The first mitigation plan, reducing risk, is activities preventing risk, for example; conducting preventive maintenance for loading or unloading equipment and revising standard operating procedures. The second mitigation plan is transferring risk to insurance organisations by insuring product or fertiliser, operators, and equipment. The third mitigation plan is creating a new strategy, for example: expanding the port area. Then fourth mitigation plan is avoiding risk by not conducting any production activities. In the simulation modelling, the mitigation plans are translated into quantitative input from one to four. One is reducing risk, two is transferring risk insurance organisation, and four is avoiding risk.

The results of the initial interview found that in order to optimise the berth occupancy ratio, and minimise risk in the port area, loading and unloading time must be minimised. The loading time was determined by standard operating procedure in material flow. Thus, a conceptual and a simulation model of material flow in the infrastructure area are demonstrated to observe the effect of resources allocation on supply network resilience. A stochastic model is applied for estimating the influence of resource changes on the level infrastructure fluctuations. The random variable is determined based on historical data. By using stochastic models, simulation models can run faster in order to achieve the desired results instead of running it gradually according to the time period.

3.2.5 The criteria for interpreting the findings

Yin (2009) suggests using the validation treatment as a way to specify criteria in interpreting the findings of the case study. This research applied validity activities from Robson (2011) by conducting internal, external, content, and construct validation to analyse the results.

Internal validity is the extent to which the treatment is plausibly able to cause or describe its relationship with the outcome. In this thesis, the treatment was the approach and the outcome was the approach that could represent or describe actual conditions in the supply network flow. The approach was internally valid if it can satisfy the decision makers by translating their requirements into the approach. Content validity was the extent to which the model contains the variable needed and not contain redundant variables (Haynes et al, 1995). External validity was the extent to which the results of a study can be applied or generalised to other research objects or case study. External validity could be carried out, by providing an argument that the resulting approach could be generalised into another case study. Construct validity was the extent to which variable results present the actual variables that were intended to be measured. Construct validity was sometimes referred to as face validity. In this research, construct validity was applied to evaluate the accuracy of the approach to key people's answers to the semi-structured questionnaire.

3.2.5.1 Criteria to interpret the approach

The approach is deemed valid if it achieves the following criteria:

1. The assessment was in accordance with the industry's goal and aided decision makers in achieving the goal. The approach must reflect the goal of the supply network. For example, the goal of the Indonesian fertiliser industry was to satisfy customers.

2. Data required were available from the industry. The approach could be applied only if data were available. The case in this research provides adequate data for generating and applying the approach.

3. The approach aided decision makers in predicting the level of risk and it could be used as a reference in determining the risk management strategy for the future. The results of the approach must be valuable and deliver benefit for the applicant.

4. The results of the approach could be used as material for internal controls in order to support the operational activities. The approach addressed risk occurring in the supply network, so it supports the internal report and was beneficial in evaluating operational activities in the supply network.

5. The output of the approach can be used as information to review the business plan, such as an expansion plan of infrastructure facilities or optimising the allocation of human resources and technology.

3.2.5.2 Criteria of the participants

This study used the Delphi method to collect information from key people to validate the approach. The Delphi method was chosen because it is considered an appropriate technique to gain information on a particular issue in the real world and participants involved are the key people who are considered experts in their field (Hsu and Sandford, 2007).

The criteria for participants who are to be deemed suitable to participate in this research to answer the question in the validation of the model are:

1. Managers or staff who have a job description or responsibility in supply network management, such as managers of staff in the Department of

Risk Management, Department of Purchasing, Department of Sales Region I and Sales Region II. For this research, the managers and the researcher agreed to invite participants involved in former data collection to review the model. Therefore, the key people understood the process, purpose, and ultimate goal of this research, and they were eligible to review the model.

2. Managers or staff who have been working for a minimum of six months. This was based on the assumption that the new employee was deemed able to replace retired employees and have enough experience and knowledge to answer the question if they had worked for a minimum of six months in their department.

3. If possible, managers or staff should have an educational background in the field of industrial engineering, finance, agriculture, or economics. This was deemed important, since this research needed their suggestions for reviewing the approach in order to help decision makers in establishing the improvement process for the supply network.

The number of participants was slightly difficult to determine directly, since it depended on the number of managers or staff in supply network management in the Indonesian fertiliser Industry. In this research, ten participants agreed to be involved. This amount was considered sufficient, in accordance with the requirements of the Delphi method (Hsu and Sandford, 2007).

The process in the Delphi method in this research is as follows:

1. The questionnaire was constructed based on the information obtained from Sargent (2010). The questionnaire used in this research is presented in Appendix C.

2. All of the key people were asked to fill out a questionnaire. The researcher provided the conceptual model and checklist of the modelling review. The researcher distributed copies of the theoretical framework, conceptual and simulation model figures, validation, and verification check lists to key people. The researcher also provided her contact details, so the participants could contact and arrange a meeting or if they needed further information from the researcher.

3. Having received agreement of the date of meetings, meetings with the key people were conducted. The key people filled out the questionnaire and submitted it to the researcher.

4. The researcher collected the answers from all the key people and then asked them to review them again or clarify their answers.

5. The final results of the questionnaire were submitted again to the key people in order to deliver the end result, for example: how many key people agreed or disagreed with the validity of the proposed model. This phase also provided a last chance to key people if they wanted to revise their answer.

3.2.5.3 Threats in internal, external and construct validity

There are several threats in validating a study that are likely to occur and cause problems to output generated from the research. Robson (2011) presents twelve threats in the internal validity and four threats in external validity. The threat must be identified to anticipate the effect of the threat on the validation results.

Threats to internal validity are as follows:

1. Instrumentation

Several studies requiring pre-tests might produce different results from the post-tests because the participant already knows or has learned the research materials. This thesis used a semi-structured questionnaire as the tool for data collection. Questions in the semi-structured questionnaire were determined based on the intent to answer the research question and the flow in the theoretical framework. The questionnaire consisted of two phases, with different objectives and contents. The first questionnaire was for data collection. The second questionnaire was to validate the conceptual and simulation models. Participants who answered any of these questionnaires were the key people in the Indonesian fertiliser supply network. There was no repetition in the process of answering this questionnaire, so presumably the participants answered according to their experience and abilities that were supported by historical data established from 2011 to 2013.

The Delphi technique was applied to validate the approach. At the beginning of the meeting, the researcher presented the results of the case study analysis and conceptual model. The purpose and important influence of the socio-technical system in supply network analysis was described. Ten participants from five departments were asked to validate the conceptual model by completing questionnaires and providing suggestions to improve model performance.

2. Selection

Research involving participants from different backgrounds can trigger bias in the results. The criteria of participants for this research must be determined based on the scope of the research. The key people from the supply network departments, such as the manager of staff in the Department of Risk Management, Department of Purchasing, Department of Sales Region I, and Sales Region II. Historical data was collected to support the answers of the key people. The data is associated with the process flow of the supply network, such as: the risk assessment report, ordering process and delivery schedule of raw material, T-port availability and data from the Sales Department Regions I and II.

3. Mortality

Participants might withdraw from the study, so the researcher must delete and eliminate data collected from anyone who withdraws. In this research one of the key people who participated in answering the semi-structured questionnaire retired in February 2013. The new member of staff that replaced the retired participant was approached to review the model. The new member of staff was considered not to reduce the validity level of the model because he had been trained for six months before replacing the retiring member of staff and the new participant was only one or 10% of the key people.

Threats to external validity are as follows:

1. Selection

Results or findings might be specific to the object of the research. A case study approach was used in this research to analyse the real phenomenon that occurs in a supply network system with specific geographical characteristics, such as the geographical condition of Indonesia as an archipelago country, with the ports as critical infrastructure facilities for the supply network. In addition, in-depth analysis was carried out on a particular type of industry, the Indonesian fertiliser industry. This industry is an important industry because it contributes significantly to the welfare of farmers in Indonesia. The Indonesian fertiliser supply network is a special case, because the entire flow and components of the supply network, such as: the amount of fertiliser supply and demand, the number of distribution centres, the number of agents, the number of consumers, are determined entirely by the government regulations that are published and revised every year. Therefore, the findings and framework resulting from this study could possibly be generalised and applied in countries or regions with the same geographical or supply network characteristics as the Indonesian fertiliser industry. The findings and theoretical framework probably could be applied in other types of industry in Indonesia, such as the Indonesian subsidised gas supply network and the Indonesian subsidized agriculture products, which are a special programme of the Indonesian government.

2. Setting

Results or findings might be applicable in a particular area of study. As described in step 1, this study works best on an industry with specific geographical characteristics, such as being an archipelago country, with the ports as the main infrastructure in the supply network. Thus, this research particularly analysed the effect of port availability on supply network resilience. In addition, the Indonesian fertiliser industry has its own port that is managed by the Port Department. Data of port availability are available from that department.

The scenarios in the experiment design were specified based on four measures of mitigation strategies planned by the risk assessment department, i.e. the experiment will be conducted by: mitigation plan by reducing risk, mitigation plan by transferring risk to a third party organization, mitigation plan by exploiting risk, mitigation plan by avoiding risk, and simulation modelling to manage material flow. Design experiments will be carried out to configure model results and visualize model interfaces, so it is understandable.

3. History

Participants might have unique or historical experiences that could influence the result. However, research can only be conducted if appropriate data is available. The assessment and decision-making process cannot be conducted if there is no supporting data available. Therefore, to assess the resilience of the supply network, this research used the data available in the case study, such as the risk assessment, the T-port availability, and profile of the supply network in the Indonesian fertiliser industry. The key people answered that the flow of the supply network is influenced by the availability of T-port. This answer was based on the experience of key people who have managed the supply network flow for more than twenty years. Basically, the fertiliser industry is already aware of this influence, however, has not been able to formulate the effect significantly in an assessment. Therefore, this study helps the industry to plan and formulate assessment of supply network resilience.

4. Construct effects

The particular construct studied or the approach proposed may be specific to the group studied. Experiences and answers from key people who participated in this study also affected the results, especially in the process of verification and validation of the model. However, the approach proposed in this research is expected to be applicable to other industries that have similar characteristics to the Indonesian fertiliser industry.

Threats in construct validity

Construct validity refer to a relationship of accuracy between the responses and the reality the responses were intended to capture (Gom, 2004). In this research, construct validity was used to identify the relationship of the accuracy between conceptual and simulation model and the real supply networks in the fertilizer industry. Table 3.3 explains the threat of construct validity in this research.

Any threat to construct validity was likely to occur when there were some issues that interfered when the key people were answering the semi-structured questionnaire. For example, the key people thought that they were less experienced in theory and less familiar with the approach proposed. To overcome these problems, the thesis applied face validity as a method to ensure the approach was constructively valid. The researcher conducted a presentation to explain the process of generating the approach and demonstrated the simulation model. In addition, the key people were also permitted to operate the simulation model.

Table 3.3 Threats in construct validity

Threat		Description	Relevance to this Research Design
Participant Biases	Co-operation bias	Participants doesn't now the correct answer, but gives an answer nonetheless.	Participants may doesn't know the correct answer (in the previous time they aren't aware the influence of infrastructure changes in supply networks), but they give the answer based on their experience.
	Self-serving bias	Participants may give an inaccurate answer that they considers is accurate.	Participants may believe that they give correct explanation regarding the process and flow of supply networks. This answer may influence simulation modelling forming.
	Social Desirability Bias	Modifying the answer in order to give a favourable impression.	Participants may give good quantitative data and a favourable answer to obtain better illustration in the supply networks.
	Acquiescence Bias	Giving answer which the participants thinks the researchers willing to.	Participants may provide answer and data that they believe it is needed by the researcher.
	Non-response	Refuse to give any answer or data.	Participants might refuse to answer the questionnaire because of confidential reason.
	Mis-interpretation	Give the answer based on a different.	Participants might misinterpret the question in the questionnaire.
Observer Biases	Fraud	Construct the result actively.	The researcher mightn't consider discrepancy data gathered with simulation modelling language.
	Self-delusion	Unintentional fabrication of results.	The researcher may concern only to how the simulation will be worked, and ignoring real biases that might happened in the supply networks.
	Biased Treatment	Treat different groups that reinforce the expected results.	Behaviour of supply networks' component is observed by considering their involvement in supply networks process.
	Biased Observation	Ignoring data that contradicts the expected results.	Observation might only applied in department and infrastructure facilities which is considered affect supply networks performance.
Reactivity		Giving behaviour because one knows one is being observed.	Participants might differently represent their activity if it compare with their daily activity.

3.3 Summary

This chapter provided details of the research process and methodology that were used. A case study method was used because the problem in this research was a specific phenomenon occurring in the Indonesian fertiliser industry supply network. An important element of the case study approach was the determination of criteria to validate the resulting theories and findings. Agent-based simulation modelling was identified as a suitable method that could help to analyse process flow and explore key performance indicators of resilience assessment.

Chapter 4
Case Study: The Indonesian Fertiliser Industry

Indonesia is an archipelago country. This geographic structure significantly affects its supply network performance. The supply network performance influences the welfare of Indonesia, because the distribution of goods to the people of Indonesia requires resilient supply networks. Moreover, as an agricultural country, the availability of fertiliser is a priority for farmers. The Indonesian fertiliser industry, which produces subsidised fertiliser for small and medium sized farmers, is an important industry to support the welfare of farmers. In 2011, the Indonesian fertiliser industry reported a lack of subsidised fertiliser available to farmers during planting time due to delays in distribution of fertiliser from manufacturers to distributors. This problem was caused by delays in the transportation system. The main infrastructure of the transport system is the port. Thus, an in-depth study of the Indonesian fertiliser industry supply network was needed to help managers improve the performance of the supply network.

This chapter provides data collected from the case study based on the answers that key people provided in response to a semi-structured questionnaire. The key people were from the departments in the fertiliser industry which manage the supply network: the Department of Risk Management, the Department of Sales Region I, the Department of Sales Region II and the Department of Purchasing. Data consisted of primary and secondary data. Primary data was gathered from direct answers of the key people in the fertiliser industry, while secondary data came from reports and documents containing historical data to support key people's answers.

This chapter begins with an overview of the fertiliser industry and the important role of government regulation in the fertiliser supply network in Section 4.1. The risk assessment processes used by the Indonesian fertiliser industry to produce the resilience assessment of the supply network are described in Section 4.2. Section 4.3 introduces supply network flows in the Indonesian fertiliser industry that were the focus of this research. A summary of the chapter is provided in Section 4.4.

4.1 Profile of the Indonesian fertiliser industry and the role of government regulation on the fertiliser supply network

The key personnel explained that the Indonesian government strives to develop the agricultural sector by increasing agricultural productivity for the welfare of society. Thus, the fertiliser industry has an important role in fulfilling fertiliser demand throughout Indonesia. The fertiliser industry is located in the East Java Province and occupies 450 hectares of land. It is the most complete fertiliser industry in South East Asia having 21 plants with a capacity of 6,177,600 tons per year. The Board of Commissioners and the management continuously conduct review monitoring and provide recommendations on several aspects relating to the fertiliser industry operations, finances and implementation of The Risk Management System.

To support self-sufficiency for food in Indonesia, the fertiliser industry has to maintain stocks and distribution to all parts of Indonesia. The fertiliser industry is a state-owned enterprise whose operational supply networks are based on various regulations. Changes in government policy will influence the company's policy every year. The government determined six principles for implementing "accurate" supply network management, which are delivering product of an accurate type, accurate number, accurate price, accurate place, accurate time and accurate quality. To support the answer, key people provided a SWOT analysis of the fertiliser industry that stated the strategy plan of the annual report. The fertiliser industry established SWOT (Strength, Weakness, Opportunity and Threat) as part of their supply network planning, as shown in Table 4.1.

Based on Regulation No 122/2013 established by The Ministry of Agriculture, the fertiliser industry has a responsibility to distribute subsidized fertiliser from Line I, (producer/fertiliser company), Line II (distribution centres) and Line III (distributors). Distribution from Line III to Line IV (Agents) is the responsibility of distributors. The company has two distribution areas managed by regional distribution managers I and II, as shown in Figure 4.1. The regional divisions are based on the geography and infrastructure conditions of each region.

Table 4.1 The fertiliser industry's SWOT Analysis

Strength	**Weakness**
- has a distribution network (buffer warehouses, distributors and agents) located across the region of Indonesia. - has a port facility to support sustainability of import and export. - has the most complete a production unit of fertiliser. - have sufficient assets. - have experienced human resources from a variety of disciplines. - has adequate laboratory facilities. - the company has implemented a programme of Corporate Social Responsibility. - infrastructure availability for new projects have unit managers for risk management.	- Some production equipment has become obsolete. - Most of its specialized human resources plant operator (unit of production and maintenance), aged 40 years and over. - Capacity constraints of raw material. - Warehouse. - investment for development. - Reliability of waste-processing unit decreases due to aging plants. - Lack of personnel capability in innovation and research activities implementation. - Risk-awareness remains low - Areas of land for development and the limited waste disposal.
Opportunity	**Threat**
- The government programme to encourage the use of compound fertiliser in order to support national food security program. - Expanding the plantation area which is the potential increase in demand for fertiliser. - Global information systems (web based) that facilitate obtaining goods and factory equipment. - Opportunities to engage into a collaboration with outside parties (agencies, colleges). - Systems and technologies availability that can improve the performance of the environmental management. - Government encourage state owned company to implement a risk management system continuously. - The spirit of cooperation in procurement and logistics activities in the state-owned fertiliser.	- Issues of land and environmental damage due to the use of inorganic fertiliser inappropriately. - The increase in new competitors (manufacturers and importers) in the free trade market. - Natural gas supplies are limited and prices are increasing. - reduction in fertiliser subsidy policy. - The issue of other companies giving more interesting welfare. - Communities increasingly critical to the existence of plant. - Regulation and enforcement of more stringent environmental laws. - R & D developments of competitors developed rapidly. - Private companies invest more quickly extremely fast in the global economic situation changes (turbulence).

Figure 4.2 illustrates the information flow of fertiliser demand initiation. Region I is the islands of Java and Bali. Region II is Sumatra, Kalimantan, Sulawesi, Nusa Tenggara Barat (NTB), Nusa Tenggara Timur (NTT) and Papua. The islands of Java and Bali are located close to the company and have better and more comprehensive infrastructure facilities compared to Region II.

Regulations for Subsidized Fertiliser Distribution are:

a. The Ministry of Trade Regulation regulates the subsidized fertiliser procurement and distribution mechanism from Line I to Line IV.

b. The Ministry of Agriculture Regulation regulates the subsidized fertiliser allocation per province as well as the Definitive Plan Group of Farmers (DPF) system.

c. Governor Regulation regulates subsidized fertiliser allocation per Regency.

d. Regent/Mayoral Regulation regulates subsidized fertiliser allocation per district.

In 2012 the national fertiliser industry faced challenges in its core business, for example: high economic costs (economies of scale), taxation system, customs system, labour, and unpredictable climate change and free trade of the APEC Economic Zones which will be fully implemented by 2020. However, it is estimated that the demand for fertiliser will continually increase in line with the efforts to improve the world's food quality. The development of the fertiliser industry should deal with problems, for example: inadequate infrastructure of building and supply network facilities, insufficient energy supply, human resource competencies, especially in optimising productivity and skills, lack of raw materials and unsophisticated technology of machinery which cause inefficient and low productivity.

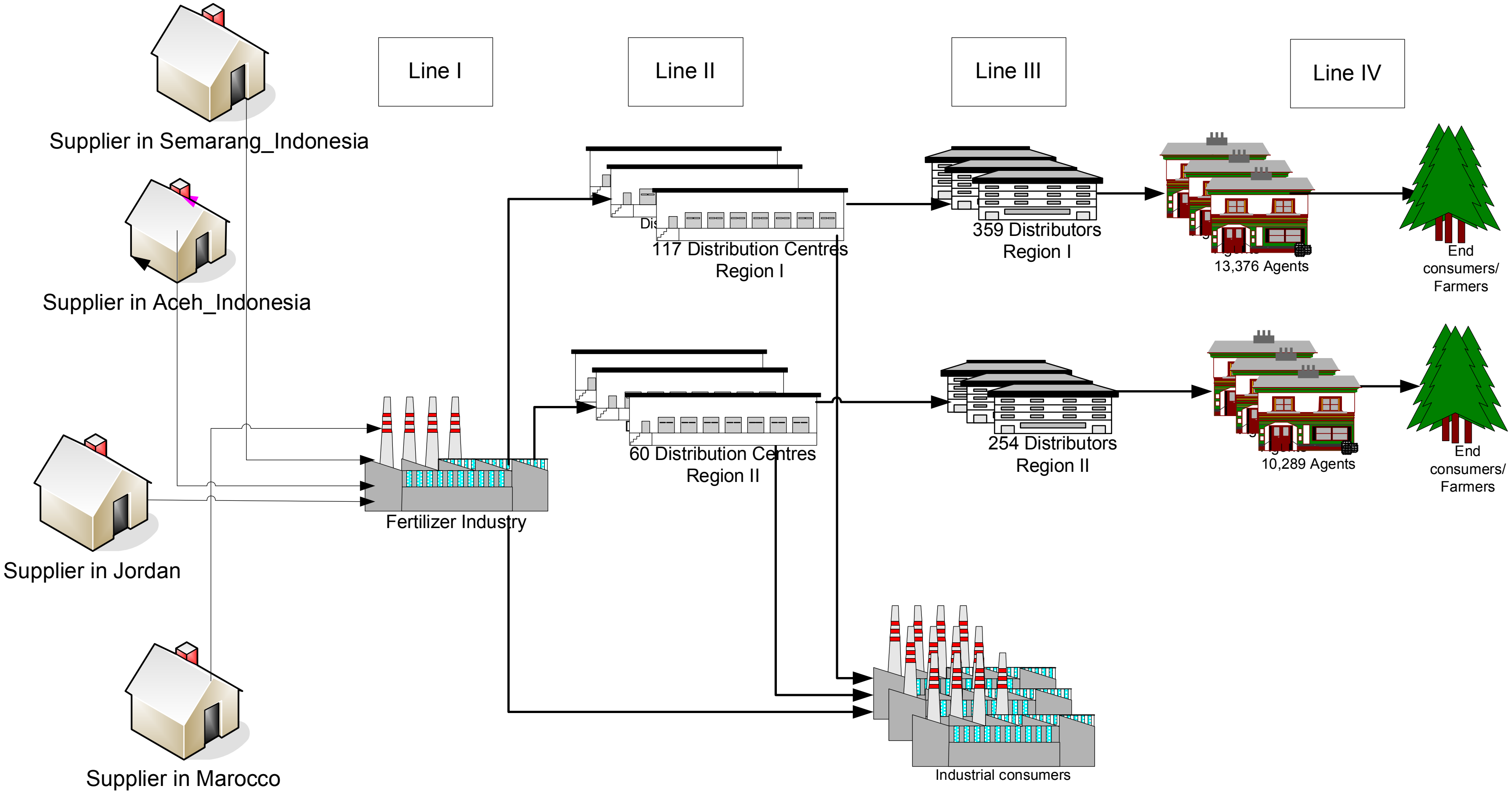


Figure 4.1 Supply networks of the Indonesian fertiliser industry

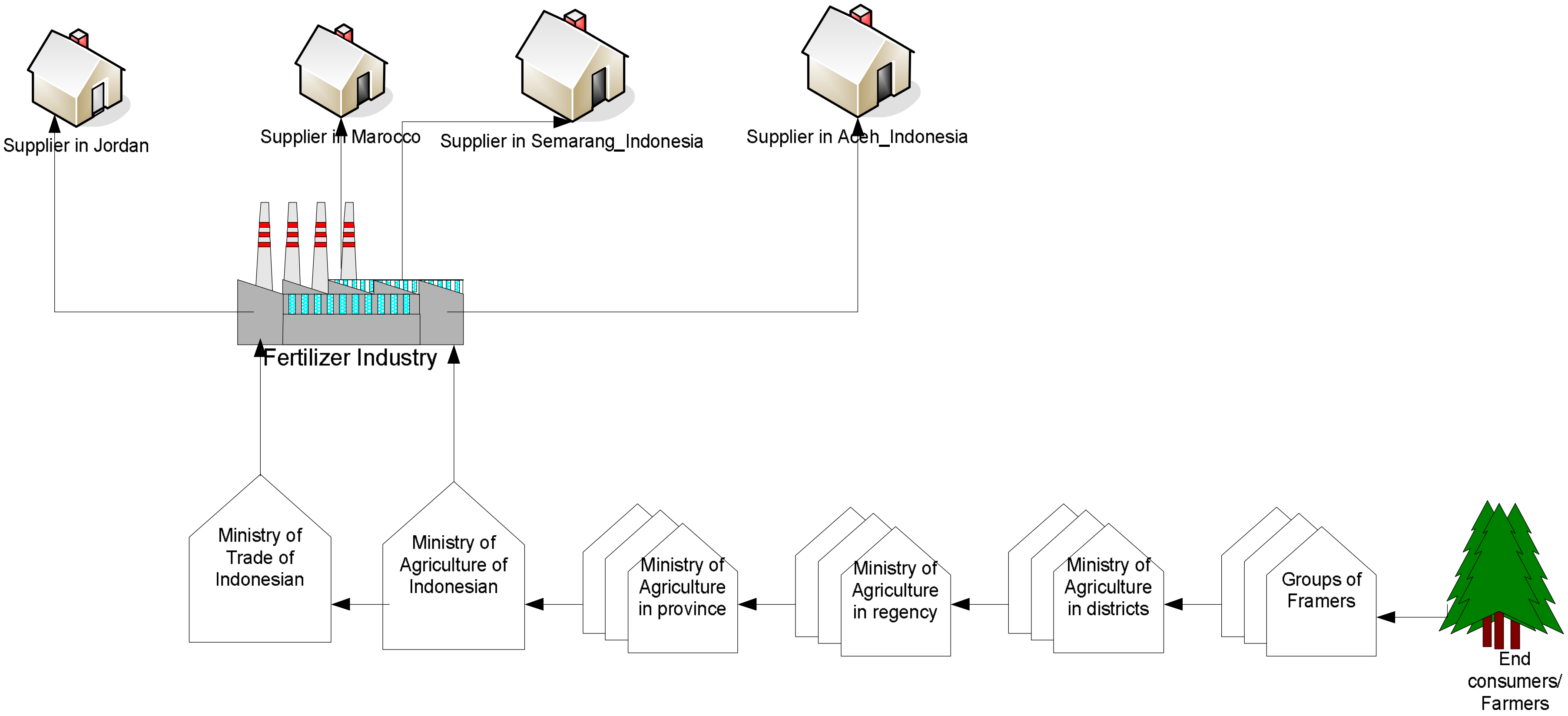


Figure 4.2 Dyad of supply networks from end customers to suppliers

Figure 4.3 illustrates an example of supply network infrastructure in one area covered in Madura Island. Madura Island is a good example for describing fertiliser flow, since the flow of the island is located in a different region I, yet it is situated on a different island from the fertiliser industry. Thus this example can represent the supply network process in Region I and Region II. The box represents supply network components and the arrows represent the relationship between the components of the supply networks. There are four arrows that describe different infrastructure facilities: dashed arrows represent railroads, pointed arrows represent ports, solid arrows represent roads, and thick arrows represent bridges.

The key people informed the researcher that the fertiliser industry's priority is to support subsidized fertiliser needs in Indonesia. Furthermore, in discussions with key people, the researcher analysed the fact that as an archipelago country, Indonesia consists of five large islands and hundreds of smaller islands. These characteristics influence supply network risk and performance. Moreover, as a developing country, Indonesia continuously builds infrastructure facilities to accelerate inter-regional and intra-islands access. Thus, to gain appropriate supply networks management, the fertiliser industry divides supply network coverage based on geographic and infrastructural availability. As mentioned before, the distribution area is divided into two regions. Region I is the islands of Java and Bali. Those islands are more developed than the others. Infrastructure availability on these islands is more complete, for example: these islands have good quality roads and highways, railroads, an international harbour and frequent container ship operations. Java Island, as the central government of Indonesia has the largest population. The infrastructure facilities are already more complete and sophisticated compared to the other islands. However, the high population density increases the risk of congestion and delays in the distribution of fertilisers.

The key people supported the premise in this research that changes to infrastructure availability have a strong effect upon the use of technology in the supply networks. For example: to manage the supply networks in Region I, the fertiliser industry is developing a plan to change technology for the delivery process. In the previous year the fertiliser industry used the highway infrastructure to deliver product.

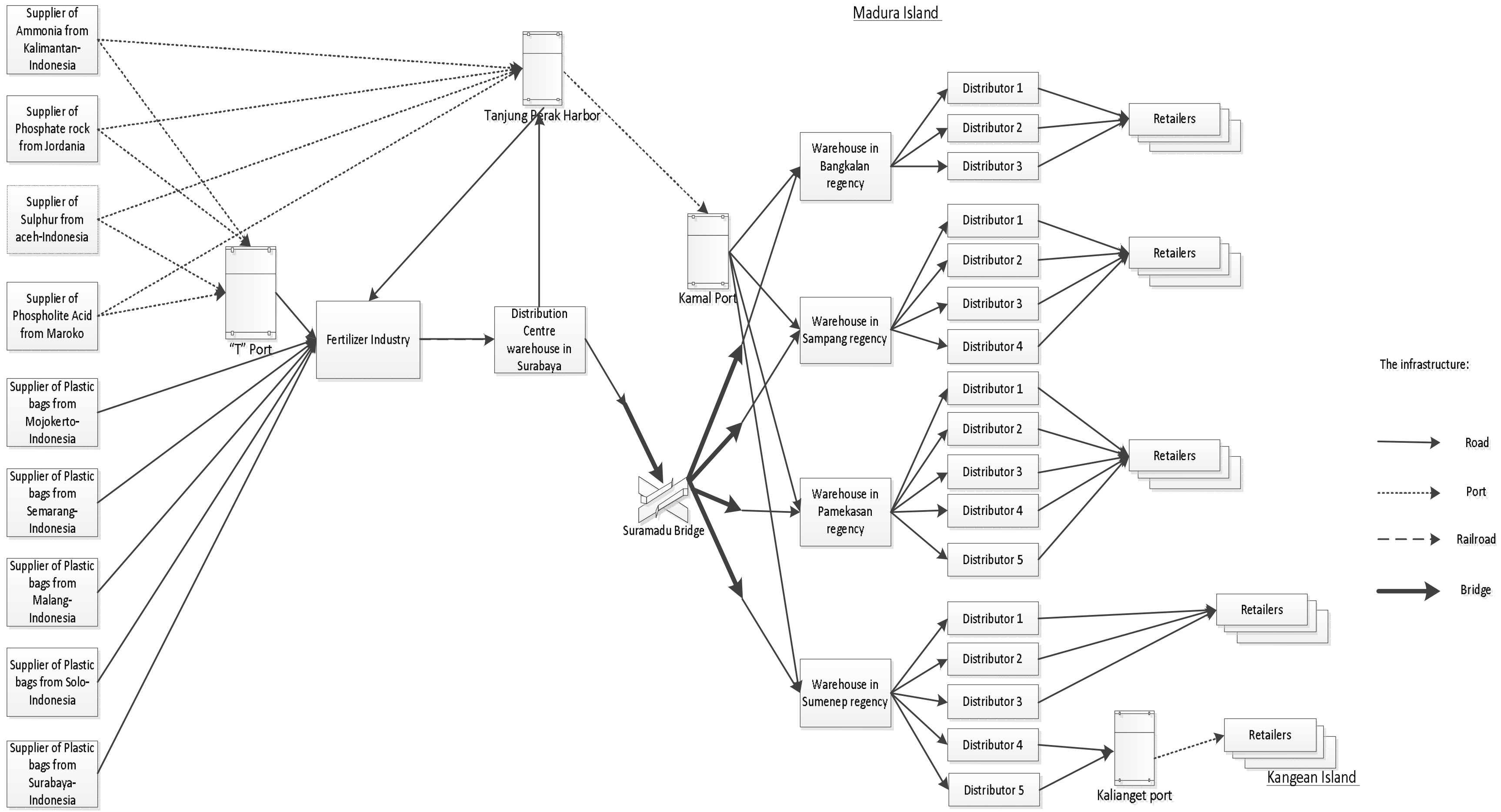


Figure 4.3 Supply infrastructure networks of fertiliser (One coverage area: Madura Island)

In 2013 the fertiliser industry was trying to collaborate with the Indonesian Rail Company to use the railroads as part of the infrastructure in its supply network. This plan was formed because of the heavy traffic on the highways of Java Island. The implementation of new technology is expected to reduce delays in the delivery of goods, maintain the quality of goods and reduce the risk of loss of goods during transportation. However, changes in technology will generate new concerns and potential risks (for example: re-scheduling delivery processes, establishing new standard operating procedures, recruiting new employees) for the fertiliser industry.

As a large archipelagic country, Indonesia has certain characteristics in its geography and infrastructure facilities. The management report of the T-Port provides characteristics of the port and availability every month. The fertiliser company has its own dock, as shown in Figure 4.4. The "T" shaped un-loading docks are 625 metres in length and 36 metres in width. The dock is equipped with a Continuous Ship Un-loader (CSU) which has a capacity of 8,000 tons/day, two Kangaroo Cranes which have a capacity of 7,000 tons/day, two units of ship loaders with a capacity of 1,500 tons/day, the conveyor belt is 22 km long and facilitates piping of liquid materials. The ocean side of the port can be used to dock three 40,000 tons of weight, and on the landside can be used to dock vessels with a deadweight of 10,000 tons each.

The results from the interviews highlighted that Infrastructure availability and changes increasingly affect the availability and timing of goods and services, energy and information. Failures in supply network operations can impact on product quality and traceability. Access to reliable and affordable transport, communications, energy, and information technology are crucial for decision making. The quality of fertiliser can be affected by a lack of, or poorly functioning infrastructure (e.g. roads, railways, bridges and ports). These risks are usually associated with very specific geographic locations. Therefore, supply network risk can affect the various participants in the supply chain in different ways.

For farmers and retailers, the greatest sources of risk are poor and perhaps seasonally impassable roads, intermittent trucking services and poor truck-loading practices (resulting in damage/loss of product in transit). The critical risk could be a weak communications infrastructure and associated gaps in time-relevant market information.

In the fertiliser industry, supply network disruptions in terms of infrastructure changes are: poor and inadequate road networks, under-developed seaports and airports. For example: the construction of Suramadu bridge which connects Java and Madura Islands influenced the line and schedule of supply networks operation to distributors, retailers and consumers in Madura Island. This bridge reduced lead-time and transportation time as well as reducing delays and congestion in Perak harbour. However, the delivery schedule should be changed and rearranged.

Another example is strategic risks identified relating to the field of marketing and distribution which could decrease agricultural fertiliser absorptive capacity, the busy activity of loading and unloading at the dock, congestion (long queues at the port), overstocking in the warehouse production and line III warehouse, the delay in the shipping out of bags. The fertiliser industry is planning infrastructure development to mitigate and overcome these risks. The plan is to expand a “T” shaped port, building an export transit warehouse, and jetty at a location near Palembang, South Sumatra and build warehouses near the railroad following up co-operation with the Indonesian railroad industry.

Figure 4.4 “T” shaped port

4.2 Risk assessment in the fertiliser supply network

The fertiliser industry has its own definition and has rules to assess risk. The fertiliser industry board defines risk as the likelihood of bad consequences (losses) of unexpected and uncertain events. The risk of failure will impact the company's mission and objectives and the emergence of consumer dissatisfaction. There are three terms of risk: the risk of occurrence, the possibility of containing risk or not, the risk that the event will lead to adverse impacts. The risk is believed to be inevitable. With regard to Good Corporate Governance (GCG) which requires transparency and improving the performance of understanding, the risk should be divided into priorities and programme strategies to achieve organizational goals. In this research, the supply network component was considered as organization. Table 4.2 presents the risks that occur in organizational units with regard to the activities of each unit (The Fertiliser Industry, 2012).

Risk may occur in management activities while using resources (assets) and operation and control of existing activities. One of the board commitments was the establishment of a Risk Management Bureau under the Business Plan and Management Division, under the Commercial Director. Critical and significant risks will result in a negative impact in the achievement of the objectives of each unit. Failure to achieve in the unit will impact directly on the unfulfilled organizational goals. In carrying out risk management, the fertiliser industry conducts five components of risk management: control environment, risk assessment, control activities, information and communication, and on-going monitoring as illustrated in Figure 4.5. Risk Management is defined as a series of methods and procedures used to mitigate risks, including a risk identifying process, risk measurement, risk management and risk supervision for every activity performed by working units. The level of risk is defined from risk probability multiplied by the level impact. Risk probability is scaled as: 1 = very small, 2 = small, 3 = medium, 4 = large, 5 = very large. Meanwhile, Risk impact is scaled as: 1 = insignificant impact, 2 = small impact, 3 = medium impact, 4 = great impact, and 5 = very great impact. Level of risk is accounted by multiplying probability of risk and the impact of risk, or risk = (probability x impact). Three risk categories were applied; high risk (15 - 25), medium risk (5 - 12), and low risk (< 4).

The key people argued that risk assessment is an increasingly important stage to achieve targets and to improve the fertiliser industry resilience and performance. Therefore, since 2005 the fertiliser industry established a Risk Assessment Department to conduct analysis on potential risks in the fertiliser industry and formulate mitigation to deal with the risk. The risk on every working unit activity has to be considered and every department has a key person who has responsibility to identify and analyse risk. Based on the risk assessment report from the fertiliser industry, Table 4.2 shows risk in twelve departments in the fertiliser industry in 2011. The amount of risk was ranked from the highest to the lowest.

Table 4.2 Risk in the fertiliser Industry (2011)

Department	High Risk	Middle Risk	Low Risk	Count	Percentage of total	Cumulative percentage
Production	46	172	20	238	46.85	46.85
Finance	40	5	25	40	7.87	54.72
Selling	1	35	3	39	7.68	62.40
Environment and health safety	9	24	2	35	6.89	69.29
Human resources	10	16	3	29	5.71	75.00
Business development	0	18	9	27	5.31	80.31
Distribution	3	15	4	22	4.33	84.65
Information technology	3	14	5	22	4.33	88.98
Law and reputation	3	11	4	18	3.54	92.52
General	2	12	1	15	2.95	95.47
Internal control	0	12	0	12	2.36	97.83
Procurement	2	6	3	11	2.17	100.00
Total	**119**	**340**	**79**	**508**	**100.00**	

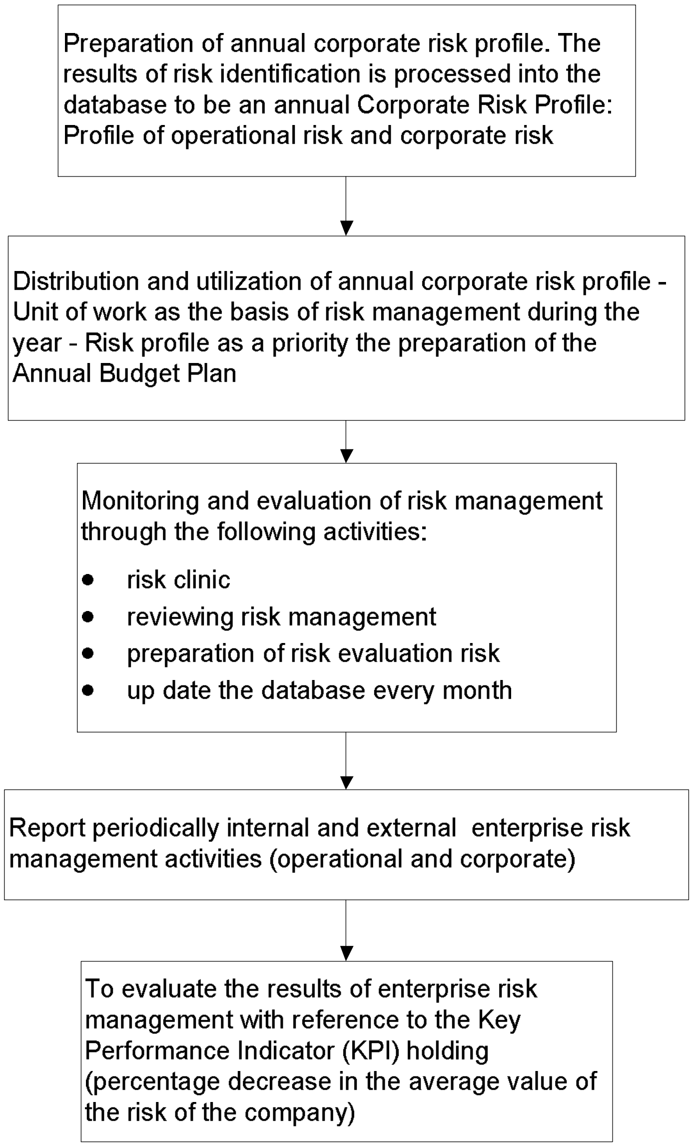


Figure 4.5 Business process of risk management

Source: adopted from the Risk management profile of the fertiliser industry 2012 (The Fertiliser Industry, 2012)

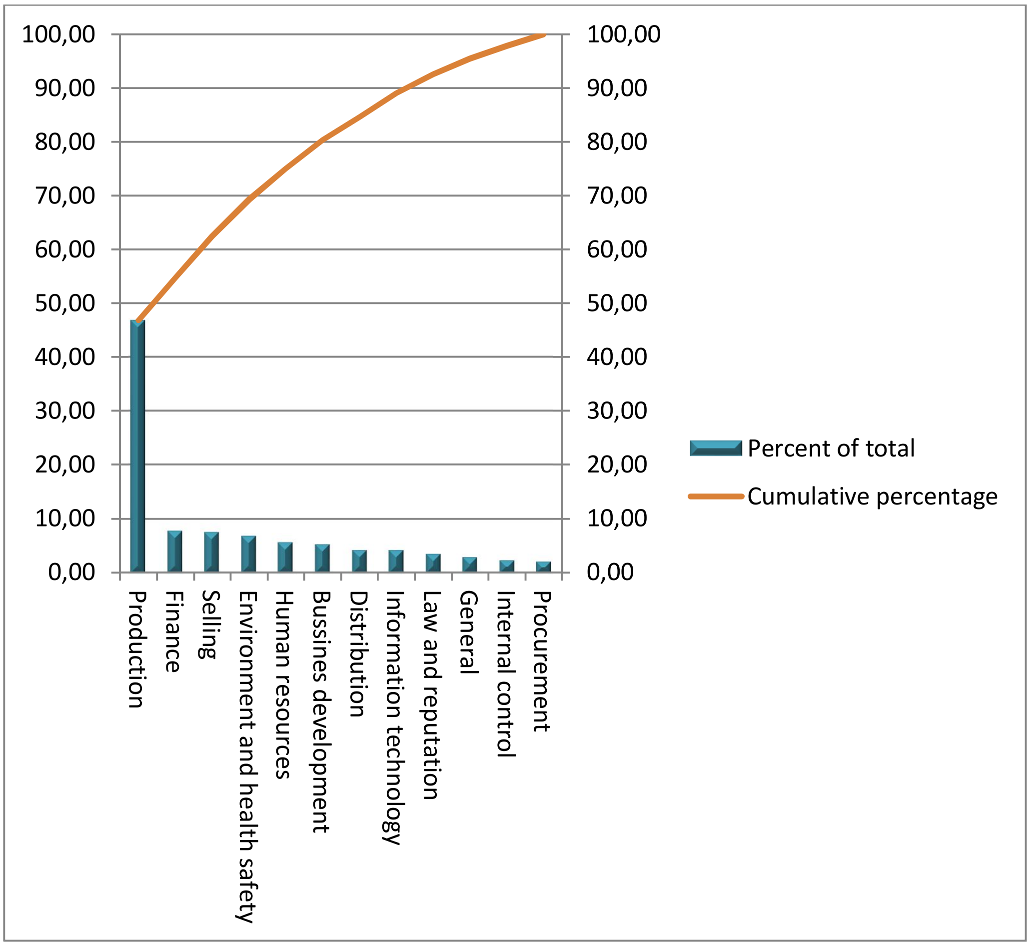


Figure 4.6 The Pareto diagram of risk in the fertiliser industry in 2011

The researcher built a Pareto diagram in Figure 4.6 to clearly represent the rank of risk in the fertiliser industry. The Pareto diagram illustrates the percentage of risk in the fertiliser industry in 2011. The bars represent the percentage value of each risk in descending order and the line represents the cumulative values of the risk. Different values can be seen for risk in each department from the Production Department through to the Procurement Department. The Production Department had the greatest risk, since the department consisted of 16 plants that made up the largest proportion of activities throughout most of this time period. The smallest risk was in the Procurement Department. While in other departments the number of risks decreased gradually from the Department of Finance to Procurement. This diagram aids decision makers concerned with setting the improvement strategy by considering the industry's resources and constraints. The researcher suggested that the fertiliser industry should separate identification of risk in the Production Department based on a variety of products and plant in order to ease risk assessment.

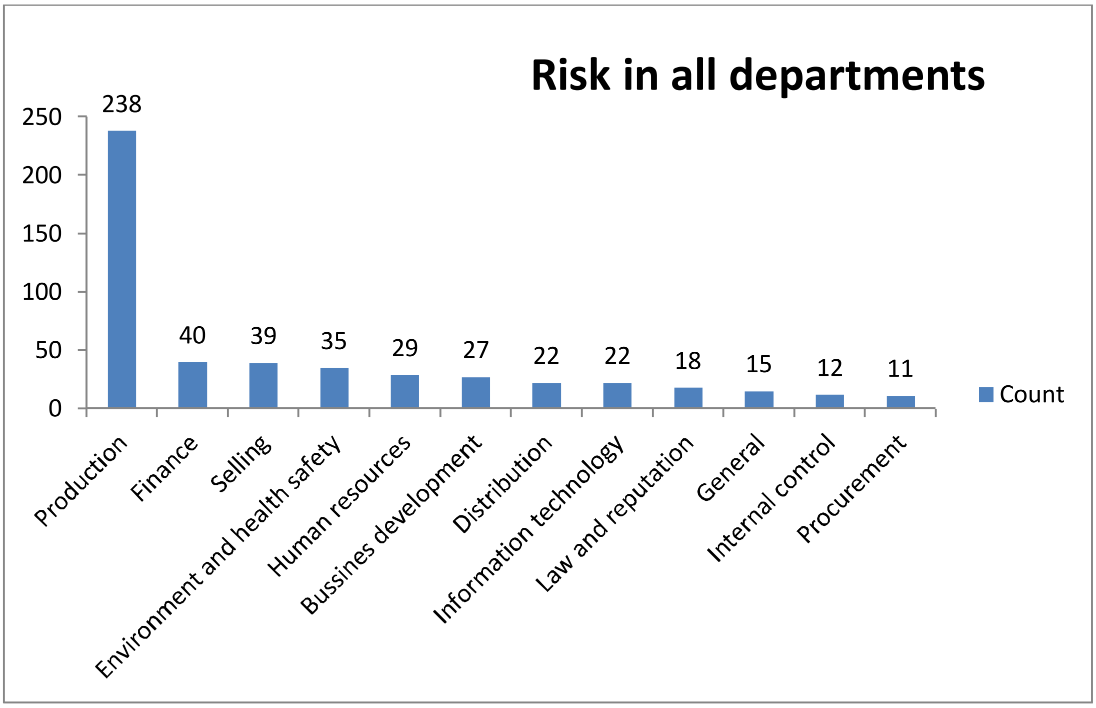


Figure 4.7 Risk in all departments

The bar charts were also drawn to compare levels of risk in all departments. The bar chart in Figure 4.7 illustrates the number of risks in the fertiliser industry. The percentage of total risk in the Pareto diagram was calculated from the total number of risks in each department.

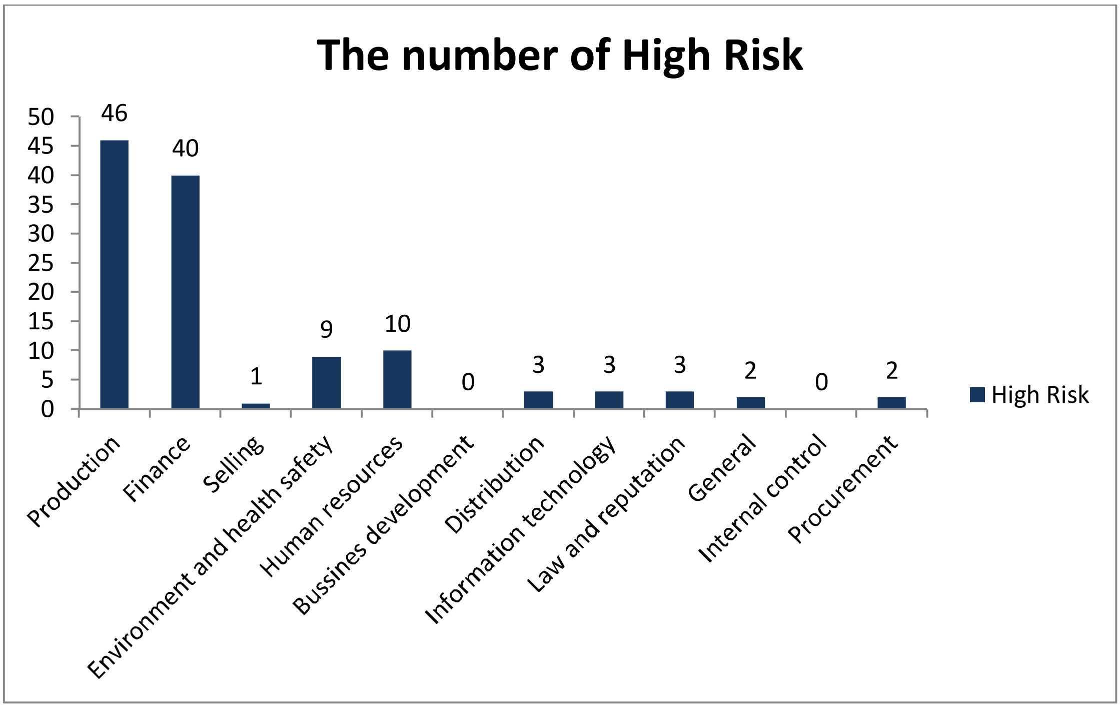


Figure 4.8 Percentage of high risk

The bar chart in Figure 4.8 illustrates the number of high risks from various departments of the fertiliser industry in 2011. It can be clearly seen that there was a large difference in the number of high risks in the departments. The highest risk was in the Department of Production and Finance. There was no high risk in the Department of Business Development and Internal Control.

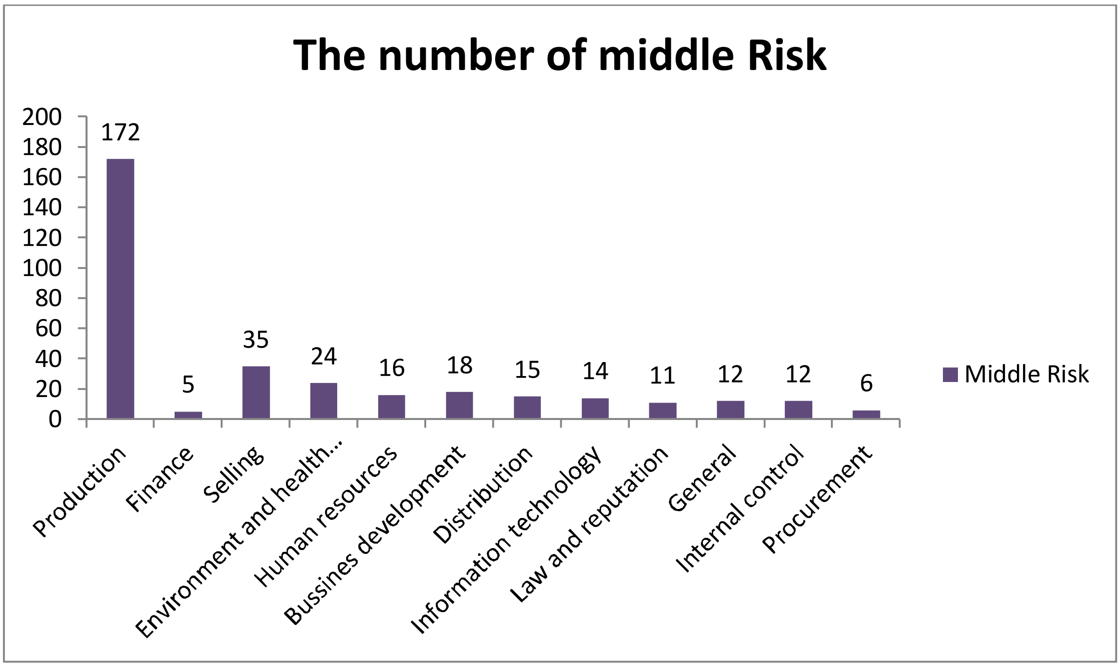


Figure 4.9 The number of middle risk

The bar chart in Figure 4.9 illustrates the middle risk in various departments in the fertiliser industry in 2011. The largest risk was in the Production Department. The second largest in the Selling Department that was the important part of the supply network system. The number of risks was similar in the other departments.

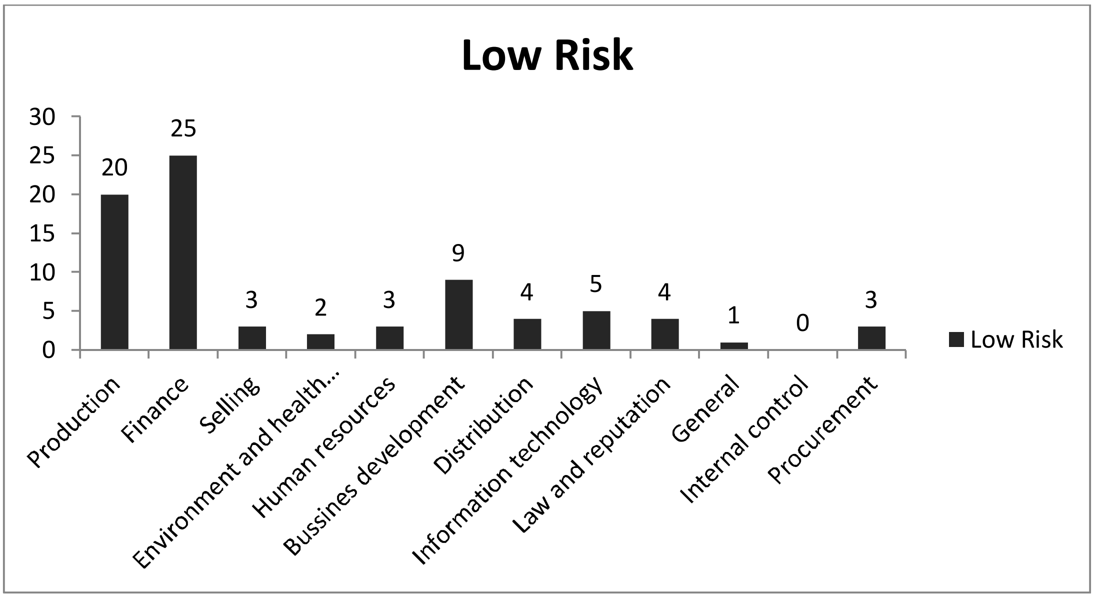


Figure 4.10. The number of low risk

The bar chart in Figure 4.10 illustrates the low risk in various departments in the fertiliser industry in 2011. The largest risk was in the Production Department. The second largest in the Finance Department.

Table 4.3 Risk in supply network systems in the fertiliser industry

Department	Count	Percentage of total	Cumulative percentage
Production	46	88	88.46
Distribution	3	6	94.23
Procurement	2	4	98.08
Selling	1	2	100.00
Total	**52**	**100**	

Table 4.3 describes risk in the supply network system in 2011. In this case study, the supply network system consisted of four departments: Production, Distribution, Procurement and Selling. The Pareto diagram in Figure 4.11 clearly illustrates the percentage of risk and cumulative percentage.

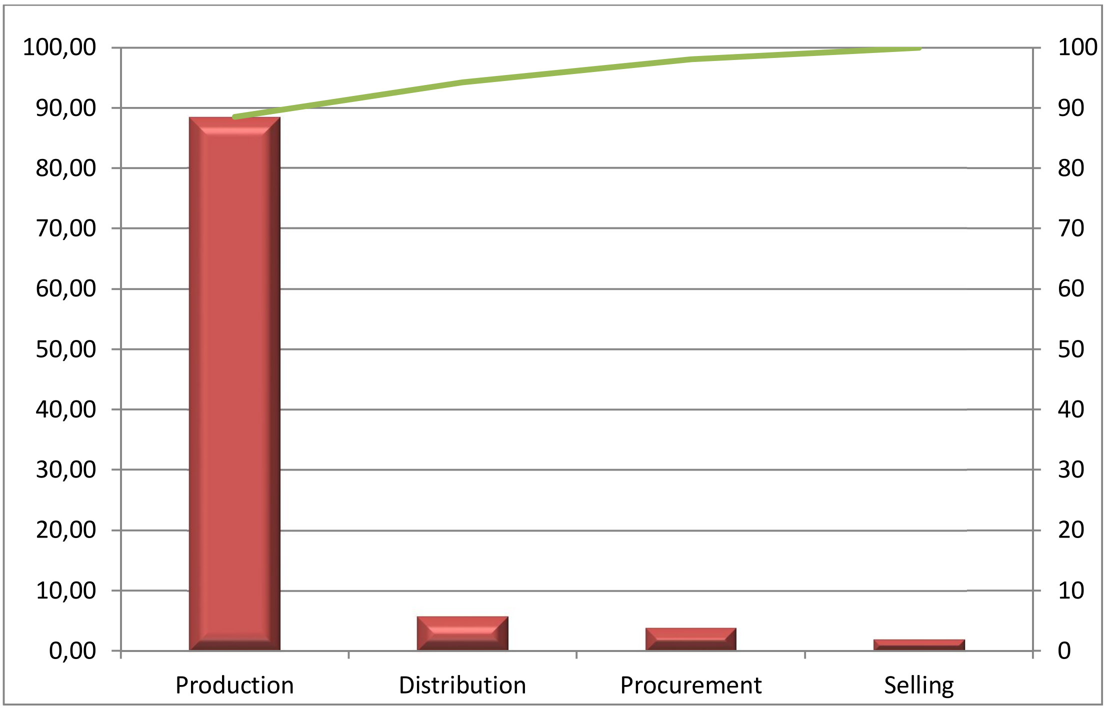


Figure 4.11 Pareto diagram of risk in the supply network system in the fertiliser industry

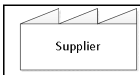
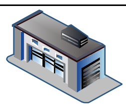
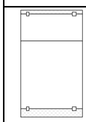
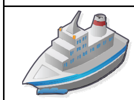
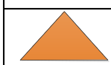
Supply network systems in the fertiliser industry consist of a number of components: suppliers, Procurement Department, Distribution Department Region I, Distribution Department Region II, Harbour Management Department, Distribution Centre, distributors, retailers and farmers as the end consumer. Data collection of the supply network component was needed in order to gain an overview and visualize the supply network process. Figure 4.12 and Figure 4.13 illustrate value stream mapping of the supply network process of the fertiliser. Value stream mapping analysis helps to identify problems and risks in supply network flow by selecting and grouping processes and activities in the supply networks. The value stream mapping of the fertiliser supply networks represents a value process, starting from the order and delivery process of raw materials from suppliers through to the order and delivery process of fertiliser to the end consumers. By implementing value stream mapping, researcher and decision makers can identify "waste" or risk and problems in the supply networks.

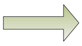
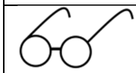
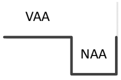
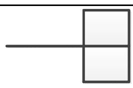
4.3 Supply network flow in the Indonesian fertiliser industry

This section presents materials and information flow in the Indonesian fertiliser supply network. Key suppliers and customers were described and analysed to gain significant insight to risk in the supply network. Materials and information flow in the Indonesian fertiliser supply network. Information on actual distribution activities was based on Operations Manuals and the Standard Operating Procedure. The cycle time or processing time measured was per week and data was collected from the Distribution Department. Value stream mapping was based on the baseline of data analysis on the current transportation time, queuing, handling and machine time, waste time, and in-process queue time. Value stream mapping helped both researcher and decision makers to assess risk in supply network flow and decide mitigation planning of the risk. Table 4.4 contains the symbols of value stream mapping. In this research, data has been available through interview and a secondary data source. The cycle time period of supply network flow was calculated over a one year period in 2011.

Value stream mapping symbols in this research are as follows:

Table 4.4 Value stream mapping symbol in the supply networks

 Supplier/Distributor/ Retailer	This symbol represents the suppliers/distributors/retailers
 Farmer	This symbol represents the farmers/end user
 Distribution centres	This symbol represents the distribution centre
 Dock	This symbol represents the dock
 Ship	This symbol represents the ship
 Cycle time	Information of cycle time in process of production or transportation. Time in seconds/hours/days/months. Batch in available capacity of machine or transportation mode.
 Inventory	Inventory of raw material or finished goods in warehouses

 Raw shipments	Material handling or movement of raw material or finished goods from origin to destination by using transportation modes. For example: movement of raw material from suppliers to the fertiliser industry, movement of fertiliser from distributors to retailers.
 Push arrows	Material handling between departments. For example: movement of raw material from milling machine n to machine n
 Safety stock	Safety stock or a specific number of stock to avoid out of stock in warehouses or distributors or retailers
 External shipment	Shipment using truck from origin to destination
 Electric info	Information flow by using electronic devices. For example: phone, internet, fax
 Go see	Inspection activity: inspection of raw material or finished goods
 Kaizen burst	Represents improvement needs or risk in particular infrastructures facilities and transportation mode
 Operator	Represents an operator in particular process. For example: drivers, checking operators
 Timeline	The time line represents duration in activities. VA: Value added activity times, NVA: non value added activity times.
 Total timeline	Total times: Lead times or total cycle time

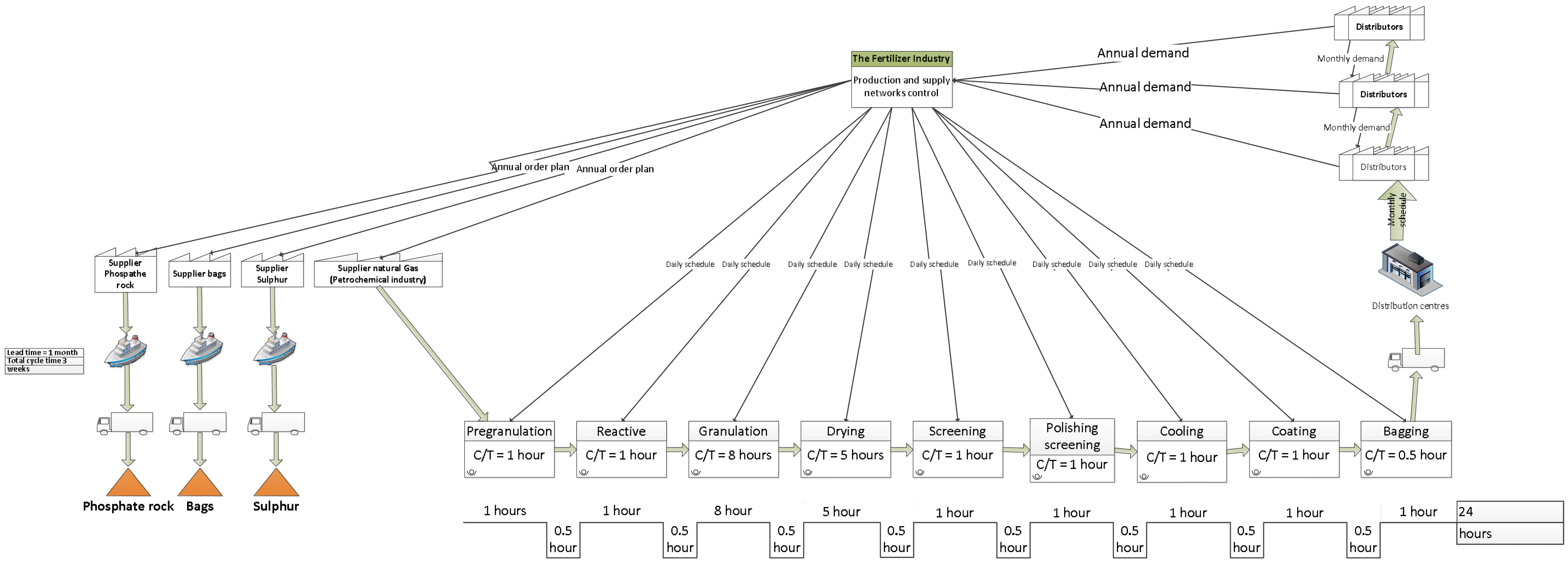


Figure 4.12: Value Stream Mapping production process of the fertiliser industry

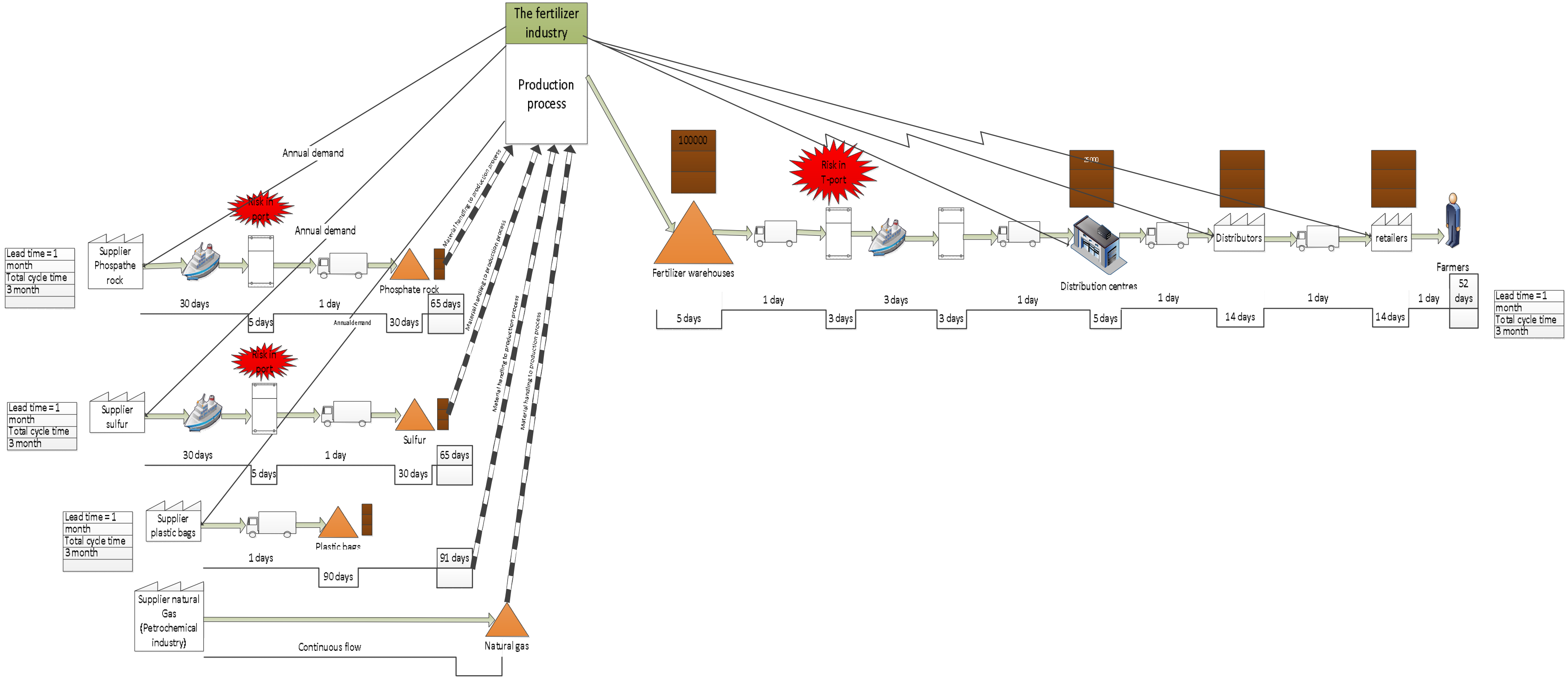


Figure 4.13 Value Stream Mapping the supply networks system

The adoption of value stream mapping was to identify risk and mitigation in the crucial stages of supply networks. Value stream mapping symbols are adapted to present activities and components in supply networks, as illustrated in Figure 4.12 and Figure 4.13.

a) Non-Value Adding Activity
Activity that is not considered as the transportation process in supply networks. Those activities could cause risk, so should be eliminated. For example: waiting time, excessive inventory in warehouses.
b) Necessary but Non-Value Adding Activity
Activities not including the transportation process in supply networks but necessary in the operation of process procedures. For example: material inspections, administration checking, loading and unloading of materials.
c) Value adding Activity
Activities that increase supply networks performance by transporting product using transportation mode and specific infrastructure facilities. For example: transportation of raw materials from suppliers to the fertiliser industry port, transportation of fertiliser from the fertiliser industry's warehouse to distribution centres.

4.3.1 Supply of raw materials

Key people from the Purchasing Department informed that key suppliers internal and external to the fertiliser industry supply raw materials. Natural gas is supplied from an internal part of a petrochemical company located near the fertiliser industry. Natural gas is distributed through the petrochemical industry pipeline. The other key suppliers are for sulphur, rock phosphate, ammonia and plastic bag suppliers.

The fertiliser industry implements an e-procurement system to recruit the best suppliers. Annual demand for raw materials is sent every year to suppliers. The fertiliser industry establishes an annual production plan based on the annual demand of distributors. Information technology is implemented in all parts of the department to keep a database. The administration process in the supply network is still supported by using paper notes or invoices. As illustrated in Figure 4.2 information flow starts from the farmers group sending an annual demand to retailers. Then retailers compile the annual demand and send it to distributors. Next, distributors compile annual demand from retailers and send it to the Department of Agriculture of the Ministry of Agriculture in each regency. The Department of Agriculture send the annual demand to the Ministry of Agriculture of Indonesia. The Ministry of Agriculture will establish the annual demand for subsidised fertiliser and distribution regulation and the fertiliser industry will be asked to produce and distribute fertiliser based on the regulations. The fertiliser industry plans annual production and sends annual demands for raw material to suppliers. The Department of Procurement of the fertiliser industry establishes a schedule of raw material delivery from suppliers to the industry. The schedule consists of the amount of raw material and lead-time in every stage of the delivery process.

Raw material flow from suppliers starts from unloading and loading activities from ships to trucks. Next, raw materials are transported to the fertiliser industry warehouses and prepared for the production process. The port is an important infrastructure facility that influences the supply network resilience of the fertiliser industry. So, the Port Department was established to manage port utilities. Risk in port is identified and mitigated as presented in Appendix B in Table B.2. Risk in port causes waiting time in ship docking and significantly influences material flow: stock out of raw material and over stock of fertiliser in warehouses. Moreover, inappropriate loading and unloading processes decrease product quality and cause equipment damage. The fertiliser industry implements information technology to manage information flow and process. However, manual checking of stock and the distribution process are still applied on the loading and unloading floor. This real condition provides supportive evidence that the supply network is a socio-technical framework that considers human and technological factors. As most product and information flow is carried out by personnel rather than by automated machinery or computer, decision makers are asked to consider a personnel skill improvement programme and monitor standard operating procedure application in transportation and distribution activities.

The Department of Risk Management of the fertiliser industry has been establishing risk based activity management to assess risk in departments every year. The department has key people who are responsible for determining and scoring risk and impact in every department and plan risk mitigation based on an industry strength, weak opportunity, and treat analysis. Yet, the researcher found that key people often have difficulties in reporting risk in their department. Even though risk management training has been conducted, there is still a lack of awareness in personnel regarding risk identification and analysis. Problem identification and the research question is as stated in Chapter 1 that the fertiliser industry produces and distributes subsidised fertiliser to Indonesian farmers. The crucial problem in supply networks is infrastructure facility changes and availability, so the researcher suggested that risk management should increase awareness in risk assessment in infrastructure changes and availability.

The researcher found that the Port Department focused on risk and utilization of a T-shaped port but did not consider other ports, especially ports located in region I and region II distribution areas. The researcher will recommend the risk management configure risk assessment sheets in terms of infrastructure changes and availability in supply networks. Personnel who have responsibility for distribution must fill in the sheets and transport fertiliser from warehouses in distribution management region I and region II to distribution centres, distributors and retailers. For example, the responsible personnel are drivers, checkers, distributors, and retailers. The researcher realizes that the fertiliser industry, as a state-owned company, has to obey the government regulation in its process operation. In doing so, the team management of the fertiliser industry needs a longer time to plan and gain government approval before new procedures can be established and implemented. The shortest period to re-design a new risk procedure is a year. Fertiliser, as a result of the production process, was kept in the finished product warehouses of the fertiliser industry. Average waiting time in this storage area is around four weeks. Fertiliser was then delivered to distribution centres in region I and region II.

The researcher identified waste in delivery in terms of supply network value stream mapping in this research are as follows:

1. Changes in transportation route

   Infrastructure changes often happen in region II of the fertiliser industry distribution coverage area. This infrastructure change influences the transportation route and total cycle time. The distribution department have to re-schedule their delivery plan and change the mode of transportation. Co-ordination between the fertiliser industry and consumers is crucial in managing delivery times and resource efficiency.

2. Waiting time

   Raw materials are waiting to be moved to another process or warehouse. Waiting time causes longer cycle time in material flow. Risk Management considers waiting time as risk in the supply networks.

3. Inappropriate loading/unloading process

   An inappropriate loading/unloading process is one of the critical risks in the fertiliser supply network. This risk can be caused by many factors:

unskilled loading/unloading operators, damaged equipment and inappropriate processing procedures.

4. Changes in scheduling

   The crucial risk or waste in the Port Department is scheduling changes for ships docking in the port as described in Appendix B in Table B.2. The researcher suggests that the risk could be managed and reduced by co-ordination and maintaining of material flow in the port area.

5. Unskilled operators/drivers

   Operators affect the quality of product and processing time. In the loading and unloading process, unskilled operators cause delays and longer processing times. Moreover, a checking operator who is unable to accurately report the result of inspection will cause problems in the next steps of stock reporting. Another example is changes in transportation route might mean changes in operator, because operators might have special skills and knowledge for particular transportation mode and areas.

6. Excessive inventory

   Excessive inventory is high probability risk in the Selling Department. The risk caused fertiliser damage and decreased product quality. This waste was affected by delays in the supply network flow and unachieved targets in product selling.

7. Congestion/excessive crowding

   Congestion at the port affects the supply network flow.

8. Unavailable transportation facilities

   Infrastructure changes lead to transportation mode changes in supply network flow. Changes in transportation mode needs sometimes cannot be fulfilled due to limitations of transportation facilities.

4.3.2 The key suppliers to the fertiliser industry

The basic function of the Procurement Department is responsibility for the procurement of raw materials, chemical substances or indirect materials, spare parts or manufacturing equipment, services and other operational requirements from domestic and from overseas. This is in accordance with specification, quality, quantity, economic cost and on time delivery based on the procurement procedure in the fertiliser industry to minimize life cycle cost.

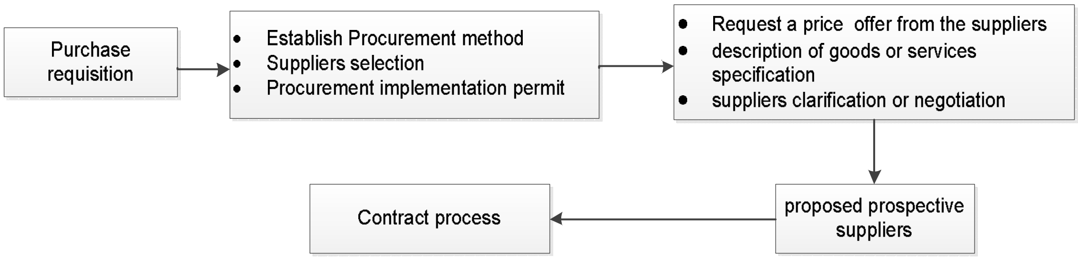


Figure 4.14 Business process of the procurement department

Table 4.5 describes key suppliers to the fertiliser industry, the raw materials that they supplied, their location, lead time delivery, capacity per delivery order, transportation process and infrastructure facilities to transport from the suppliers location to the fertiliser industry.

Table 4.5 Key suppliers of the fertiliser

Raw material	Location	Lead time	Capacity	Transportation process	Infrastructure facilities
Phosphate rock	Jordan	3 times/ month	40.000 – 45.000MT (Metric Tonnes)	Phosphate rock is transported by ship from Jordan to T shaped port, then by truck from port to fertiliser industry.	The infrastructure facilities they need are ports, railroad and road.
Sulphur	Aceh, Indonesia	2 times/ month	20.000MT	Sulphur is transported by ship from Jordan to T shaped port, then by truck from port to fertiliser industry.	The infrastructure facilities they need are ports, railroad and road.
Ammonia	Morocco	3 times/ month	20.000MT	Ammonia is transported by ship from Jordan to T shaped port, then by truck from port to fertiliser industry.	The infrastructure facilities they need are ports, railroad and road.
Plastic bags	Semarang, Indonesia	From 2 to 3 times/ month	20.000 MT	Plastic bags is transported by truck from suppliers in Surabaya to the fertiliser industry.	The infrastructure facilities they need is road.

The biggest risks to supply networks from suppliers to the fertiliser industry are port congestion, port expansion and road congestion. Historical data from 2011 to 2012 of risks, causes and mitigation are illustrated in Appendix B.

Based on the result of discussions with key people, the researcher suggested that the decision makers still deal with challenges in identifying and defining risk and impact. In the risk assessment report, as shown in Appendix B, decision makers reported that risk in excessive inventory was caused by lack of warehouse capacity. This report should be analysed by taking into account the real capacity of warehouses and the amount of inventory and supply network flow. The researcher suggested that the risk of excessive inventory could be caused by over production or inappropriate supply network systems management. Moreover, the researcher also suggested that decision makers in the fertiliser industry have different perspectives in terms of risk definition.

4.3.3 Key consumers

Regarding key consumers of the fertiliser, the key people explained that the fertiliser industry has a responsibility to distribute subsidized fertiliser from Line I (producer/fertiliser company), Line II (distribution centres) and Line III (distributors). Distribution from Line III to Line IV (Agents) is the responsibility of distributors. The company has two distribution areas managed by regional distribution managers I and II, as shown in Figure 4.15. The regional division is based on the geography and infrastructure conditions of each region. Region I is the islands of Java and Bali. Region II is Sumatra, Kalimantan, Sulawesi, Nusa Tenggara Barat, Nusa Tenggara Timur and Papua. The islands of Java and Bali are located close to the company and have better and more comprehensive infrastructure facilities compared to Region II. Region I consists of 117 distribution centres, 359 distributors and 13,376 retailers. Region II consists of 60 distribution centres, 254 distributors and 10,289 retailers. Distribution centres are warehouses located in the provinces of Indonesia. The distribution centres are utilized as a warehouse to maintain stock availability and as buffer stock before fertilisers are delivered to distributors. Distribution centre locations are selected based on the nearest location to distributors, retailers or farmers.

4.3.4 Risk in the Port Department

Further discussion between the researcher and key people found that disruption occurring in the port area was caused by a lack of transportation facilities, such as the structure of coastal borders and ships with a certain capacity due to considering risks during a journey. Other risks are delay in loading activities in the fertiliser industry port and other ports that are located close to the fertiliser industry, and shipping schedules with regard to destination port and duration time for loading and unloading. Delays in unloading activities at the destination dock can be caused by prolonged congestion, limited unloading equipment or other non-technical problems.

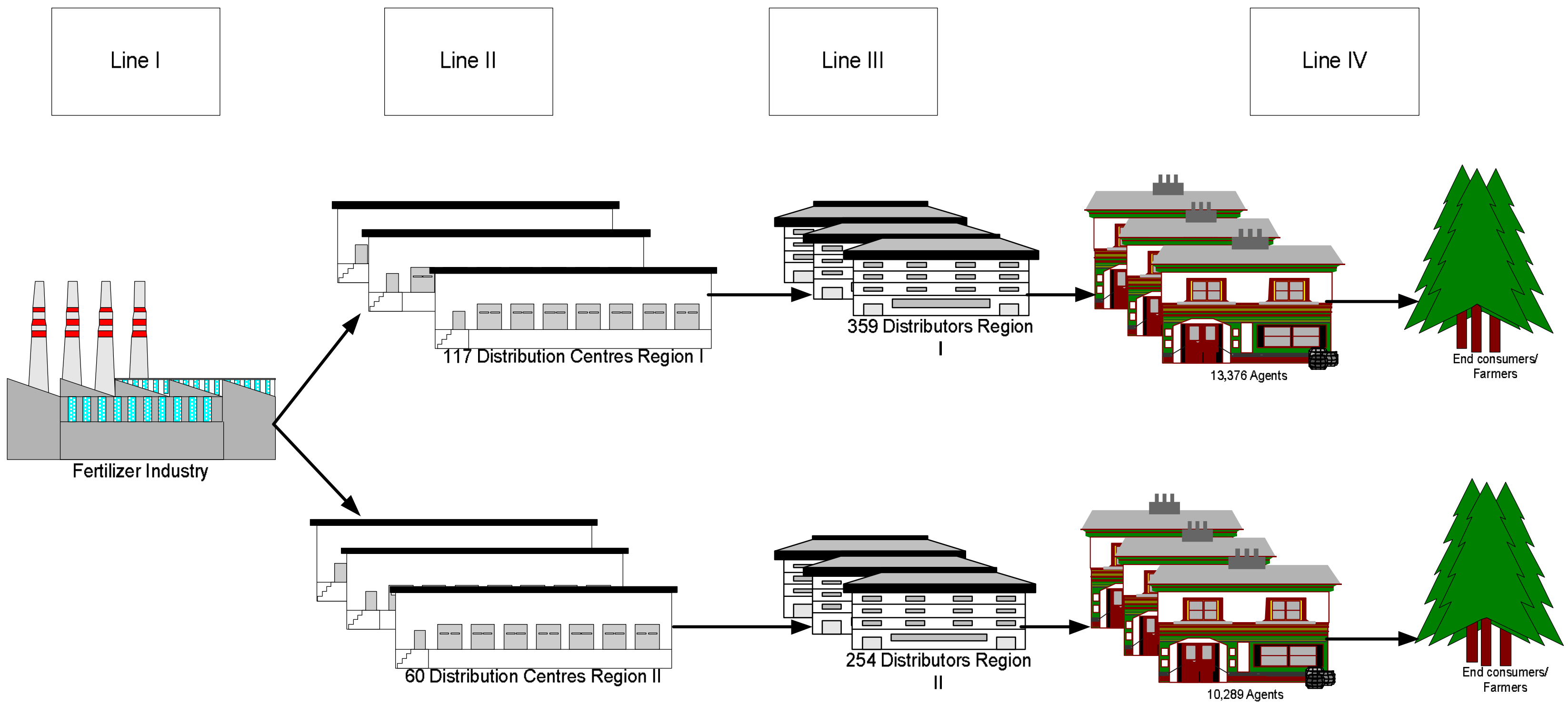


Figure 4.15 Consumers associated with the fertiliser industry

4.4 Summary

The fertiliser industry is an important industry for Indonesia as an agricultural country. It is controlled by the government and has responsibility for producing and distributing subsidized fertiliser across Indonesia. A finding of the research was that the port is the main infrastructure needed to ensure the stability of fertiliser distribution to farmers. The risk assessment report in the fertiliser industry reported that the highest risk was delays in the loading and unloading processes in the port. Delays in this process lead to several impacts on fertiliser industry performance such as, increases in the berth occupancy ratio at the port, increases in the number of customer complaints and delays in the production process.

A further finding was that decision maker involvement during the risk assessment process was extremely important. Presently, this involvement was limited because the risk assessment was carried out by operators who were not involved in the decision making processes. The risk assessment was considered only as an administration procedure to complete the annual report. Key people were unaware of the importance of the risk assessment report to support resilience assessment. This research has addressed this problem by exploring the feasibility of computational tools to support the assessment of supply network resilience in the Indonesian fertiliser industry. Chapter 5 discusses the process of generating a theoretical framework by integrating literature reviewed and data collected from the case study.

Chapter 5
A Framework for Assessing Supply Network Resilience

After conducting a review of the literature (Chapter 2) and collecting data from the Indonesian fertliser industry (Chapter 4), the next step was to formulate a theoretical framework that could be used to answer the research question. The position of this chapter in the research is illustrated by the grey box in Figure 5.1. This chapter introduces the theoretical framework and the processes that were used to develop it.

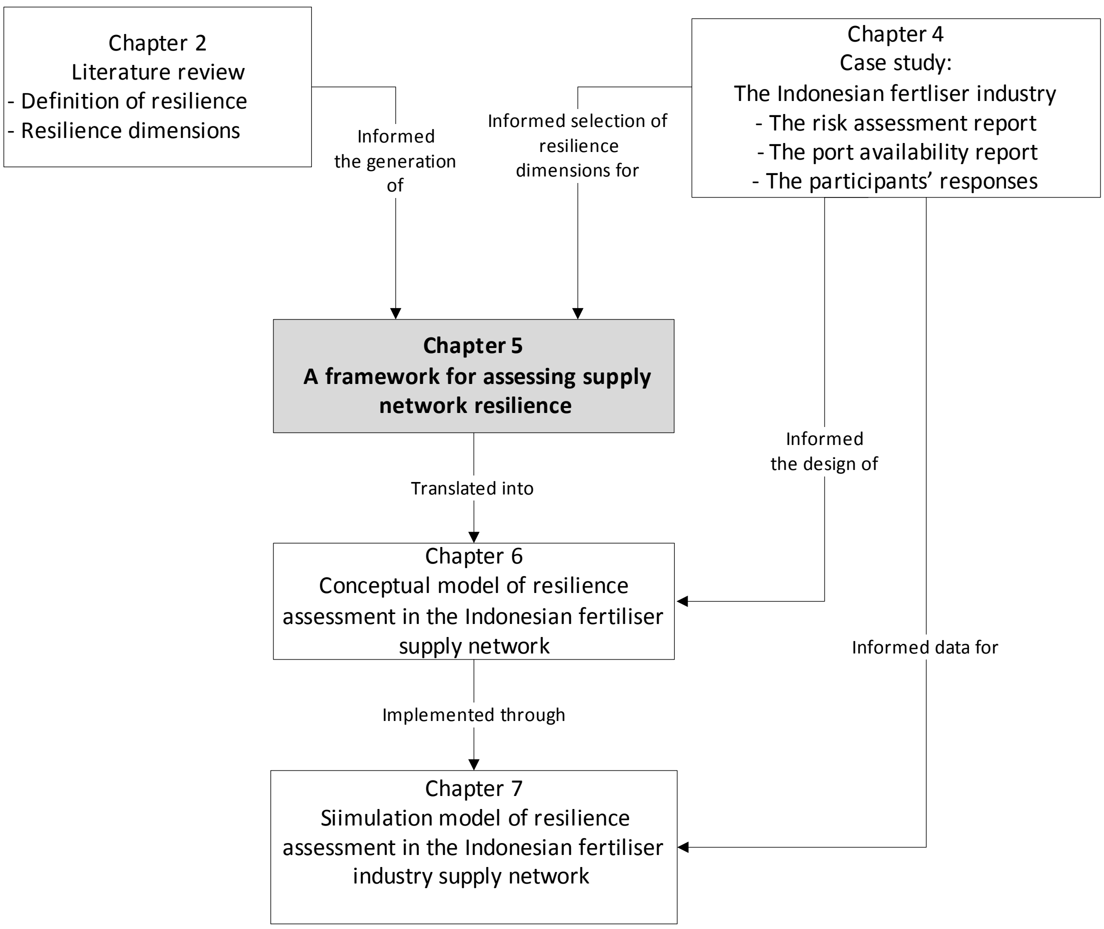


Figure 5.1 Chapter 5 the theoretical framework of the resilience assessment framework

Section 5.1 describes the processes used to generate the theoretical framework. These processes included: identification of the purpose of the theoretical framework, inputs to the resilience assessment produced, details of the processes themselves, and definition of the processes. Section 5.2 provides an application of an enterprise engineering framework to define details of the relationship between the industry and the supply network. The identification of decision makers' requirements is decribed in Section 5.3. By considering that social and technical components were involved in the resilience assessment process, this research incorporated a socio-technical systems approach to resilience assessment, as described in Section 5.4. The dimensions of resilience in the Indonesian fertiliser industry are presented in Section 5.5. A summary of the chapter is provided in Section 5.6.

5.1 Generating the resilience assessment framework

Supply networks are complex systems that must be managed properly to achieve competitiveness, such as: maintaining profitability, customer satisfaction, long term relationship with stakeholders, management of the quality of products and avoidance of labour turnover. Resilience is also important when considering the interconnectedness of modern organisations, where disruptions can have significant and widespread impact globally. Additionally, the increasing reliance on technology and technology providers influences the desire for organisations, and the communities that they serve, to become more resilient.

Principally, the fertiliser industry was already aware of the influence of risk level on the resilience of the supply network. Hence, currently the focus is on reviewing risk periodically to produce a risk assessment report. The report is being used as a recommendation for directors and the board of Commissioners in establishing new strategy and providing approval on risk management policy. However, they have not been able to discover the insight relationship of risk level with resilience. Moreover, they also have not been able to combine data from the Port Department with the risk assessment report as information for decision making. So this research aids managers in the Indonesian fertiliser industry to employ their data as valuable information to assess resilience in their supply network. From the business process learned from the case study, this research argues that risk assessment is one of the stages for assessing resilience because problems in supply networks could be identified from risk assessment results. Risk assessment consists of two stages: risk identification and risk analysis. Risk assessment is identification of the probability of occurrence and impacts of risks in supply networks. Key aspects of the risk analysis are how to use information, when available, to quantify probabilities of the identified threats as well as the potential consequences of the events (Maliszewski and Perrings, 2012). Vilko and Hallikas (2012a) state that resilience has strong links with risk assessment. When organizations, industry, or supply networks attempt to be resilient, they must have the ability to deal with risk occurring in their system. Vilko and Hallikas (2012b) also argue that risks occurring in the infrastructure tend to disturb the process in the supply networks. However, that literature has not provided in-depth justification on what the link is between risk and resilience and what the influence of infrastructure availability changes have on resilience. Thus, this research generates a framework that identifies the link between risk and resilience and influence of infrastructure availability into the resilience. This research puts forward the proposition that the risk assessment can be used as information for the resilience assessment. This study defines resilience as the ability to respond to risk by maintaining social and technical resources to reduce and control risk. Resilience assessment is a process used to investigate the level of resilience. Information generated from the resilience assessment is important to identify the level of resilience of supply networks. Further, resilience assessment results can be used as resource information to decide risk mitigation and control risk.

The risk assessment report generates information for designing resilient supply networks, planning to prevent disruption and forecast recovery time. Based on the information from risk assessment, decision makers could organise strategies to assess supply network resilience. The risk assessment report is important to establish a strategic plan and mitigation in order to perform supply chain resilience (Scholten et al., 2014). Finally, the strategies should be evaluated by level of risk, performance measurement, and constraints identification.

The new theory generated from synthesis of the literature and the results of the case study analysis should be depicted visually, so it could be easily learnt and understood by users. A suitable tool was needed to designate flow of the process in the theory. In this study, influence diagrams were used as a systematic structure needed to describe the processes in the theoretical framework. The influence diagram provides a simple graphical representation of a decision problem, such as decision, uncertainty, value, relevance link and information flow (Clemen, 1991). Hence, this research constructs an influence diagram to represent the theoretical framework. The theoretical framework in Figure 5.2 represents resilience assessment as a sequential process. Five steps of analysis were required to adequately assess the resilience of supply networks: risk assessment, information finding against risk assessment results, decision making on how to mitigate risk and design resilience supply networks, strategy planning and implementation of resilience methodology, and controlling of the strategy by comparing targets and achievement of performance, for example; the level of customer satisfaction (Utami et al., 2014a).

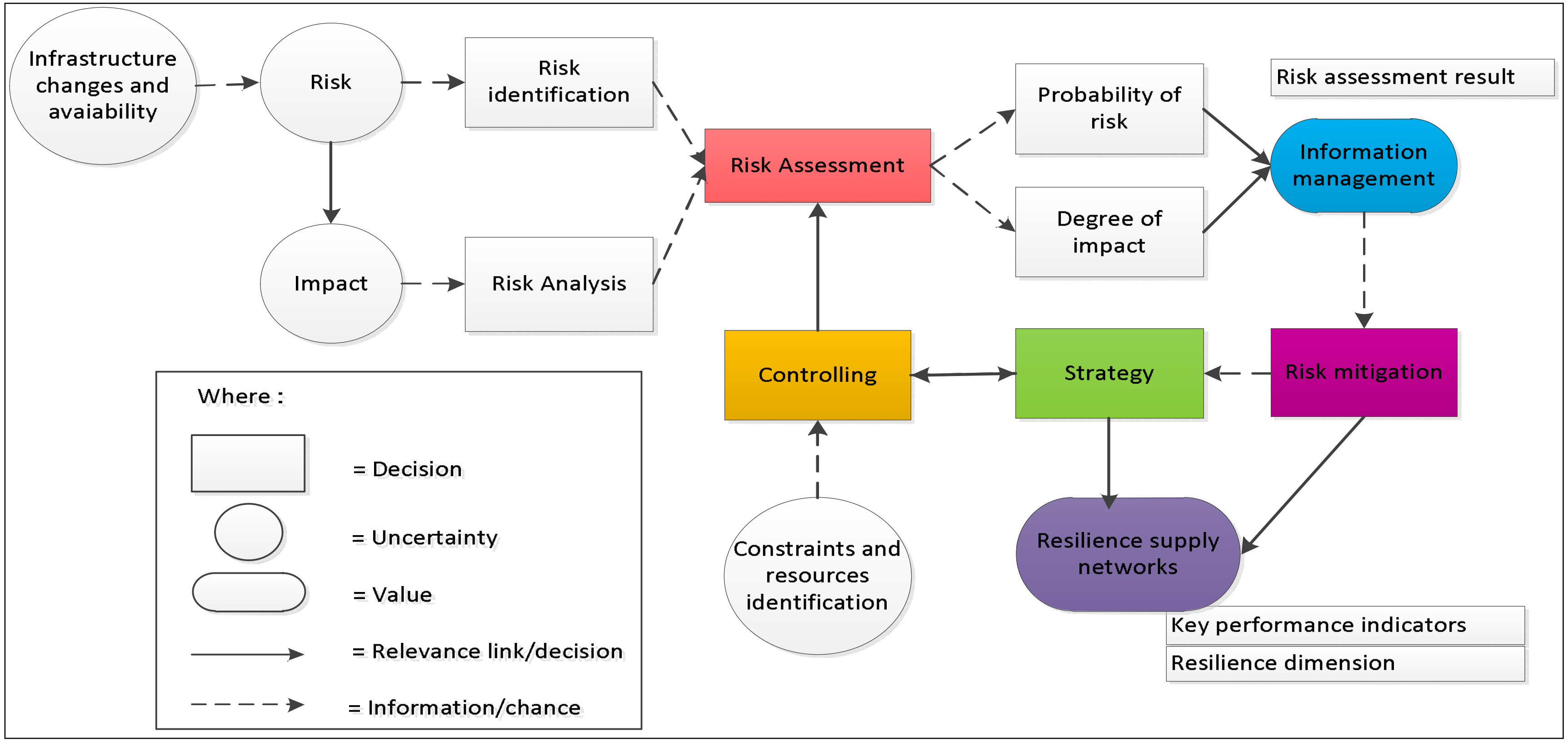


Figure 5.2 Theoretical framework of resilience assessment in supply network

5.2 Application of enterprise engineering framework to address configuration of resilience assessment approach

The enterprise engineering framework (Section 2.3.2) can be used as a guideline to support the analysis of the case study in conducting process assessment of the fertiliser supply network resilience. Analysis presented an in-depth understanding of the real supply network situation and activities in the industry. The enterprise engineering framework develops the principle that the architecture of networks of organizations can be designed with a view to delivering the strategic intents of all organisations within the enterprise rather than merely providing an optimal process for selection of stakeholders (McKay et al., 2009). Integration of a socio-technical system and an enterprise engineering framework in supply networks resilience assessment can be achieved by creating the desired environments within which evolution to a desired system state can take place, rather than trying to control the behaviour of individual elements (McKay et al., 2009).

Table 5.1 presents the function of the enterprise engineering framework in the case study analysis. The purpose row on the enterprise engineering framework was used to represent strategic intents as developed through the life of the enterprise. The Indonesian fertiliser supply network as the enterprise in this framework, sat in the agency row and serves as the intended organisation. It applied a developed framework or an approach to serve the purpose of defining supply networks resilience assessment with the focus on infrastructure changes and availability. The purpose was to achieve customer satisfaction by providing an adequate amount of subsidized fertiliser. By developing a conceptual framework and simulation modelling for assessing the supply network resilience the agency will conduct sequential steps to assess resilience. The subsidizing of fertiliser, which sits in the product and service row of the enterprise engineering framework, comprises a physical product and associated services that support the product life through the supply networks. During the enterprise realisation process, the key performance indicator of resilience assessment results can be translated to achievable customer satisfaction. Comprehensive application of the frameworks should be present in order to enhance decision makers' understanding. In doing so, the enterprise engineering framework will be combined with the resilience assessment framework. The framework will be applied in five stages of supply network resilience assessment.

Table 5.1 Enterprise engineering framework for assessing supply network resilience

	Define	Develop	Deploy
Purpose	How to assess supply network resilience in the Indonesian fertiliser supply network?		
Agency	Enterprise architecture: the resilience of Indonesian supply networks in infrastructure changes and availability	Conceptual framework and simulation modelling for assessing the resilience of supply network.	
Products & services	The availability of subsidized fertiliser industry for farmers (end users)		How should we assess the resilience of supply network?

Based on key people's answers and data collected, a method was needed to translate existing data into a resilience assessment approach. The researcher applied the enterprise engineering framework to address the resilience assessment approach based on information from key people in the fertiliser industry. The researcher generated five stages to translate decision makers' requirements into key performance indicators and resilience dimensions. Table 5.2 presents stage one of the applications. The Purpose row defines how to assess risk in the fertiliser supply network. The risk assessment management sits in the Agency row as the department that carries out risk assessment and plans mitigation. Since every department has key people (decision makers) whose responsibility is to identify and analyse risk based on activities in the department, there is ambiguity in risk definition and determination. These gaps are caused by two significant factors. First, it is not clear how, or how well, individuals articulate and communicate what they know about the world (risk). Second, because of differences in role, expertise, or background, individuals may focus on different aspects of the information stream as they focus on the task in hand (Caldwell, 2008). The researcher suggests that the fertiliser industry needs to establish a risk assessment procedure that accommodates real conditions of risk in the departments.

Stage 1

Table 5.2 Stage 1 application of the enterprise engineering framework to address the resilience assessment approach based on the case study

	Define	Develop	Deploy
Purpose	How to assess risk in the Indonesian fertiliser supply networks?		
Agency	The Risk Management Department coordinate with the Department of Sales Region I and Region II, the Procurement Department, the Port Department and the Subsidized Fertiliser Production Department.	Risk assessment: risk identification and risk analysis with focus on supply networks and consider socio-technical system.	
Products & services	Risk identification and risk analysis of raw material procurement and distribution of subsidized fertiliser to consumers.		How should the fertiliser industry assess the risk in the supply networks?

In Stage 2, information collected from risk assessment is important output that can be used to establish mitigation and strategy planning. Information fundamentally affects the socio-technical system by using it to achieve desired goals (Caldwell, 2008). For example, Personnel use information to identify the task and to communicate the task into actions or activity by using devices. Caldwell (2008) also identified three functions of information: to identify and determine aspects of the world that require team or organisational response; to co-ordinate task requirements and performance among team members; to support shared knowledge and developments of team-level (not simply individual level) experience as ranges of operational expertise.

In Stage 3, the fertiliser industry established mitigation planning based on the output of Stage 2. Team management in the fertiliser industry sits as an agency that manages components in the industry to use resources and minimize constraints in order to improve performance by implementing mitigation. A summary of these two stages is illustrated in Table 5.3.

Table 5.3 Stage 2 and Stage 3 of the application of the enterprise engineering framework

	Define	Develop	Deploy
Purpose	How to do data processing of risk assessment as the important information for decision making? ↓ How to plan risk mitigation and supply networks resilience by using information from stage 2?		
Agency	The risk assessment department ↓↑ The team management of the Indonesian fertiliser industry	The risk assessment information data processing ↓ Mitigation plan to achieve resilience supply networks	
Products & services	Information availability for decision making process ↓ Risk mitigation		How should risk assessment be used for decision making process? ↓ How should the fertiliser industry establish risk mitigation and supply networks resilience by using information from stage 2?

Stage 4 is shown in Table 5.4. Elements in supply network systems must be involved in the supply network resilience assessment, since interaction and mutually exclusive relationships are significantly important to maintain a good relationship in supply networks. Design and re-design of the supply network system in the fertiliser industry is a crucial activity in the system control and improvement stage of the resilience assessment. The supply networks system must adapt in an uncertain risk situation. The researcher found in the real supply network system, uncertain events occur in almost every part of the supply network flow. For example: infrastructure changes affect demand for fertiliser from end customers, because retailers could not transport the fertiliser to isolated areas.

Stage 4

Table 5.4 Stage 4 of the application of the enterprise engineering framework

	Define	Develop	Deploy
Purpose	How to set up strategy to deal with infrastructure changes in supply networks?		
Agency	The team management of the Indonesian fertiliser industry.	Strategy to deal with infrastructure changes and availability to achieve supply network resilience and increase the supply network performance.	
Products & services	Strategy to deal with infrastructure changes and availability.		How should the fertiliser industry set up strategy to deal with infrastructure changes in supply networks?

In Stage 5, described in Table 5.7, controlling implementation of strategy through comparing planning and real implementation to ensure that goals are being achieved. By identifying the gaps, the management team could establish new strategy to increase performance. This stage will be demonstrated by using a design experiment based on four mitigation plans in simulation modelling. As the example of application strategy planning, this research demonstrates simulation of material flow (Section 7.6) in the port area in order to observe the effect of resources allocation on supply network resilience.

Stage 5

Table 5.5 Stage 5 adapted enterprise engineering framework

	Define	Develop	Deploy
Purpose	How to control the strategy in supply networks?		
Agency	The team management of the Indonesian fertiliser supply network.	Controlling strategy to deal with infrastructure changes and availability to achieve supply networks resilience and increase the supply networks performance.	
Products & services	Controlling the strategy to deal with infrastructure changes and availability.		How should the fertiliser industry control the strategy to deal with infrastructure changes in supply networks?

5.3 Identification of decision maker requirements

Decision maker involvement during the configuring process of the resilience assessment approach is definitely important. This research generated the expression of a purpose dimensions matrix to identify decision maker requirements. Table 5.7 illustrates the matrix that consists of decision maker requirements, performance indicators of resilience assessment, and the relationship between decision makers' needs and key performance indicators. There are three scores of relationship: strong relationship (9), medium relationship (3) and weak relationship (1).

Blanchard (2004) stated that the objective of House of Quality in system engineering is to meet the requirements of the consumer in an effective and efficient manner. House of Quality emphasises the interaction of the decision maker requirements with the theoretical framework. This research applied three steps of the system engineering life cycle process: identifying decision maker requirements based on interview reports and secondary data, defining the key performance indicator as a technical requirement of the theoretical framework and translating the initial resilience assessment approach requirements.

Decision maker requirements are mapped against key performance indicators in the framework process to arrive at how the frameworks can meet these requirements. The goal of this step is to track decision maker requirements throughout the life cycle of system development. Based on the matrix, the value of important weight of each key performance indicator is represented in Table 5.6, Figure 5.3, and Figure 5.4. They show that the highest weight is integrity, followed by customer satisfaction. This data indicates that the fertiliser industry needs to improve the integrity of supply network systems in order to be resilient. This data analysis result is in line with the SWOT (strength, weakness, opportunity, and threat) analysis of the fertiliser industry. The strength analysis indicated that the fertiliser industry has a robust supply network physical infrastructure that consists of distribution centres, warehouses, transport facilities, and a port located in the Indonesian area.

The matrix indicates that the highest weight of key performance indicator is integrity and followed by customer satisfaction. It could indicate the decision maker's suggestion in supply network resilience assessment. They suggest that in order to achieve and maintain supply network resilience, the fertiliser industry should concern itself with supply network integrity among supply networks components (suppliers, the fertiliser industry, distribution centres, distributors, retailers and farmers). Integrity as the highest weight of performance indicator, as shown in Table 5.6, also suggests that the supply networks are affected by socio-technical factors. Customer satisfaction, as the fertiliser industry's primary goal, could be achieved by considering and managing not only physical facilities but also co-ordination of high quality human resources.

Table 5.6 Important weight of performance indicator

Key performance indicator	Important weight	Percentage weight	Cumulative percentage
Integrity	266	23.71	23.71
Customer satisfaction	225	20.05	43.76
Availability of transportation facilities	104	9.27	53.03
Capacity of transportation facilities	99	8.82	61.85
The number of warehouse	96	8.56	70.41
Warehouse capacity	89	7.93	78.34
Delivery time	83	7.4	85.74
Employee performance	66	5.88	91.62
Stock availability	55	4.9	96.52
Innovation	39	3.48	100

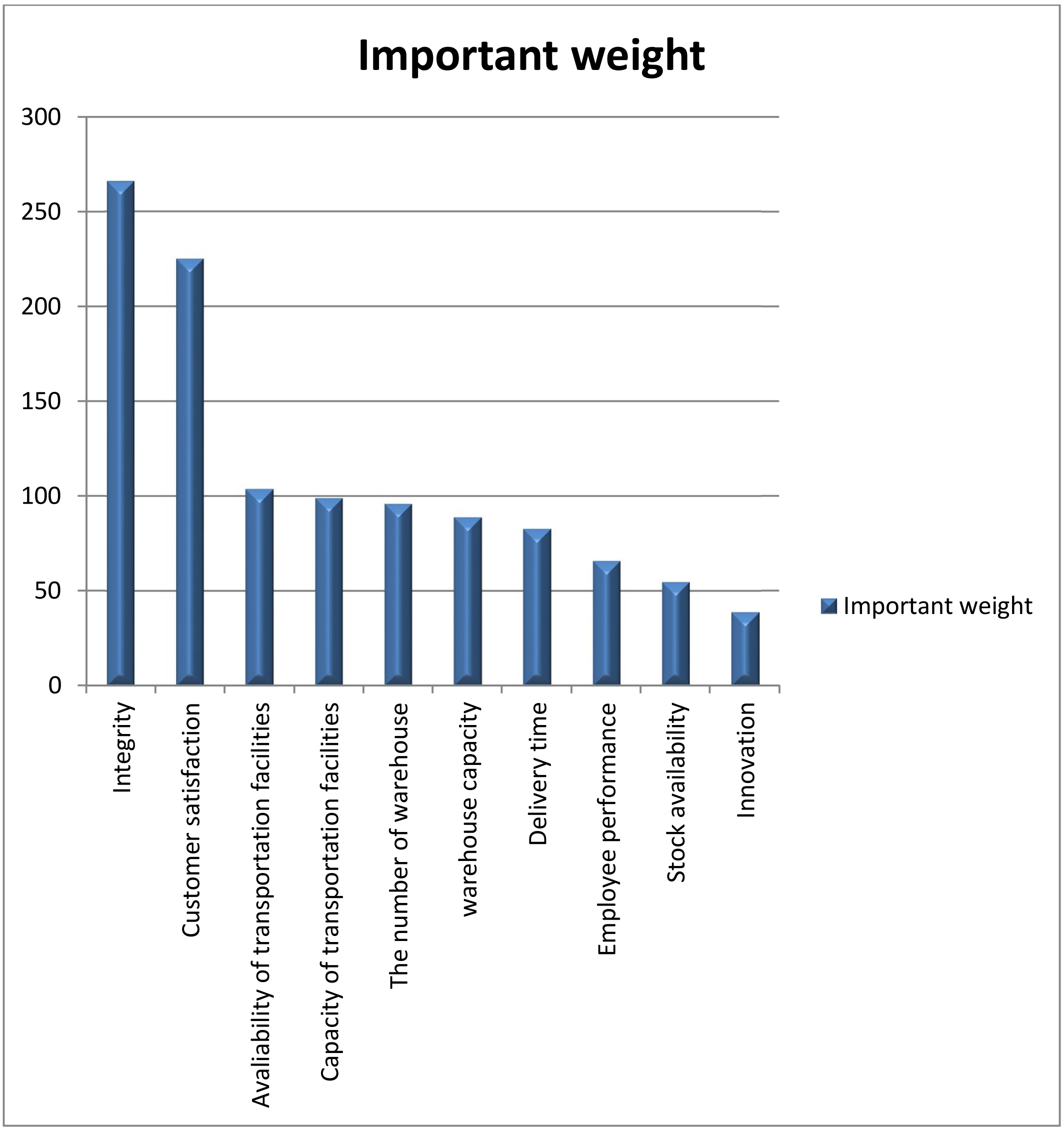


Figure 5.3 Important weight of the key performance indicator

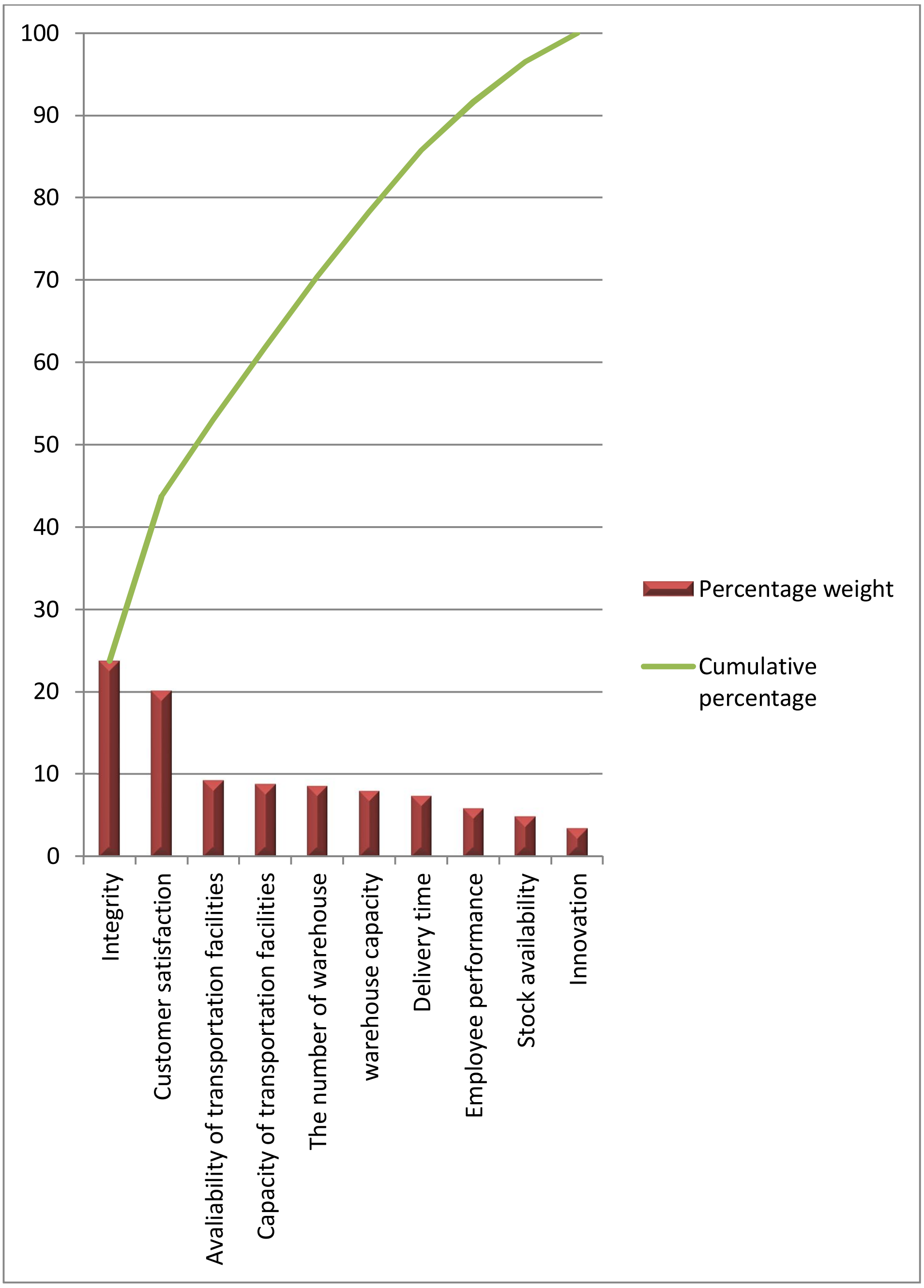


Figure 5.4 Pareto diagram of percentage weight

Table 5.7 The expression of purpose dimensions matrix to identify key performance indicators and resilience dimensions

● = Strong relationship

○ = Medium relationship

△ = Weak relationship

		Resilience Dimension									
		Interoperability			Safety	Reliability		Safety	Availability		
		Key Performance Indicator									
Decision makers requirement	**The importance**	Customer satisfaction	Innovation	Integrity	Employee performance	Delivery time	Stock availability	Availability of transportation facilities	Capacity of transportation facilities	Warehouse capacity	The number of warehouses
To improve management control and compliance that gain performance.	4		○	●	△						
To adjust the industry Good Corporate Governance procedure.	4			●	○						
To explore the employee professionalism for improving customer's satisfaction.	3	○			●						
As a working method to manage Risk Management implementation in all the industry departments.	5			●		○					△
To maintain relationship with customers.	5	●				△	○				
To perform transparency to all shareholders and society in the form of information disclosure.	3	●					○	△			
As self-assessment team planning.	3			●				△			○
To support company business development.	3		●							△	○
To review risk periodically, management policy and provide recommendation to the Board of Commissioners as the consideration in providing approval on the Risk Management policy.	5							●	○	△	
To evaluate and provide risk and resilience analysis to the Board of Directors with regard to the industry's asset utilization and other company's activities, in order to provide recommendation or approval from the Board of Commissioners.	5								△	●	○
To gain recommendation in reviewing the industry Business Plan.	5	●							○	△	
To provide recommendation to the Board of Commissioners in order to improve and develop the company's Risk Management policy.	5		●			○		△			
To review the industry ethic implementation.	1			●							
To support the relationship with suppliers by gaining honest and fair treatment to the suppliers, establishing proper and long-term relationship with suppliers with regard to quality, competitive advantages and trust.	5					○		△	●		
To implement fair competition to competitors by respecting rights on intellectual resources.	1	●				○	△				

The material to prepare the annual audit plan.	5			◉							
To facilitate the work unit in identifying critical and potential risks that will disrupt target.	5	◉					○			△	
To ensure that risks are the real risk of unit activities because of the core of risk inherent in the critical work unit.	5				△	◉			○		
The effective internal controls/assessment is expected to support operational activities properly and in accordance with the plans and the level of optimal efficiency and effectiveness.	5			△			○	◉			
The results of risk assessment and resilience as a material consideration in decision.	4								△	○	◉
Assessment activities and the results can be used as report or administration requirements in the process of reporting to the directors or government.	4			◉							
As a corporate risk management evaluation.	5	◉									
To keep the integrity in the industry.	3			◉							
To accelerate the administrative procedure in supply networks.	3							△		○	◉
To build team spirit cohesively.	2				◉						
Important weight		225	39	266	66	83	55	104	99	89	96
Percentage weight		20.05	3.48	23.71	5.88	7.40	4.90	9.27	8.82	7.93	8.56

5.4 The incorporation of the socio-technical system perspectives to the resilience assessment

The supply network is a system consisting of social and technical elements. Examples of social elements are human and culture, where technical elements are: equipment, vehicles, and standard operating procedure. Balancing consideration of social and technical factors in the supply network flow is important. Thus, a socio-technical approach was integrated to determine the dimension of resilience assessment in order to identify the key performance indicators. The six perspectives of the socio-technical approach: goal, people, culture, procedure, infrastructure and technology, were combined, so decision makers will be able to analyse and control problems and conduct improvements based on the six perspectives. The theoretical framework developed in this thesis was different from the framework in Worton, Figure 2.4. The socio-technical approach was used in this thesis to help in identifying key performance indicators in the supply network resilience based on the supply network element in the case study.

The key performance indicators identified from the theory must be translated into operational language in order to facilitate the process of identification of key performance indicators in real systems, as described in Figure 5.5. In addition, to support the resilience assessment process, the qualitative definition of key performance indicators must be transformed into a quantitative definition. This transformation was important in order to obtain the resilience level. For this reason, this research provided examples of how to translate the key performance indicators in a real operational language system. This example was generated from the literature review and the results of preliminary observations from the case study.

1. Goal/Vision/Value

Key performance indicator Goal/vision/value identifies, “what is the goal to be achieved?” in the system.

The key performance indicator goal of supply network systems was to maintain or achieve a targeted level of customer satisfaction. The level of customer satisfaction was measured from the customer feedback and complaints with regard to the supply networks service in a specific period during infrastructure facility changes. The unit of customer satisfaction was expressed as a percentage.

2. Process/Procedure

Key performance indicator procedure/process identifies, “How to achieve the goal?” and “What is the operational method to achieve the goal?”.

The key performance indicator process/procedure in the supply network system was the schedule of delivery times. Delivery time was defined as the time interval from departure to arrival of the product. The unit of delivery time was hours. In addition, process also was defined as stock availability, which was the availability of products in warehouses, distributors, or retailers. It was calculated based on the comparison between targets with the real conditions of available stock. The unit of stock availability was tons.

3. Culture

Key performance indicator Culture observes, “What is the social behaviour in the system?”.

The key performance indicator culture was defined as Innovation. This research defined innovation as a ratio between the numbers of new ideas with regard to supply network problem solving in a specific period. Culture was measured from the level of integrity in the system, as stated by Davis et al. (2014). Integrity was measured by a ratio, the number of applications of standard operating procedure concerning the supply networks procedure. For example: issuing of a delivery order letter.

4. Technology

Key performance indicator Technology identifies, “What are the tools/equipment to conduct the procedure?” and “How many tools/equipment are needed?”.

Key performance indicator Technology was defined from the availability of transportation facilities. It was the ratio of transportation availability and transportation needed in a specific period concerning infrastructure changes. Key performance indicator technology was also defined as the capacity of the transportation facility as a ratio of utilisation of transportation capacity per its capacity.

5. Building

Key performance indicator building identifies, “What buildings are needed?” and “How many buildings are needed?”.

Key performance indicator building/infrastructure was defined as warehouse capacity, which was a ratio of utilisation of warehouse capacity per its capacity. This key performance indicator was measured by the number of warehouses, which is a ratio of the number of warehouses to the warehouses needed.

6. People

Key performance indicator of people identifies, “Who carries out the procedure? and “How many people carry out the procedure?”.

Key performance indicator people was defined as the employees’ performance, which is operators working hours to complete the tasks.

5.5 Dimensions of resilience in the Indonesian fertiliser industry

Key performance indicators were defined in order to determine the level of resilience. The design of key performance indicators should be aligned with the practicalities in the real world and the possibility of repeating measurements (Woxenius, 2012). Key performance indicators interpreted the critical aspects of theoretical and practical processes of resilience assessment in supply networks into numerical data. In this research, key performance indicators were defined by combining elements of supply network performance, resilience assessment and infrastructure availability. Figure 5.5 illustrates the alignment between key performance indicators with resilience dimensions. Determining the level of resilience uses five scales based on the Indonesian fertiliser risk assessment level (Section 4.2). The scales started from one to five. 1 = very low, 2 = low, 3 = medium, 4 = high, 5 = very high.

The resilience assessment approach in this thesis was constructed based on decision makers' requirements identified (Section 5.3) and dimension of resilience constituted from review literature (Table 2.3 and 2.4). This research integrated the dimension of resilience from supply chain resilience and infrastructure resilience. Table 5.5 describes the link between socio-technical system, key performance indicators, supply network operation and the resilience dimension. For social factors, the resilience dimensions are adopted from the organisational and supply chain resilience, for example, integrity and availability. Those two dimensions were chosen by taking into account requirements in the supply network performance criteria in the fertiliser industry. Meanwhile, for technical factors, these were adopted from the dimension of infrastructure resilience, such as, safety and reliability. Those dimensions were determined based on technical factors involved in the supply network flow, which were the port, warehouses and operators. Other variables were not used because they were incompatible with definition resilience, purposes of resilience assessment in this research, and decision maker requirement.

In this thesis, dimensions represented characteristics of key performance indicators based on a system engineering approach (Blanchard, 2004) and case study analysis. The dimensions were Interoperability, Safety, Availability, and Reliability. A supply network system consists of social and technical elements. So for resilience assessment constituted in dimensions, it must accommodate those two elements. As the focus of this research was on infrastructure availability changes, so the resilience dimensions were determined by reflecting infrastructure resilience dimensions and supply network resilience dimensions from Section 2.1.5 key performance indicators are grouped into several dimensions based on the similarity of data. Table 5.8 describes relevance and irrelevance of dimension of resilience from the literature and reason for choosing the resilience dimension for this thesis.

Table 5.8 Relevance/irrelevance of dimension of resilience in this thesis from the literature

Dimension	The relevance/ irrelevance of the dimensions to the thesis	Reason	Dimension of resilience in this thesis
Organisational Resilience			
Situation Awareness	Relevant	The Indonesian fertiliser industry is aware that risk could cause crucial negative impact to the performance of supply network. The Department of Risk Management of the Indonesian fertiliser industry has responsibility to analyse and evaluate risk in supply network.	Interoperability
Management of Keystone vulnerability	Relevant		
Adaptive capacity	Irrelevant	The Indonesian fertiliser industry is governed by the Indonesian government regulation. Thus, capacity of the industry to adapt to risk, was depend on the government's regulation.	-
Human resources	Relevant	Human resources in the Department of Risk Management, the Department of Sales, the Department of Purchasing, and the Department of Port Management cooperate to maintain supply network resilience.	Interoperability
Infrastructure Resilience			
The nature of external shocks	Irrelevant	This thesis focused on the availability of infrastructure, which was T-port to supply network resilience. The availability of the port was calculated from berth occupancy ratio without including disturbances caused by nature shocks.	-
Prevailing environmental	Irrelevant		
Land use	Relevant	Based on respond from the key people in the Indonesian fertiliser industry, congestion in the port area frequently occurred during loading or unloading.	Availability

Continues on next page

Table 5.8 Continued

Dimension	**The relevance/ irrelevance of the dimensions to the thesis**	**Reason**	**Dimension of resilience in this thesis**
Infrastructural characteristics	Relevant	Resilience assessment in this thesis considered infrastructure availability based on berth occupancy ratio of the port.	Availability
The number of customers affected	Relevant	The main goal of the Indonesian fertiliser industry supply network was to provide fertiliser for farmers in Indonesia. Hence, delay in the supply network flow could affect level of customers' satisfaction.	Availability
Type of customers affected	Relevant	The Indonesian fertiliser industry produced subsidised fertiliser and governed by the Indonesian government. So that, type and number of customers regulated by the Ministry of Agriculture of Indonesia. The subsidised fertiliser was distributed to small and medium farmers. The number of customers affected reported from level of customers' complaints that reported by the Sales Department.	
Access of utility repair trucks to outage location	Irrelevant	This dimension was not in accordance with focus of this thesis.	-
Supply Chain resilience			
Key location	Relevant	The Indonesian fertiliser industry distributed subsidised fertilisier to smal and medium sized farmers in Indonesia. Key location of customers regulated by the Ministry of Agriculture.	Reliability
Adaptability	Irrelevant	Operation of supply network in the Indonesian fertiliser industry regulated by the Indonesian government that established annually. Thus, the supply network was unable to adapt to changes.	-

Continues on next page

Table 5.8 Continued

Dimension	The relevance/ irrelevance of the dimensions to the thesis	Reason	Dimension of resilience in this thesis
Safety	Relevant	Based on the key people responding, Safety was an important dimension in the Indonesian fertiliser industry supply network.	Safety
Mobility	Irrelevant	This thesis focused on distribution of fertiliser in the port area.	-
Recovery	Irrelevant	Operation of supply network in the Indonesian fertiliser industry is regulated by the Indonesian government that established annually. Thus, human resources and tools used the supply network depend on the regulation.	-
Diversity	Irrelevant	Similar reason with “Recovery”	-
Adaptability	Irrelevant	Similar reason with “Recovery”	-
Cohesion	Irrelevant	Similar reason with “Recovery”	-
Availability (supply availability rate)	Relevant	The Indonesian fertiliser industry distributed the subsidesed fertiliser to small and medium farmers in Indonesia. Availability of fertiliser must be control to maintain customers’ satisfaction.	Availability
Connectivity	Irrelevant	Similar reason with “Recovery”	-
Accessibility	Irrelevant	Similar reason with “Recovery”	-
Green behaviour (BG)	Irrelevant	The Indonesian fertiliser industry has not considered green behaviour in the supply network.	-
Resilient behaviour (BR)	Relevant	Currently the Indonesian fertiliser industry analyse resilience of supply network through the risk assessment report.	Reliability
Flexibility	Irrelevant	Similar reason with “Recovery	-
Velocity	Irrelevant	Similar reason with “Recovery”	
Visibility	Irrelevant	Similar reason with “Recovery”	-

Continues on next page

Table 5.8 Continued

Dimension	The relevance/ irrelevance of the dimensions to the thesis	Reason	Dimension of resilience in this thesis
Collaboration	Relevant	Human resources in the Department of Risk Management, the Department of Sales, the Department of Purchasing, and the Department of Port Management collaborate to maintain supply network resilience.	Interoperability
Complexity	Relevant	The Indonesian fertiliser industry is governed by the Indonesian government. The subsidised fertiliser was distributed to small and medium farmers. This lead to complexity of supply network operation.	Reliability
Density	Irrelevant	This dimension was not in accordance with focus of this thesis.	-
Vulnerabilities	Relevant	Similar reason with “Situation awareness”	Interoperability
Capability	Irrelevant	Operation of supply network in the Indonesian fertiliser industry is regulated by the Indonesian government that established annually. Thus, human resources and tools used the supply network depend on the regulation.	-
Coherence	Relevant	Human resources in the Department of Risk Management, the Department of Sales, the Department of Purchasing, and the Department of Port Management cooperate to maintain supply network resilience.	Interoperability
Control	Relevant	The Indonesian fertiliser industry aware that risk could cause crucial negative impact to the performance of supply network. The Department of Risk Management of the Indonesian fertiliser industry has responsibility to analyse and evaluate risk in supply network.	Reliability
Connectedness	Irrelevant	Similar reason with “Recovery”	-
Agility	Irrelevant	Similar reason with “Recovery”	-
Robustness	Relevant	Similar reason with “Control”	Reliability

This research used terms of resilience dimension from Table 2.3 and 2.4. However, in the process of generating a theoretical framework, definitions of the dimension were defined by synthesising literature and information collected from case study. Detailed definition of the resilience dimensions used in this research are:

1. Interoperability: integration of diverse sub-systems to collaborate in order to achieve goals. Integration of elements in the system is very important to achieve the system's goal. Aware that the system supply network consists of several different departments, so alignment between the sub-systems is needed to achieve the goal. Each sub-system must perform their respective functions and its results provide an output that can be beneficial to other sub-systems.

2. Reliability: continuity in achieving targets. In accordance with the main objectives of the industry, which is to satisfy consumers, so in the event of a disturbance that causes the risk, the system must be able to continue its function and immediately conduct improvement action to overcome or minimise the problems.

3. Availability: the availability of resources in dealing with system changes. The system must be able to optimise resources allocation; human resources and technology resources in order to achieve the target.

4. Safety: the ability to protect people or product against failure or damage. Product and people safety is important in maintaining supply network flow. This is in line with preventive maintenance for the equipment and health and safety procedures for the staff and operators.

5.6 Summary

This chapter described the development of the theoretical framework. The framework was generated from the synthesis of literature and knowledge gained from industry practice (case study). It was designed to provide support for the process of resilience assessment. Supply networks are systems consisting of social elements, such as, people and culture; and technical elements, such as, equipment, vehicles, and standard operating procedures. In order to accommodate the different kinds of elements, six perspectives of a socio-technical system approach were used to determine key performance indicators of resilience assessment, as can be seen in Figure 5.5. The theoretical framework was then translated into a conceptual model in Chapter 6, by populating it with real world data from the case study.

The input data in the simulation model was based on historical data taken from the risk assessment and port management reports. The output was the resilience assessment model is reported in Chapter 7. The output of the simulation model was verified as the critical relationship between the risks associated with berth occupancy ratios in the port and the flow of fertiliser to Indonesian farmers.

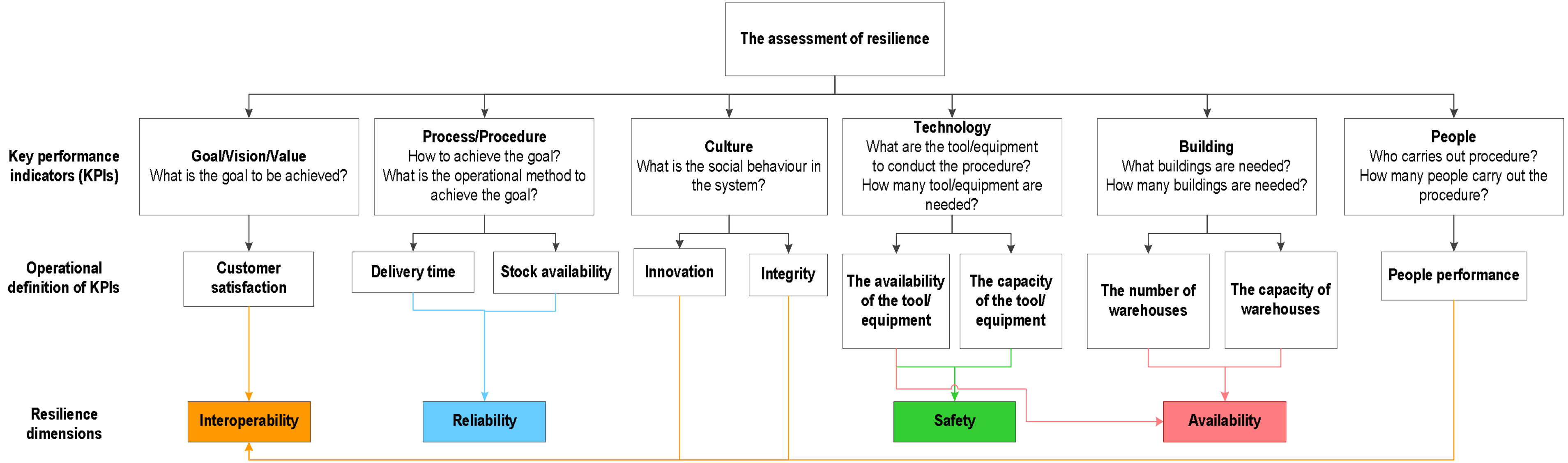


Figure 5.5 Relationship between key performance indicators and dimensions of resilience of the Indonesian fertiliser industry supply network

Chapter 6
Conceptual Model of Resilience Assessment in the Indonesian Fertiliser Supply Network

This chapter presents a translation of the theoretical framework into a conceptual model that informed the implementation of the simulation model that is reported in Chapter 7. Figure 6.1 describes the position of this chapter in this research.

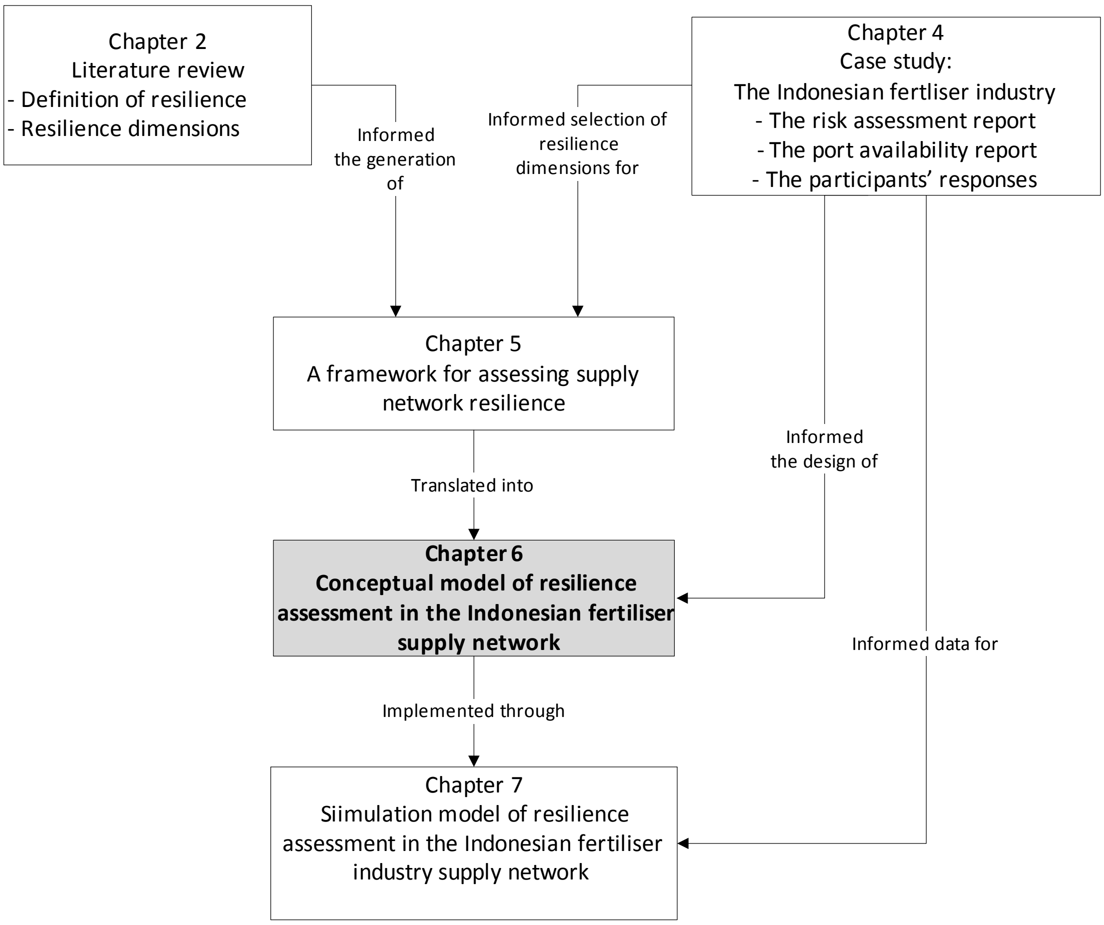


Figure 6.1 Chapter 6 the conceptual model of resilience assessment in supply network

Conceptual model configuration is an important stage in model building because it provides definition of an ideal system including information and process requirements in simulation model building. This chapter is divided into four sections. Section 6.1 provides an overview of the processes used to specify the conceptual model. The model itself has two key elements; a process definition in IDEF3 and a definition of data requirements in the form of a data model. These elements are reported in Section 6.2. Section 6.3 describes the validation and verification of the conceptual model in the fertiliser industry to ensure that the resilience assessment approach fulfilled decision makers' requirements. Section 6.4 provides a summary of this chapter.

6.1 Configuration of the conceptual model

The main objective of conceptual model development was to transfer data from a real world system into a model language, as illustrated in Figure 6.2. The formation of the conceptual model was a step that must be carried out before creating the simulation model. The emergence of a conceptual model can help researchers in transforming decision maker's requirements from real-world data into the form of a diagram or flow chart so that the elements, processes and relationships between elements can be visualized and understood by users. Formation of a conceptual model is expected to produce a resilience assessment model that can satisfy the managers in the supply network system.

It is important to translate a real supply network process into a more detailed system level as guidance to build computer-based simulation modelling. The conceptual model was built to ensure that the model fulfils the decision makers' requirements. It is also an important model to determine the completeness and correctness of the model by proving that it is sufficiently accurate and researchers can gain enough confidence in the model and accept the results.

6.2 Conceptual model of resilience assessment

As shown in Figure 6.3, IDEF3 can be used to further understand the key persons' perspectives. IDEF3 visualised product and process flow in one figure. Raw material from suppliers was processed in three stages of chemical processing. Quality control activities are applied at the end of the process, before fertiliser is packed and distributed. The risk assessment was implemented in the activities of the departments. Brainstorming with participants concluded that the greatest risk in the key of supply network flow was the process of distributing the products from warehouses to the loading process onto ships in the port area. For these reasons, this research focuses on process nine in the IDEF3 diagram. Material flow from the trucks to the ships is often delayed; this affects the berth occupancy ratio (measured as a percentage) at the port. Currently the fertiliser industry has set a target of berth occupancy ratio at 70%. If the percentage of the berth occupancy ratio is more than the set target, this will cause loss to the company because the company has to pay larger demurrage costs.

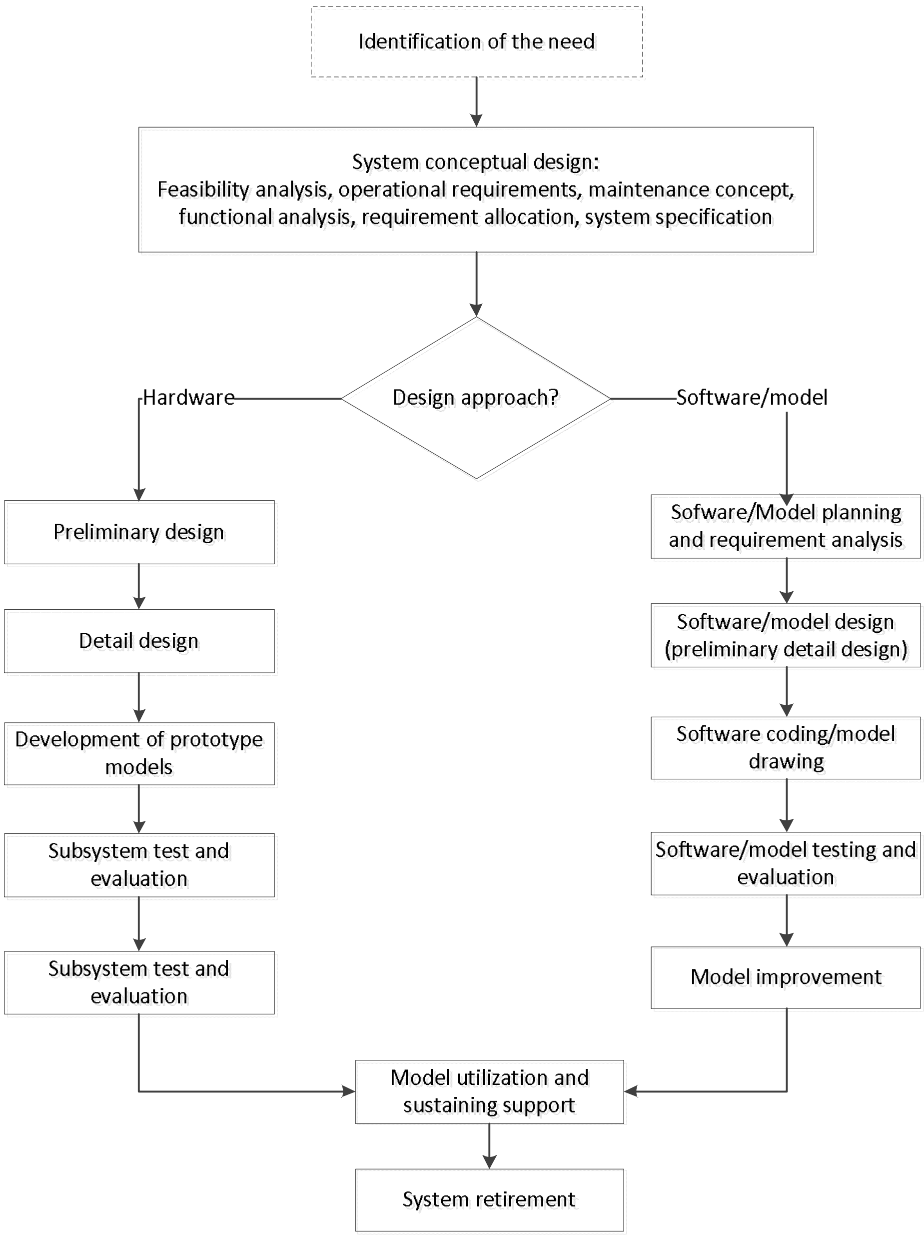


Figure 6.2 A disciplined approach to the development of software
(Blanchard, 2004)

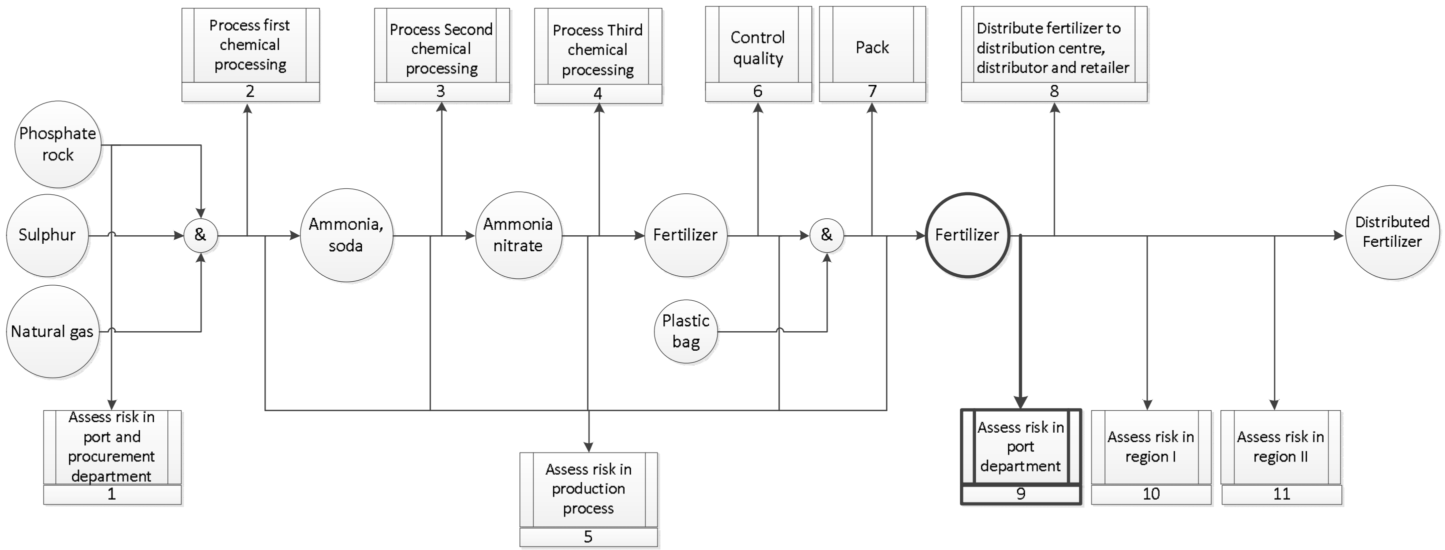


Figure 6.3 IDEF3 the fertiliser product and process flow and the focus of this was on process 9

Figure 6.4 Express G of information model to support resilience assessment in general

Conceptual modelling of resilience assessment in the fertiliser supply network was built using the EXPRESS G notation (McKay, 1997). Figure 6.4 illustrates the conceptual modelling drawn in sequence order. The model consists of entities and attributes. The entities were the main concepts of the theoretical frameworks, which were the supply network, infrastructure facilities, risk assessment, decision-making process, and resilience assessment. The process flow of the conceptual model was based on the five stages of the theoretical framework identified in Chapter 5. The attributes of entities were drawn to represent the relationship between entities. Entities were presented in boxes, a fine line represented the attributes of the entity, and the circle at the end of the boxes represented the data types of attributes. The names of the entities were written in the boxes, the name of the attributes was written in fine lines. The entities were defined in terms of a process and a process definition relationship (McKay et al., 2001). The entities definition relationship allows the relationship between entity definitions to be defined. For example: the relationship between the supply network elements and infrastructure facilities.

The conceptual modelling was started with the supply network element. The infrastructure entities were linked to the supply network element in order to show the effect of infrastructure on the supply network flow. These effects will be defined in the risk assessment entity. Information from the risk assessment will be used as the basis for the decision-making process in the resilience assessment and mitigation. Information from the risk assessment and analysis of strategy planning were intended to provide sufficient information for decision makers to assess resilience in the supply network. The output of the model was key performance indicators that were represented by values and graphs in simulation modelling.

- Agents: Agents in the process of supply networks in this study were composed of persons or departments involved in the process of the flow of products and information in the supply networks and those who had responsibility for identifying, analysing, and assessing risks and mitigation plans.
- The relationship between the elements represented in the element definition relationship.
- The infrastructure entities were attached between the supply network elements to describe the influence of infrastructure facilities on the supply network flow.

- The risk or effect in supply networks caused by infrastructure changes will be identified and specified in the risk assessment entity.
- Information from the risk assessment was used as basic data for the decision making process in mitigation and strategy planning to reduce risks.
- The results of the risk assessment were intended to provide sufficient information for decision makers to assess resilience in the supply network.
- The output of the model was key performance indicators that have been defined in the theoretical framework. The description of key performance indicators was represented by graphs at the interface of the simulation model.

The application of the conceptual model into the case study is illustrated in Figure 6.5. The table data population of the conceptual model based on data from the Indonesian fertiliser industry is presented in Appendix F. The definitions of elements in Figure 6.5 are described here:

- The supply network elements are agents in the system of the fertiliser supply networks. They are the Sales Department of Region I and Region II, the Department of Purchasing, the Department of Risk Management and the Department Managers in the port.
- T-port was identified as the key infrastructure facility in the fertiliser supply network.
- The identified Key Performance Indicators were:
    a) Goal: to achieve customer satisfaction. The goal was defined by the number of customer complaints.
    b) Procedure: standard operating procedure in loading and unloading of material.
    c) Culture: the culture of the fertiliser industry in accomplishing business process. For example: the level of accuracy in data entry.
    d) Infrastructure: the infrastructure facilities were warehouses and the capacity of open storage.
    e) Technology/tools: technology was represented in the utilisation of tools in supply network flows. For example: the process of loading and unloading tools, the different modes of transportation to distribute raw materials from the port to the fertiliser industry.

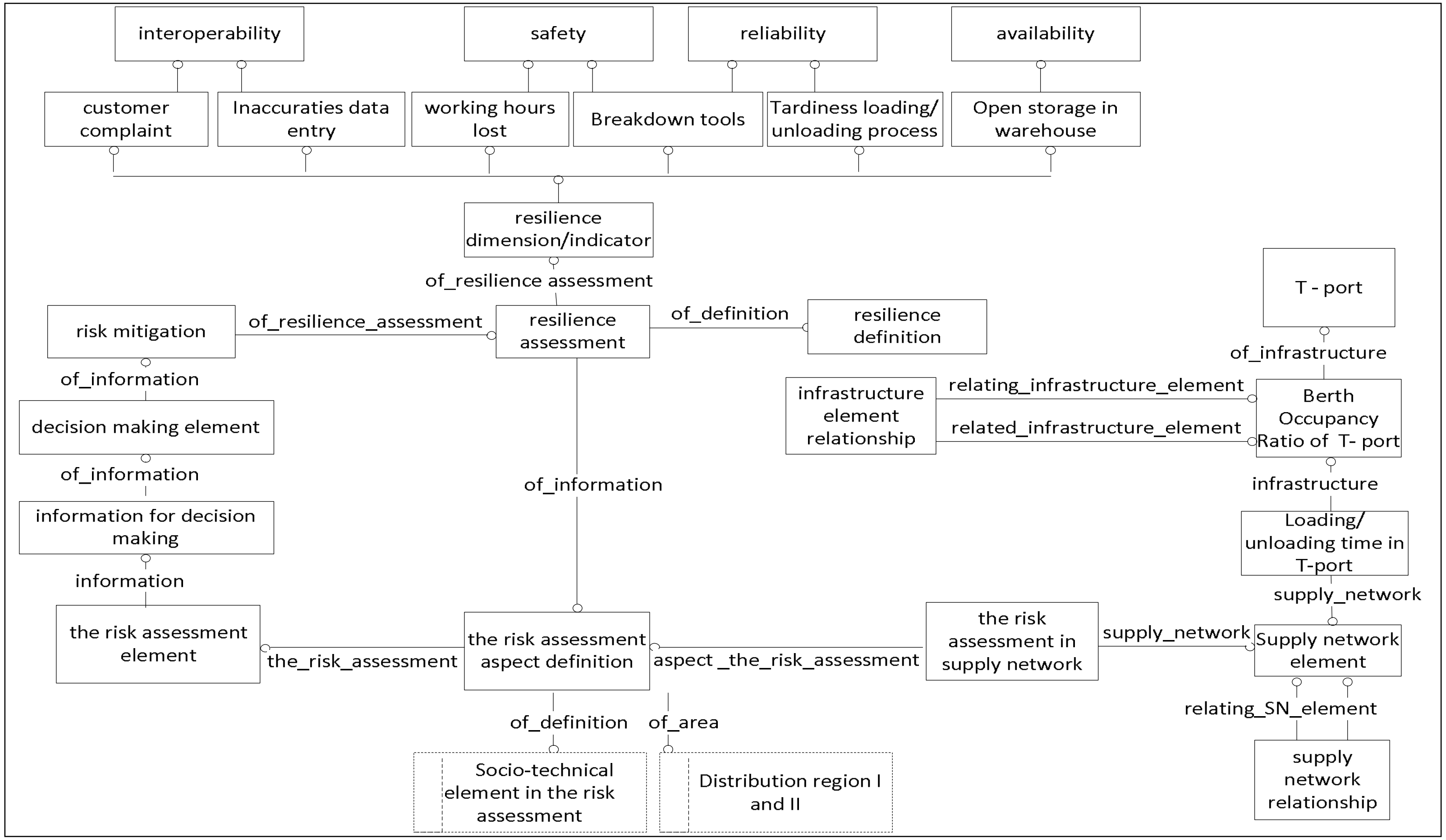


Figure 6.5 Express G of information model to support resilience assessment in the Indonesian fertiliser industry

f) People: people were defined by the performance of operators. For example: the number of working hours lost due to the delay in loading or unloading.

- Mitigation and strategy to reduce risk in the fertiliser supply network were as follows:

a) Training for operators to improve their skills and performance.

b) Sub-contracting of product if the Production Department could not achieve their production target.

c) Port expansion to increase port availability.

d) Preventive maintenance to increase safety of operators and maintain quality of product.

- Resilience assessment indicators were calculated as follows:

a) Inter-operability: level of training – level of risk in operator performance.

b) Safety: level of preventive maintenance – level of tools maintenance.

c) Availability: level of sub-contract – level of truck availability.

d) Reliability: level of port expansion – level of delivery method.

6.3 Conceptual model validation and verification

A conceptual model must be validated to ensure that the model represents the real world system and meets the decision maker's requirements, which were stated in both quantitative and qualitative key performance indicators, before the model could be transformed into computer language programming in a simulation model. This section describes the validation process for the conceptual model proposed in this research.

Conceptual and simulation model validation must be carried out continuously during model development, because the earlier potential problems are identified, the easier it will be to incorporate changes if needed (Blanchard, 2004).

6.3.1 Internal validity

The result of validation activities from each department are discussed as follows:

a. Risk Management Department

All participants in the Risk Management Department agreed that the resilience of supply networks was influenced by infrastructure availability. They understood and approved conceptual models that had been described and explained by the researcher. They provided suggestions for model improvement by focusing on the cultural elements of the risk management system. The fertiliser industry applies "a risk assessment based on activity" in order to reduce risk.

The results of discussions with the participant in this department are described in Figure 6.6. Participants suggested that in order to reduce risk, departments should identify risk from the simplest part of the business process. The researcher argued that operators should record the risk assessment process every day so it represented real conditions and the real case on the shop floor. Those activities were possible because the industry has disseminated the risk assessment process to all levels in the industry. Thus, the researcher suggested that the industry could use Standard Operating Procedure that consists of several core activities in the business process, as the basic element to identify risk in “risk assessment based on activities” culture. The risk assessment could be started from operators who conduct activities on the shop floor, reporting risks as they occurred, to their managers. Then, the managers analyse the risk, determine the level, and identify possible mitigation planning that could be done according to the industry resources and capabilities.

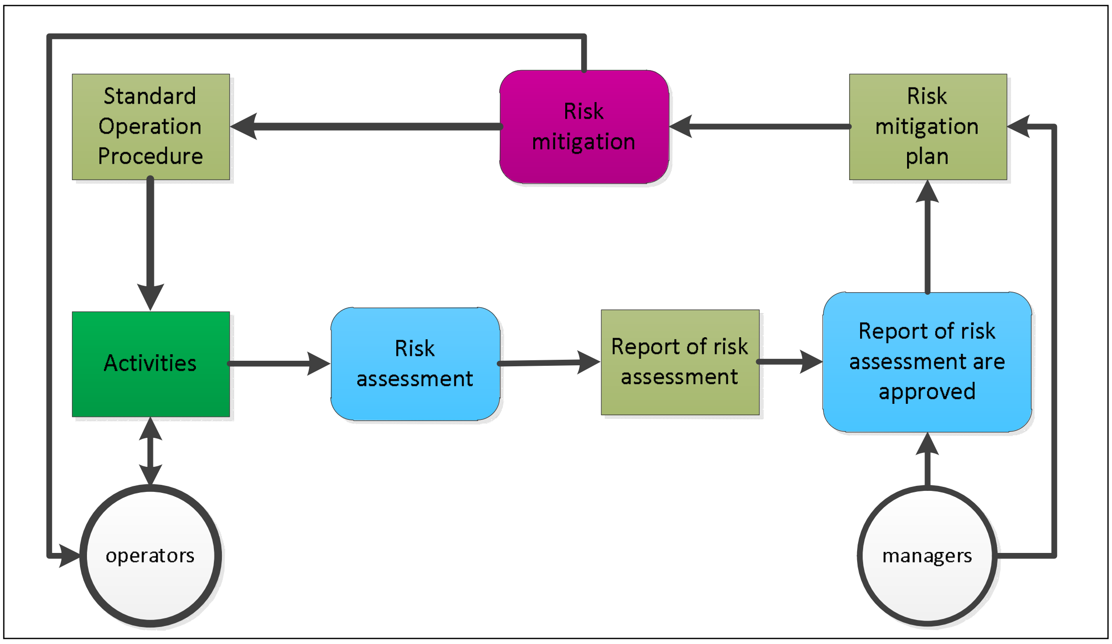


Figure 6.6 Business process flow in risk assessment

The lesson learned by the researcher from brainstorming with the participants was the industry already has a strong awareness of the influence of risk to supply networks resilience. Further, the industry has implemented risk assessment into the business process. However, fundamental thinking on risk assessment in the supply networks was not yet fully understood and realised by the industry. This validation process helped the industry to identify significant challenges in supply network elements. The researcher found that operators as agents in supply networks have a very strong influence on the accuracy and success of risk analysis results. Hence, for mitigation planning, the operator should be given training on how to define, identify and assess risk and be aware of the impact of these risks on the next process in supply networks.

b. Sales in Regions I and II Departments

The fertiliser industry distributes products to consumers (farmers) based on government policy. The amount of demand for fertiliser, delivery schedules, buffer stock and the amount of fertiliser to be shipped are dependent on government regulations that have been established in earlier years. Thus, the industry applies a special delivery schedule that was established by the Sales Departments; they are the Sales Department Region I which distributed fertiliser to the islands of Java and Bali; the Sales Department Region II which distributed fertiliser to the other islands (Kalimantan, Sumatra, Sulawesi, Nusa Tenggara and Papua). This condition causes the supply network management in the fertiliser industry to be different from other industries that use lead-time in delivery scheduling.

The result of brainstorming with key people in the Sales Department indicated that the highest risk in supply networks occurred in the process of loading products from trucks to ships, as illustrated in Figure 6.7. By applying socio-technical systems and an enterprise engineering framework, the researcher helped participants to investigate the cause and impact of risk. The results of the analysis showed that the risk in the loading process was influenced by the performance of the operators who conducted the loading process manually. Consequently, the operator's skill and behaviour greatly affected the effectiveness of the process. It has been recognized that operators often do not comply with standard operating procedures established. This caused a negative impact on supply networks, for example: the quality of products decreased because the arrangement of fertiliser was not in accordance with standard operating procedure, packaging was damaged, product weight was reduced, the area around the product becomes dirty, lateness in loading time, equipment damaged, and percentage of berth occupancy ratio increased. Berth occupancy ratio is the degree of utilisation of an available berth (Weille and Ray, 1974). Berth occupancy ratio is the ratio of time the berth was occupied by a vessel to the total time available in that period (Mwasenga, 2012). Participants considered that those impacts had a significant effect on the utility in the ports.

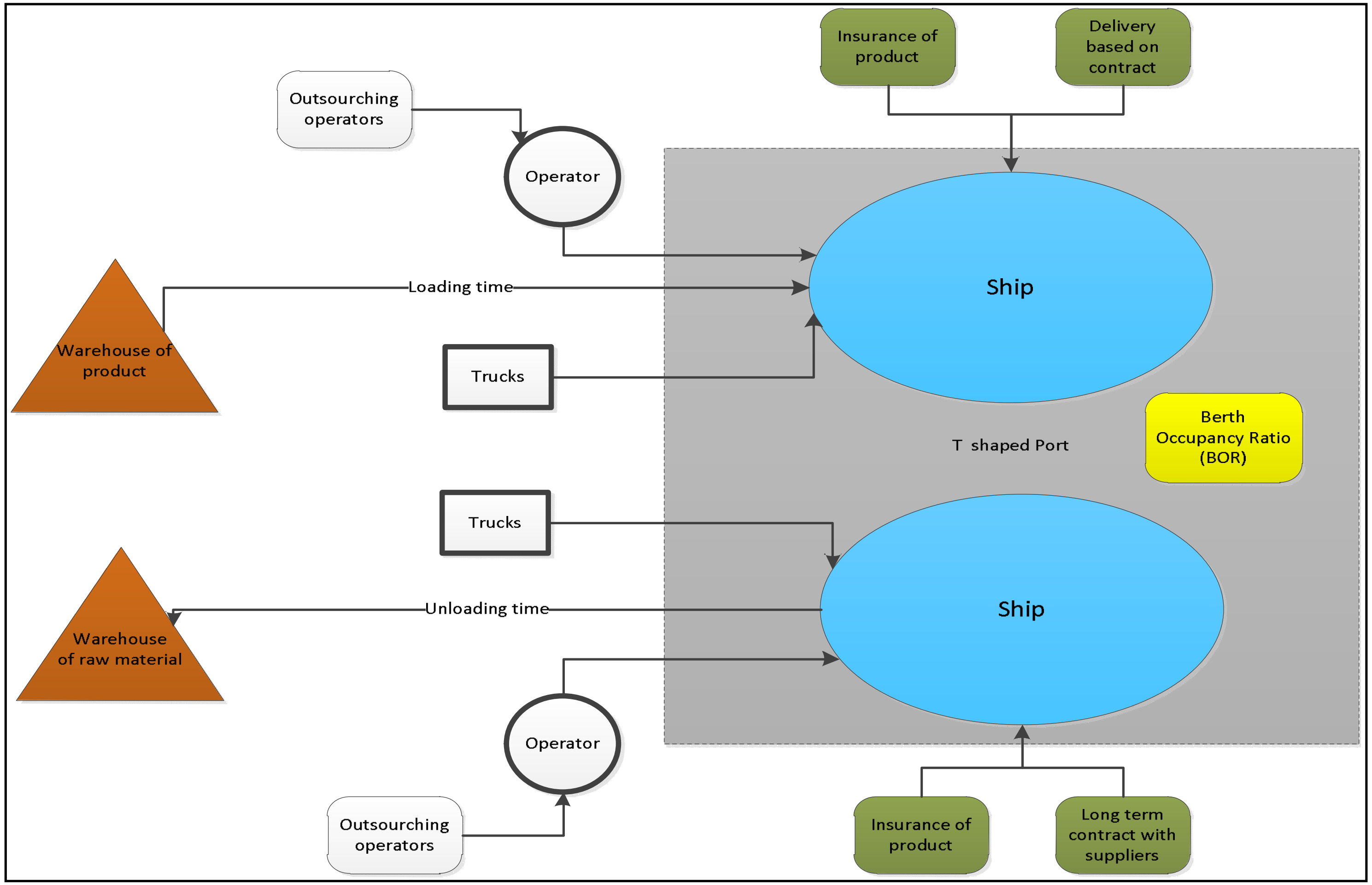


Figure 6.7 Loading and unloading in the supply network flow

c. Procurement Department

The key people in the Procurement Department pointed out that the conceptual model presented is clear and could be used to assess supply network resilience. They also suggested that the most influential infrastructure on resilience of supply networks is the port. Raw materials from suppliers that were transported by ships were unloaded in port before being transported to the fertiliser industry's warehouses. The length of the unloading process affected the overall effectiveness of the flow of the supply networks. Further, the unloading process uses automated equipment. Hence components of technology greatly influenced this process in terms of the socio-technical system. In addition, people and methods also affected the resilience of supply networks in the Procurement Department, as described in Figure 6.7. The performance of operators who operated unloading machinery determined the length of the process. This was evidence that port availability has a significant influence on the unloading time.

d. Port Management Department

All key people understood and approved the conceptual model proposed. Further discussion with the staff from the Port Department, revealed that the Indonesian fertiliser industry supply network assess port utilisation every month by measuring the port's berth occupancy ratio. In accordance with the answers from the key people in the Sales Region I and II Departments, port utilisation is a main factor influencing the supply network performance. Hence, the researcher aided the key people in the supply network system to investigate the relationship between the berth occupancy ratio and risk and resilience in supply by adding the percentage of berth occupancy ratio as one element in the conceptual model. This element was intended to determine the level of significant effects of the berth occupancy ratio on the resilience of supply networks. Figure 6.8 and Figure 6.9 provides a schematic illustration of material flow in the fertiliser industry's port. A further result of brainstorming with participants indicated that the greatest problem in material flow was maintaining operator performance in the unloading process of product from trucks onto ships in the port area.

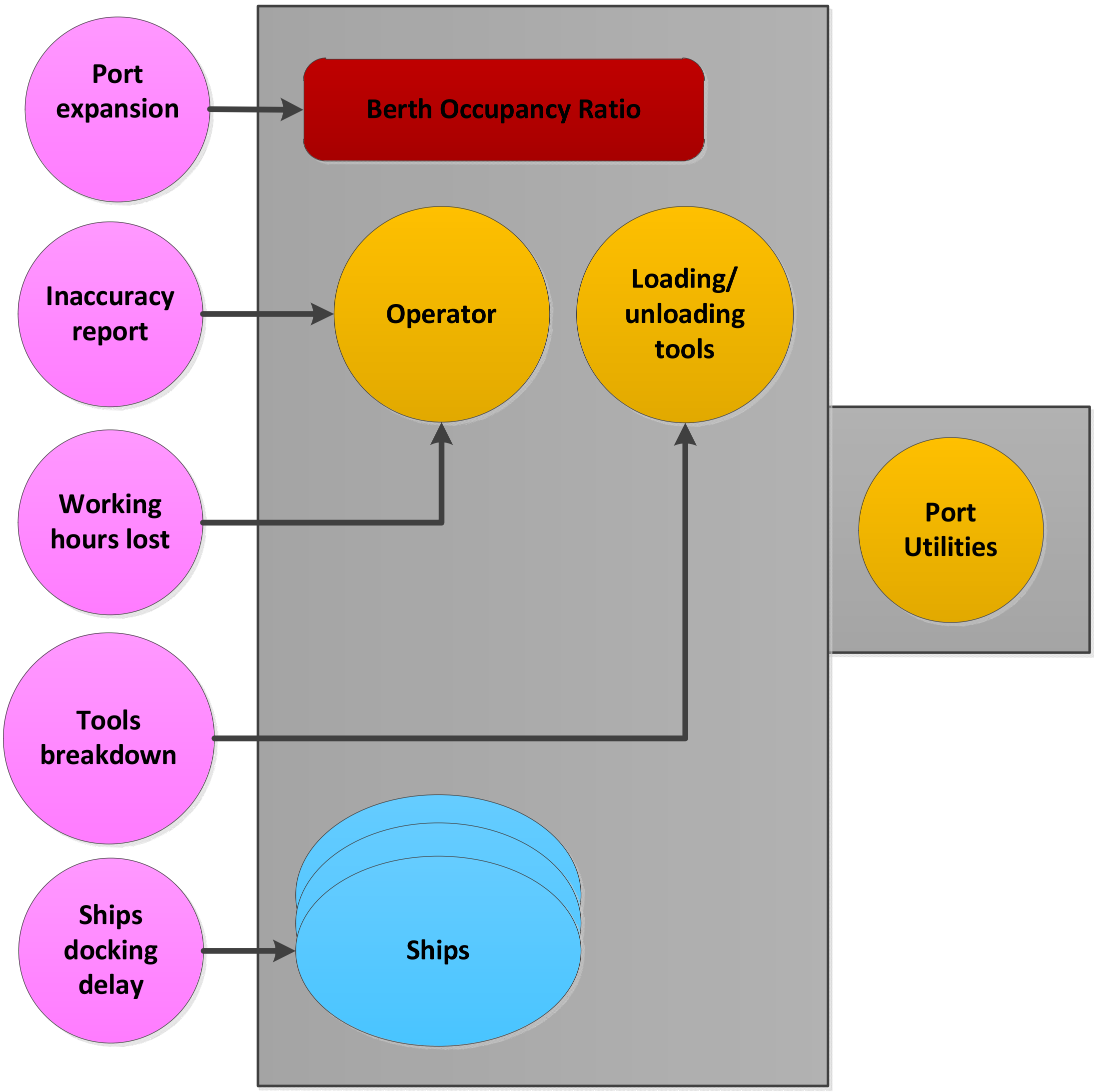


Figure 6.8 Risks in supply networks

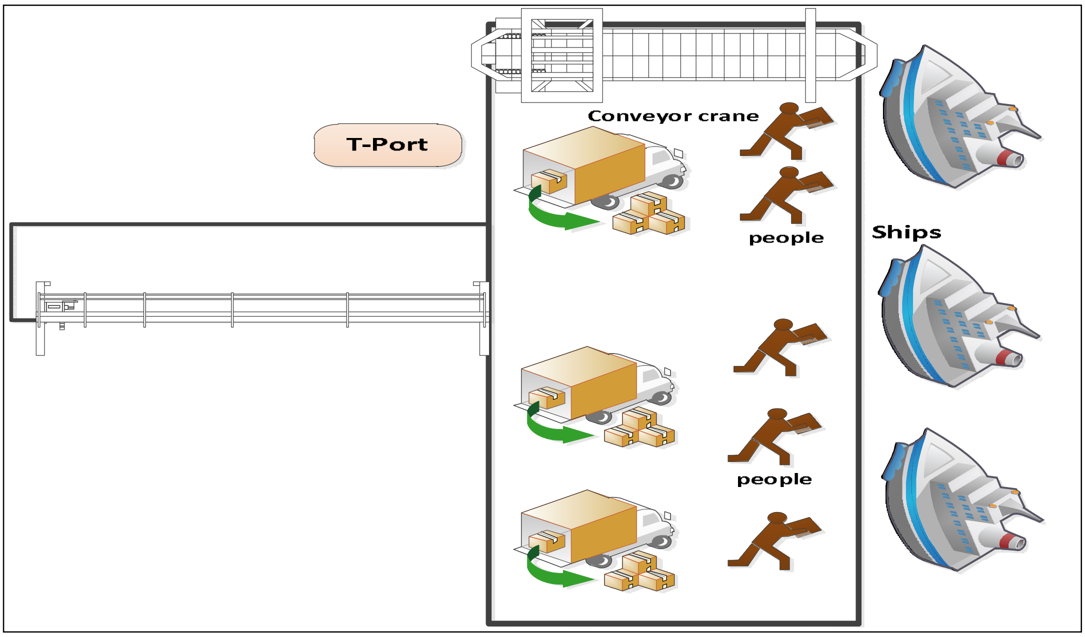


Figure 6.9 Material flow in the fertiliser industry port

6.3.2 Construct and content validity

The experience and knowledge of key people greatly affects the results of model validation. This phenomenon was acceptable, since the process formation of conceptual models was commenced with identification of key performance indicators and resilience dimension specified based on decision makers requirements. Decision makers define the importance of the requirement, for example: this research identified the requirements in Section 5.3 affected the mapping results on key performance indicators and resilience dimension. Furthermore, the definition, content, and resilience dimensions were changeable and depend on the vision or goal of the business process in the industry. All the participants agreed that the conceptual model built accommodates their requirements.

6.3.3 External validity

Application of the theoretical framework in this research could be adapted to other industries that have the same characteristics as the Indonesian fertiliser industry. The definition of six perspectives of socio-technical systems could be adjusted with the purpose and strategy of the industry. For example, in this research, the theoretical framework was employed in the fertilizer industry that has the goal to fulfil the fertiliser demand in accordance with the amount of fertilizer needed. Furthermore, in material handling processes, human resources or operators had a very important role in the effectiveness of the process. The geographical position of Indonesia as an archipelago makes the port the main infrastructure facility in fertiliser distribution to the consumers. Hence, when the theoretical framework is employed to other types of industry, it needs to be adjusted to the characteristics of the industry, such as the location and geographical conditions, the location and number of key suppliers, the location and number of consumers, as well as major infrastructure facilities that are used in the process of product distribution. In addition, the review of business processes and risk management should also be considered.

Information or historical data availability influence the outcome of decision making. Similarly, the application of the theoretical framework was largely determined by the information available in the industry, since the theoretical framework was established based on data currently available. Thus, the model could assess the current level of resilience and then predict the level of risk and resilience in accordance with changes in the level of availability of infrastructure facilities.

6.3.4 Improvement of the conceptual model

Validation and verification of the conceptual model were used as important information for model improvement. The researcher suggested the following recommendations:

Based on data on risk assessment in the supply network systems analysed, participants agreed that the port, as an infrastructure facility in supply network flow, caused significant risk to supply network performance and resilience. The important risk was the unloading time of raw material and the loading time of fertiliser in the port. All participants agreed with the results of data analysed and they considered applying a socio-technical system in the risk assessment and mitigation activity and the report. Further, participants suggested that the utilisation of loading tools and the performance of operators also contributed significantly to supply network resilience.

The results of checklists completed by participants are:

1. Model representation: participants agreed that the model was complete, correct, minimal, understandable, extendable, and represented a real system in the fertiliser supply networks. Further, participants accepted the theoretical framework and conceptual model proposed to assess supply network resilience.

2. Participants understood the process flow of the resilience assessment of the fertiliser supply networks that were described in EXPRESS G.
3. The conceptual model could be improved by adding port availability to analyse the effect of infrastructure on supply network resilience. The fertiliser industry provided data on total berth of occupancy ratio (BOR) of the port to measure port availability. The formula to measure BOR is:

$$\frac{\text{Average length of ship in berth + allowance x loading/unloading time}}{\text{Length of time in port x the amount of days x 24}}$$

   The fertiliser industry established target of BOR was 70%. The target set based on the United Nations Conference on Trade and Development - UNCTAD. The target was used as a guideline to determine targets and level in analyzing risk in supply networks. Berth occupancy ratio higher than 70% was a sign of congestion, while lower than 70% signifies under-utilization of the port. Percentages of BOR of the fertiliser industry's port from June to August 2013 were 90.94, 84.95 and 86.71 respectively. The data could be used for controlling processes or operation in port, for example: for planning loading and unloading times.
4. One of the participants suggested adding safety of product or fertiliser as an element of safety dimension in resilience assessment. Product safety was also influenced by the socio-technical system. For example: the method of loading affected the quality of the product. Data from the Port Department indicated that inappropriate loading methods could significantly reduce quality and weight of product. This risk was caused by incorrect processing in the loading method.
5. Another participant suggested distinguishing between people and tools in the safety dimension of resilience. The suggestion was based on actual activities that the fertiliser industry implemented of inspection to maintain tool safety and reliability. The researcher considered tools inspection in the risk and resilience analysis could be measured in the reliability dimension.
6. The researcher found that the fertiliser industry did not apply lead-time standards in managing delivery methods from the industry to customers. In managing delivery scheduling, the industry applies a weekly delivery method based on an annual target. The researcher suggested the method

to be implemented in order to minimise risk in port availability and manage loading time.

7. The goal of the supply networks was delivering product of the right type, quantity, price, place, time, and appropriate quality. These were important factors in measuring the performance of the supply networks. However, the fertiliser industry did not have procedures in place for measuring the performance in terms of supply network elements. The researcher suggested applying a socio-technical system to analyse the performance by establishing the performance assessment procedure. This procedure could be an area for future research.

Based on the conceptual model reviewed, the key performance indicators to build a simulation model were configured in Table 6.1. Since the value of key performance indicators in real data from the Indonesian fertiliser industry consisted of various scales, so the level of resilience assessment is presented in five scales from one to five as stated in Section 4.2. The resilience levels are: 1 is very low, 2 is low, 3 is medium, 4 is high, and 5 is very high. The target and actual value of loading or unloading time was influenced by port availability or berth occupancy ratio. The fertiliser industry could establish risk assessment to analyse and compare targets and actual values of loading or unloading times. The results of the risk assessment could be used as input to decision making to analyse the cause of risk, to plan mitigation and to measure key performance indicators of resilience assessment. Key performance indicators were categorized and the average values were calculated to generate the value of the resilience dimension.

In this research, key performance indicators were defined by taking account of supply network performance, resilience assessment and infrastructure availability. The researcher worked with decision makers to understand their requirements by using the expression of purpose dimensions matrix. Meanwhile, six socio-technical perspectives (goal, method, people, culture, infrastructure and technology) have been applied to identify the key performance indicators. The decision makers suggested that in order to achieve and maintain supply network resilience, the fertiliser industry should concern itself with risk reduction. Customer satisfaction, as the fertiliser industry's primary goal, could be achieved by considering and managing not only physical facilities but also co-ordination of high quality human resources. Further, T-port, as the infrastructure facility that influences the supply networks in loading or unloading would gain significant effects in risk and resilience in the supply networks. The fertiliser industry uses berth occupancy ratio to measure port availability. One important component in berth occupancy ratio is loading or unloading time. The loading or unloading time is determined by the key performance indicator of procedure. Thus, the resilience assessment must observe the effect of the berth occupancy ratio on the supply network resilience.

Historical data of the risk assessment report in Appendix C were used to generate key performance indicators. The scale of the key performance indicators were configured based on level of risk, as shown in Table 6.1

Table 6.1 The scale of key performance indicators

Key performance Indicators	**Scales**				
	1	**2**	**3**	**4**	**5**
Goal	0%	0.1% - 0.2%	0.2% - 0.3%	0.3%- 0.4%	>0.4%
Procedure	2 hours	2-4 hours	4-6 hours	6-8 hours	>8 hours
People	4 hours	4-8 hours	8-12 hours	12-24 hours	>24 hours
Culture	0-20%	20-40%	40-60%	60-80%	80-100%
Infrastructure	0-20%	20-40%	40-60%	60-80%	80-100%
Technology	1 per month	2 per month	3 per month	4 per month	5 per month

Sources: the Risk assessment Department of the Indonesian fertiliser industry (2013).

During fieldwork, the researcher worked with the manager and the senior staff (participants No. 1, No. 2 and No. 3 in Table 3.1) and formulated six key performances based on the risk assessment list in Appendix C. The key performance indicators were determined from the major concern supply networks performance in the Indonesian fertiliser industry. The value of key performance indicators was based on data as described in Table 6.1.

The value of key performance indicators is identified as follows:

1) Key performance indicator for Goal: the minimum number of Customer Complaints (Table B.3 and B.4 in Appendix B): the target established by the industry for customer complaints was from 0% to 0.4%.
2) Key performance indicator for Procedure: lateness in the loading process from trucks to ships by operators (Table B.2 in Appendix B): The lowest value was 2 hours and the highest value was 8 hours.

3) Key performance indicator for People: the number of working hours lost due to the delay in loading or unloading (Table B.3 and B.4 in Appendix B). The lowest value was 4 hours the highest value was 24 hours.
4) Key performance indicator for Culture: inaccurate data entry by administration staff (Table B.3 and B.4 in Appendix B): The lowest value was 0% and the highest was 100%.
5) Key performance indicator for Infrastructure: amount of excess space in warehouse (Table B.1 in Appendix B). This key performance indicator's lowest value was 0% and the highest value was 100%.
6) Key performance indicator for Technology: number of equipment breakdowns in loading or unloading per month (Table B.2 in Appendix B). The industry assigns a breakdown at least once per month and a maximum of five times per month or more.

Key performance indicators were identified based on six socio-technical system perspectives. Since the fertiliser industry has a standard value in determining the lowest and highest values of key performance indicators, this study adopted the interpolation calculation from Jeffrey (2005) as shown Equation (1) to calculate the relationship between the value of the key performance indicators (KPI) and the berth occupancy ratio (BOR).

Interpolation formula of key performance indicators is as follows:

$$KPI_d = 1 + \frac{(KPIe - KPIc)}{(BORe - BORc)} \times (BORd - BORc) \quad (1)$$

BOR_c = standard value of berth occupancy ratio in the fertiliser industry, that is 70 %

BOR_d = Estimated value of berth occupancy ratio

BOR_e = the highest value of berth occupancy ratio, that is 100%

KPI_c = the lowest value of key performance indicator

KPI_d = key performance indicator calculated

KPI_e = the highest value of key performance indicator

a) Key performance indicator of goal: $1 + \frac{(0.4 - 0)}{(100 - 70)} \times (BORd - 70)$

b) Key performance indicator of method: $1 + \frac{(8 - 2)}{(100 - 70)} \times (BORd - 70)$

c) Key performance indicator of people: $1 + \frac{(24-4)}{(100-70)} \times (BORd - 70$

d) Key performance indicator of culture: $1 + \frac{(100-0)}{(100-70)} \times (BORd - 70)$

e) Key performance indicator of infrastructure: $1 + \frac{(100-0)}{(100-70)} \times (BORd - 70)$

f) Key performance indicator of technology: $1 + \frac{(5-1)}{(100-70)} \times (BORd - 70)$

For example: if BOR_d is 80,

Key performance indicator of goal: $1 + \frac{(0.4-0)}{(100-70)} \times (80 - 70)$: 1.33%

Key performance indicator of method: $1 + \frac{(8-2)}{(100-70)} \times (80 - 70)$: 3 hours

Key performance indicator of people: $1 + \frac{(24-4)}{(100-70)} \times (80 - 70)$: 21 hours

Key performance indicator of culture: $1 + \frac{(100-0)}{(100-70)} \times (80 - 70)$: 34.33%

Key performance indicator of infrastructure: $1 + \frac{(100-0)}{(100-70)} \times (80 - 70)$: 34.33%

Key performance indicator of technology: $1 \frac{(5-1)}{(100-70)} \times (80 - 70)$: 2.33 or twice.

The risk level for each perspectives of the socio-technical system was calculated after determining the key performance indicators. Calculation of risk levels also adopted an interpolation formula as shown in Equation (2) to determine the relationship between the value of the berth occupancy ratio and level of risk. Data on input in the simulation model was determined based on data collected from the industry. The level of risk was from one to twenty five. The highest level for risk based on the socio-technical systems approach was determined based on assumptions and decision maker's judgment.

Interpolation formula of risk assessment level is as follows:

$$RST_c = 1 + \frac{(Re-Rc)}{(KPIe-KPIc)} \times (KPId - KPIc) \quad (2)$$

BOR_c = standard value of berth occupancy ratio in the fertiliser industry, that is 70%

BOR_d = Estimated value of berth occupancy ratio

BOR_e = the highest value of berth occupancy ratio, that is 100%

RST_c = the lowest value of risk

RST_d = Level of risk calculated

RST_e = the highest value of risk

a) Risks goal: the percentage of customer complaints. The decision maker assigned the highest value of risk of goal was 16 while the percentage of berth occupancy ratio was 100%. Calculation level of risk was:

$$RST_g = 1 + \frac{(16-1)}{(0.4-0)} \times (KPIgoal - 0)$$

b) Risk of method components: length of lateness in the process of loading or unloading caused by decreased levels of T-port availability. The highest risk level of risk was 25 while the percentage of berth occupancy ratio was 100%. Calculation of risk levels in the simulation model was:

$$RST_m = 1 + \frac{(25-1)}{(8-2)} \times (KPImethod - 2)$$

c) The risk to the people component: loss of operator working hours due to delays in the process of loading or unloading in berth occupancy ratio changes. The highest level risk of people was 15 while berth occupancy ratio was 100%. Calculation of risk levels in the simulation model was:

$$RST_p = 1 + \frac{(15-1)}{(24-4)} \times (KPIpeople - 4)$$

d) Risk culture components: an error in the data entry process for the reporting system. For example: a misunderstanding of the risk definition caused errors in data reporting in the risk mitigation process. The highest level risk of culture was 12 while berth occupancy ratio is 100%. Calculation of risk levels in the simulation model was:

$$RST_c = 1 + \frac{(12-1)}{(100-0)} \times (KPI_{\ culture} - 0)$$

e) Risk on infrastructure components: over space in warehouses caused by overstocking due to the lateness of the loading process. The highest level risk of infrastructure was 20 while berth occupancy ratio was 100%. Calculation of risk levels in the simulation model was:

RST$_I$ = $1 + \frac{(20-1)}{(100-0)} \times (KPIinfrastructure - 0)$

f) Risks in technology: equipment of loading or unloading damaged that caused equipment breakdown. The highest level risk of technology was 15 while berth occupancy ratio was 100%. Calculation of risk levels in the simulation model was:

RST$_T$ = $1 + \frac{(15-1)}{(5-1)} \times (KPItechnology - 1)$

For example: if BORd is 80:

RST$_g$ = $1 + \frac{(16-1)}{(0.4-0)} \times (1.33 - 0)$: 1

RST$_m$ = $1 + \frac{(25-1)}{(8-2)} \times (3 - 2)$: 5

RST$_p$ = $1 + \frac{(15-1)}{(24-4)} \times\ (21 - 4)$: 12

RST$_c$ = $1 + \frac{(12-1)}{(100-0)} \times (34.33 - 0)$: 1

RST$_I$ = $1 + \frac{(20-1)}{(100-0)} \times (34.33 - 0)$: 1

RST$_T$ = $1 + \frac{(15-1)}{(5-1)} \times (2 - 1)$: 5

6.4 Summary

The conceptual model built in this research was a representation of the resilience assessment approach in the Indonesian fertiliser industry supply network. The model was used to support information needed for resilience assessment. Then, the conceptual model was translated into a simulation model in Chapter 7. This chapter presented the conceptual model of the resilience assessment approach and its verification and validation with key people in the Indonesian fertiliser industry. The conceptual model was demonstrated to key decision makers who expressed confidence that the conceptual model reflected current Indonesian fertiliser industry practices.

The fertiliser industry uses berth occupancy ratio to measure the utility of the port. The ideal target for an efficient berth occupancy ratio is 70%. This target however, has become increasingly difficult to achieve because of tardiness in the load time taken to load and unload ships. This is in line with Equation 6.1, which states that the main variable in the berth occupancy ratio is the time taken to load and unload. In 2013, the berth occupancy ratio was higher than the target set; for example, it was 84.95% in July 2013 and 86.71% in August 2013. An analysis of data collected in this research identified that delays in the material flow in the port area increased the level of the berth occupancy ratio. Further, it was found that the key processes of the supply network system, such as material flow from the fertiliser industry warehouses to the ships in the port, was influenced not only by technical factors but also social factors. For example, the amount of time loading or unloading of product was influenced not only by the performance of the machinery, but also by the performance of people and communication processes. Information sharing among the personnel in supply chain elements is essential to reduce risk and uncertainty (Dattaa and Christopher, 2011). For this reason, this research applied a socio-technical approach to analyse the link between the supply network processes and the availability of the infrastructure using the port a case study.

Next, Chapter 7 reports the use of a simulation model based on the conceptual model presented in this chapter to bring resilience assessment and scenario planning into the existing risk assessment approach of the Indonesian fertiliser industry.

Chapter 7
Simulation Model of Resilience Assessment in the Indonesian Fertiliser Industry Supply Network

The implementation of the simulation model was the final stage in the resilience assessment approach. The theoretical framework was translated into an operational form through the conceptual model in Chapter 6, and then built into a simulation model in order to enable decision makers to operate the approach practically. The position of this chapter in the thesis is described in Figure 7.1.

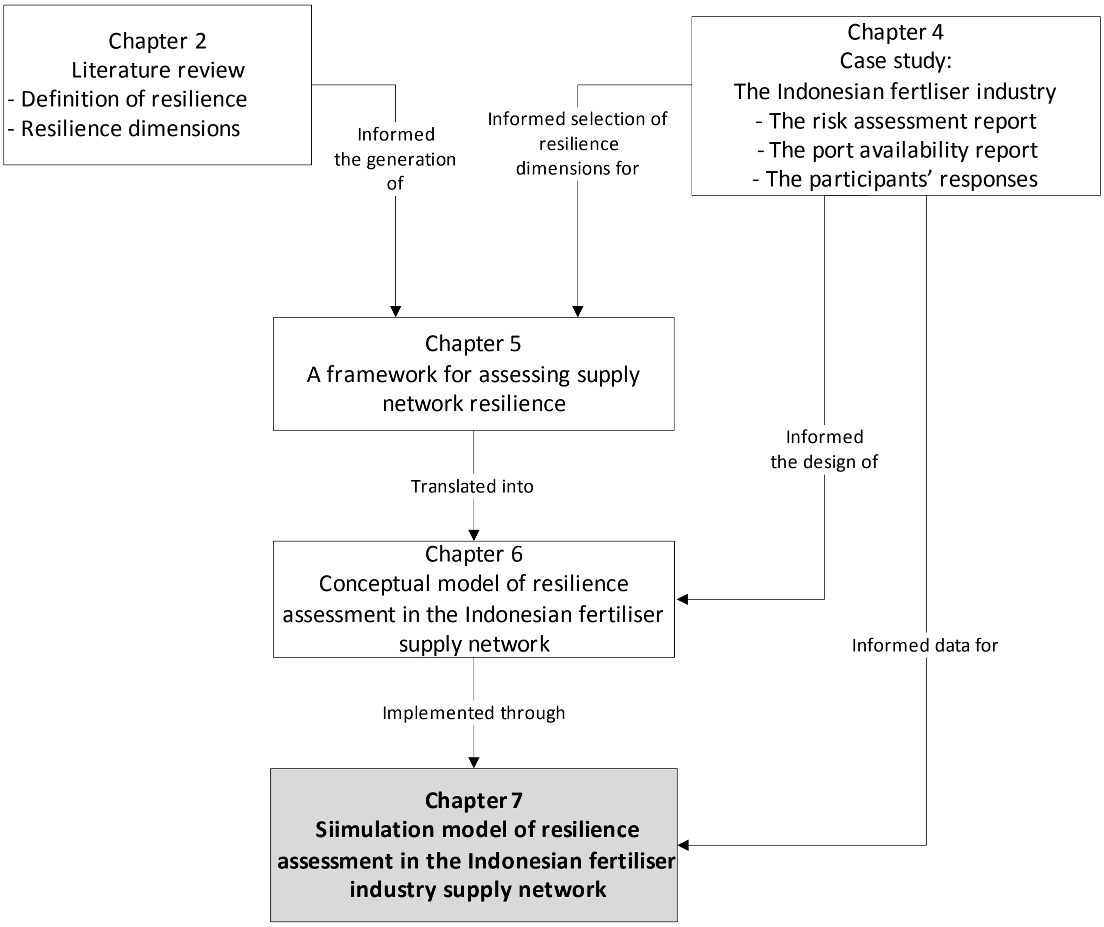


Figure 7.1 Chapter 7 simulation model of the resilience assessment of supply network in the Indonesian fertiliser industry

By implementing the conceptual model as a computer model populated with historical data from the Indonesian fertiliser industry, the simulation model can be used to inform the assessment of resilience in the supply network. This chapter presents the simulation modelling that was implemented using the NetLogo 5.0.4 software. The initial simulation model (in Section 7.1) was built to investigate the impact of the berth occupancy ratio fluctuations on supply network resilience. This model was verified and validated by asking the key people in the Indonesian fertiliser industry to review the model, as described in Section 7.2. The results of the validation were then used to improve the initial model and resulted in the final model in Section 7.3.

In Section 7.4, a stochastic model is applied to investigate the level of resilience if the berth occupancy ratio changes. Design experiments underpinned by the simulation models in Section 7.5 explored the resilience assessment of supply networks under different scenarios of infrastructure availability and mitigation plans. Further, in Section 7.6, movements of the operators in the material flow process were analysed in an experiment designed to minimise risk and increase the level of supply network resilience. Section 7.7 discusses the relationship between variables in the theoretical framework, the conceptual model, and the simulation model. This section also discusses the result. A summary of the chapter is provided in Section 7.8.

7.1 Generating a simulation model of resilience assessment in the Indonesian fertiliser industry supply network

This research used NetLogo 5.0.4 to build a resilience assessment model based on the conceptual model defined in the previous chapter to represent the effect of infrastructure changes in supply network resilience. NetLogo has an agent-based and dynamic systems modeller in the model library, thus the model designer can combine these two types of model in the simulation model. The agent-based approach in NetLogo, can be used to program the behaviour of individual agents and watch what emerges from their interaction, while the System Dynamics Modeller can be used to program how populations of agents behave as a whole (NetLogo, 5.0.4, 2014).

This research used a dynamic system modeller to construct elements in a resilience assessment approach and then used the agent-based interface model to describe the simulation output results in the form of graphs and figures on the monitor.

Inputs of simulation modelling are as follows:

a. Type of infrastructure facilities
b. Score of risk impact in the Department of Distribution Region I, Department of Distribution Region II and the Procurement Department
c. Score of probability of occurrence in risk assessment
d. Mitigation strategy and facilities.

The simulation model assists the decision maker to assess resilience by analysing risk and identifying key performance indicators of resilience assessment on the supply networks. The formation began with a simulation model of a dynamic systems modeller to describe the processes of risk assessment and calculate key performance indicators. This system is also used to describe and incorporate elements of the T-port that influenced the infrastructure in fertiliser industry supply networks.

The effects of infrastructure facilities were assessed by applying a socio-technical system approach. This approach was used to identify variables of risk and mitigation. The dimension of resilience was assessed using the following formulas:

Interoperability = (((Innovation + Training + Degeneration)/3) – ((People + People-I + People-II + People-III)/4)) * The-Industry

Safety = (((Preventive-Maintenance + Training)/2) - ((Disaster + Road-maintenance + Truck-availability + Tools + Infrastructure-facility + Dist-Infrastructure-facility + Dist-transportation-availability + Infrastructure-facility)/8)) * The-Industry

Reliability = (((P-Expansion + Forecasting)/2) - ((Scheduling - Delivery-Schedule - Queue-in-port - Dist-Deliver-Schedule - Retailer-delivery-method)/5)) * The-Industry

Availability = (((Preventive-Maintenance + Sub-contract) / 2) - ((Truck-availability + Warehouse-capacity + Ret-transportation + Dist-warehouse-capacity + Dist-transportation-availability)/5)) * The-Industry

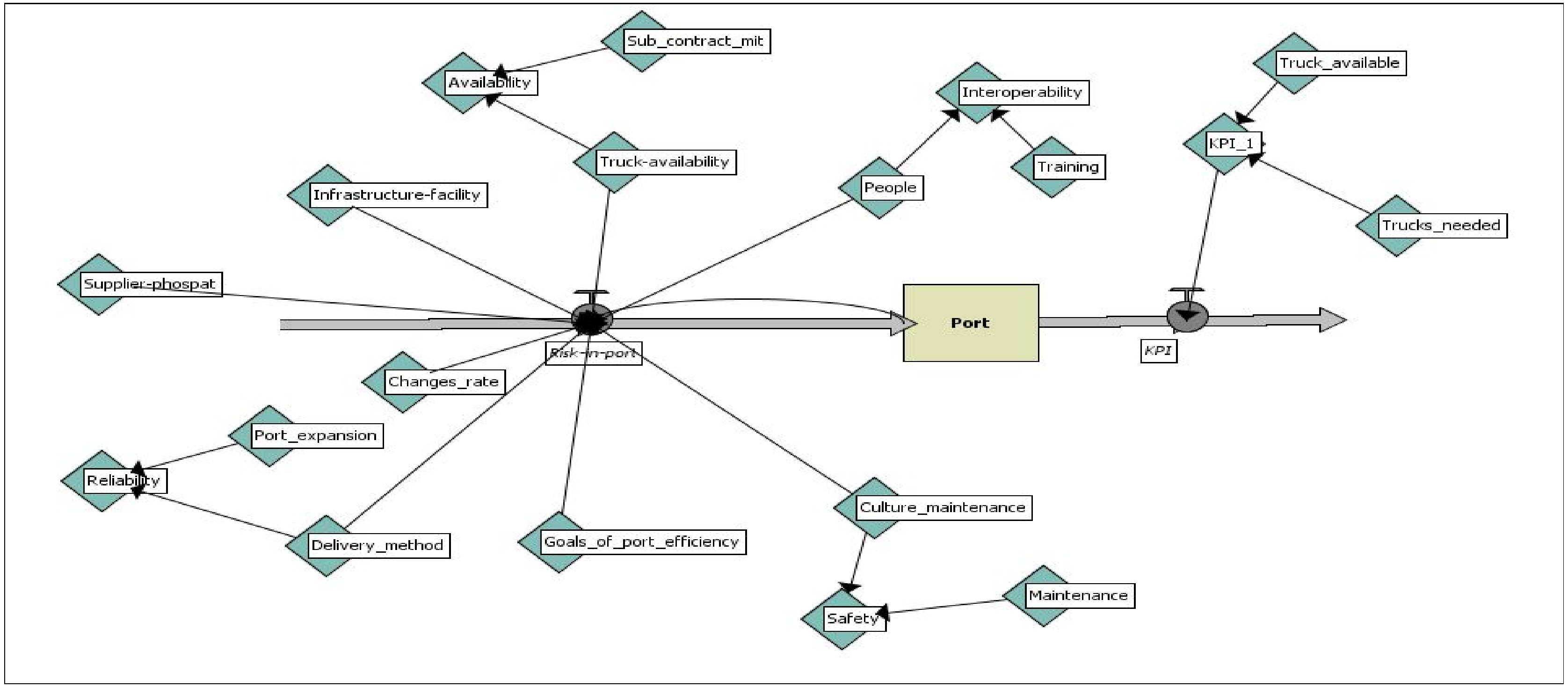
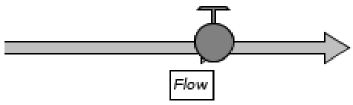


Figure 7.2 Initial simulation modelling of the resilience assessment

Table 7.1 Description of diagrams in the simulation model

Diagrams	Description
	Variable = to represent Key performance indicators
	Stock = to represent area
	Flow = to represent flow of supply network process
	Link = to represent relationship between the variables, stock or flow

The simulation model in this research was started with a simple model so that the simplest possible behaviour and simulation output can be easily understood and errors can be quickly recognized. The variables of the model are described in Appendix E. The simulation model of the resilience assessment with the port as the infrastructure facility that influenced the supply network resilience is illustrated in Figure 7.2. Meanwhile Table 7.1 describes the symbols of the system dynamic modeller used in the simulation model interface. The interface of the simulation model is illustrated in Appendix D. The value of variable was determined based on historical data in the industry. Ticks in the interface represent the running time of the simulation model. In real world terms of the case study, ticks represent one cycle period of the resilience assessment. For example, the Indonesian fertiliser industry carries out the risk assessment report and the port management report every month. Thus, the unit of tick is monthly. By the time the model was tested, the output of the simulation model started showing consistent values at 38000 ticks, so the simulation model ran continuously from ticks 1 to 204116. These constant values indicate that the simulation model is consistent. The model could aid decision makers to assess risk and resilience in the fertiliser industry supply networks by considering six components of socio-technical frameworks comprehensively instead of considering only one variable.

7.2 Verification and validation of the simulation model

Simulation models that have been established need to be verified and validated to ensure that the model has successfully represented the real system and fulfilled the desired objectives.

7.2.1 Internal validity

Formal meetings with ten key people in the fertiliser industry were conducted for implementation of verification and validation. Similarly with the conceptual model verification and validation process, the researcher invited ten key people from the first field study to review the simulation model. As informed in Section 3.2.3, one of the key people retired in February 2013. So for the model validation process, he was replaced by the new member of staff who replaced him. The result of the reviews with the new staff member was considered accurate because he had been trained for six months before taking up the position. In addition, the researchers also conducted a meeting with the new staff and explained the goal and objectives as well as the research process.

The researcher provided a printed copy of the simulation models, so that the participants could give their opinion and might provide data to support model validation. The model should be readable and understandable by the key people. The researcher also provided her contact details, so the key people could contact and arrange a formal meeting or if they needed any further information from the researcher. Meetings were held based on agreement with key people.

In the meeting, the researcher explained processes flow in the model until it generated results. Participants were given time to complete the check list and were given the opportunity to ask if they did not understand the terms contained in the check list. At the same time, discussions were also conducted while participants reviewed and suggested improvements to the model.

The data used as input in the simulation model are the risk assessment reports from 2011 and 2012. Formulae and variables generated in the simulation model are determined based on the theoretical framework and adapted to the availability of information on the fertiliser industry. Formulas in Section 6.3.4 were translated into a computer language program by employing modules in the 5.0.4 software.

Design experiments and determination variable changes in simulation scenarios are based on the mitigation plans that have been established in the supply network system. The scenarios could be adopted in other industries since the Indonesian fertiliser industry applies to the mitigation plan in the risk assessment guidelines from ISO 13000. This guideline is generally implemented by industry.

The results of the review are as follows:

a. Participants understood the process of resilience assessment in simulation models.
b. Participants considered the possibility of applying the approach in the industry.
c. Participants suggested changing the interface of the system dynamic modeller by changing the arrangement of variables so it could be more easily read and understood by users or readers.
d. Suggested improvements in the conceptual modelling in Chapter 6 could be applied to simulation modelling.
e. The design of experiments could be achieved by incorporating the mitigation plan to the model.

7.2.2 Construct and content validity

This research applied a combination of face validity (Sargent, 2010) and subjective approaches (Liu et al., 2012) to verify and validate construct and content validity of the simulation model. The researcher demonstrated the computer simulation model during meetings with the key people. Interface and elements of the model were discussed to ensure that the model fulfilled the decision maker’s requirements and modelling purposes. The key people were allowed to operate the simulation model and provide suggestions to improve the model interface, especially element arrangements and process flow of information definition of six socio-technical perspectives.

All key people agreed that the simulation model fulfilled their requirements. However, four key people suggested revising the lay out of the key performance indicators so they can be read more easily in the interface.

7.2.3 External validity

This research presented a simulation model to assist realization of the theoretical and conceptual models into practice. Through the creation of simulation models, historical data and information on the industry could be executed into a visual model that could provide output in quantitative data.

This assisted the researcher and decision makers in analysing and predicting the level of risk and resilience in the supply network. The structures of the model in computer simulations were adapted using the existing variables in the case study. Thus, the port was included in the model as the infrastructure facility as well as the elements of the key performance indicators and the dimension of resilience. Model simulations were built in this study and could be used in a wide range of industries that have similar characteristics or data with the Indonesian fertiliser industry. However, the model would need to be adjusted if it were employed in other industries that have different characteristics or supply network elements from the presented case study. The possibility is by analysing the definition of variables and formulas in accordance with data available in the industries.

The key people who reviewed the validity of the simulation model were staff members who have a wide variety of educational backgrounds, which were: engineering, management, accounting, and agriculture. When the researcher demonstrated the simulation model during a meeting with them, it was found that they easily understood how to run the model. They were also given the opportunity to try to run the model to observe whether the user could easily operate the model. The researcher found that the simulation models were quite easy to run by the users even though the users did not have an educational background in engineering or computer science. This indicated that the simulation model could be used by general users.

7.3 Final model design

The improvement of the simulation model was carried out based on the improvement of the conceptual model detailed in Chapter 6 and the results of the simulation model validation in Section 7.2. As the focus of the simulation model in this research was to analyse the influence of the berth occupancy ratio on supply network resilience, thus the simulation modeller code in Figure 7.3 was built to represent the relationship of the berth occupancy ratio to key performance indicators and risk assessment. Determining the berth occupancy ratio was required in the resilience dimensions, since the berth occupancy ratio is considered to affect the level of resilience. Six perspectives in the socio-technical system approach were integrated in the model to assist decision makers in identifying risk and establishing the mitigation plan. For example: in the fertiliser supply networks, the highest risk is tardiness in loading time. By mapping the cause and mitigation of risk from a socio-technical system perspective, decision makers could control key performance indicators and assess the resilience level of the supply networks based on the perspectives.

Table 7.2 describes the variables, input and formula of key performance indicators for simulation modelling, and Table 7.3 describes the variable of risk assessment level for simulation modeling. Those variables were translated into the system dynamic modeller in Figure 7.3. The code of the computer language model of the simulation model is presented in Appendix D.

Table 7.2 Variable codes and formula of key performance indicator in the simulation model

Variables Code	Value/Based on Equation (1)	Interface Model
BOR_Port	0 – 100%	BOR
KPI_Goal-customer_complaint	0 + (((0.4 – 0) / (100 – 69) * (BOR_Port – 69	KPI Goal
KPI_Method-loading_unloading_time	2 + (((8 – 2) / (100 – 69) * (BOR_Port – 69)	KPI Method
KPI_People-working_hours_lost	4 + (((24 – 4) / (100 – 69) * (BOR_Port – 69	KPI People
KPI_Culture-Inacuraties_data_entry	0 + (((100 – 0) / (100 – 69) * (BOR_Port – 69	KPI Culture
KPI_Infrastructure-Openstorage_in_warehouse	0 + (((100 – 0) / (100 – 69) * (BOR_Port – 69	KPI Infrastructure
KPI_Technology-Tools_breakdown	1 + (((5 – 1) / (100 – 69) * (BOR_Port – 69	KPI Technology

Table 7.3 Variable codes and formula of risk assessment level the simulation model

Variables Code	Value/Based on Equation (2)	Interface Model
Risk_of_Method	1 + (((25– 1) / (8 – 2) * (KPI_Method-loading_unloading_time – 2)))	R_Method
Risk_of_People	1 + (((15 – 1) / (24 – 4) * (KPI_People-working_hours_lost – 4)))	R_People
Risk_of_Culture	1 + (((12 – 1) / (100 – 0) * (KPI_Culture-Inaccuracies_data_entry – 0)))	R_Culture
Risk_of_Infrastructure	1 + (((20 – 1) / (100 – 0) * (KPI_Infrastructure-Openstorage_in_warehouse - 0)))	R_Infrastructure
Risk_of_Technology	1 + (((15 – 1) / (5 – 1) * (KPI_Technology-Tools_breakdown – 1)))	R_Technology
Resilience_in_risk_of_goal	Ticks / Risk_of_goal	Plot red
Resilience_in_risk_of_method	Ticks / Risk_of_goal	Plot Blue
Resilience_in_risk_of_People	Ticks / Risk_of_goal	Plot Grey
Resilience_in_risk_of_Culture	Ticks / Risk_of_goal	Plot Pink
Resilience_in_risk_of_Infrastructure	Ticks / Risk_of_goal	Plot Green
Resilience_in_risk_of_Technology	Ticks / Risk_of_goal	Plot Yellow
Resilience_in_KPI_of_goal	Ticks / KPI_Goal-customer_complaint	Plot black
Resilience_in_KPI_of_method	Ticks / KPI_Method-loading_unloading_time	Plot purple
Resilience_in_KPI_of_people	Ticks / KPI_People-working_hours_lost	Plot blue_1
Resilience_in_KPI_of_culture	Ticks / KPI_Culture-Inacuraties_data_entry	Plot brown
Resilience_in_KPI_of_infrastructure	Ticks / KPI_Infrastructure-Openstorage_in_warehouse	Plot orange
Resilience_in_KPI_of_technology	Ticks / KPI_Technology-Tools_breakdown	Plot pink_1

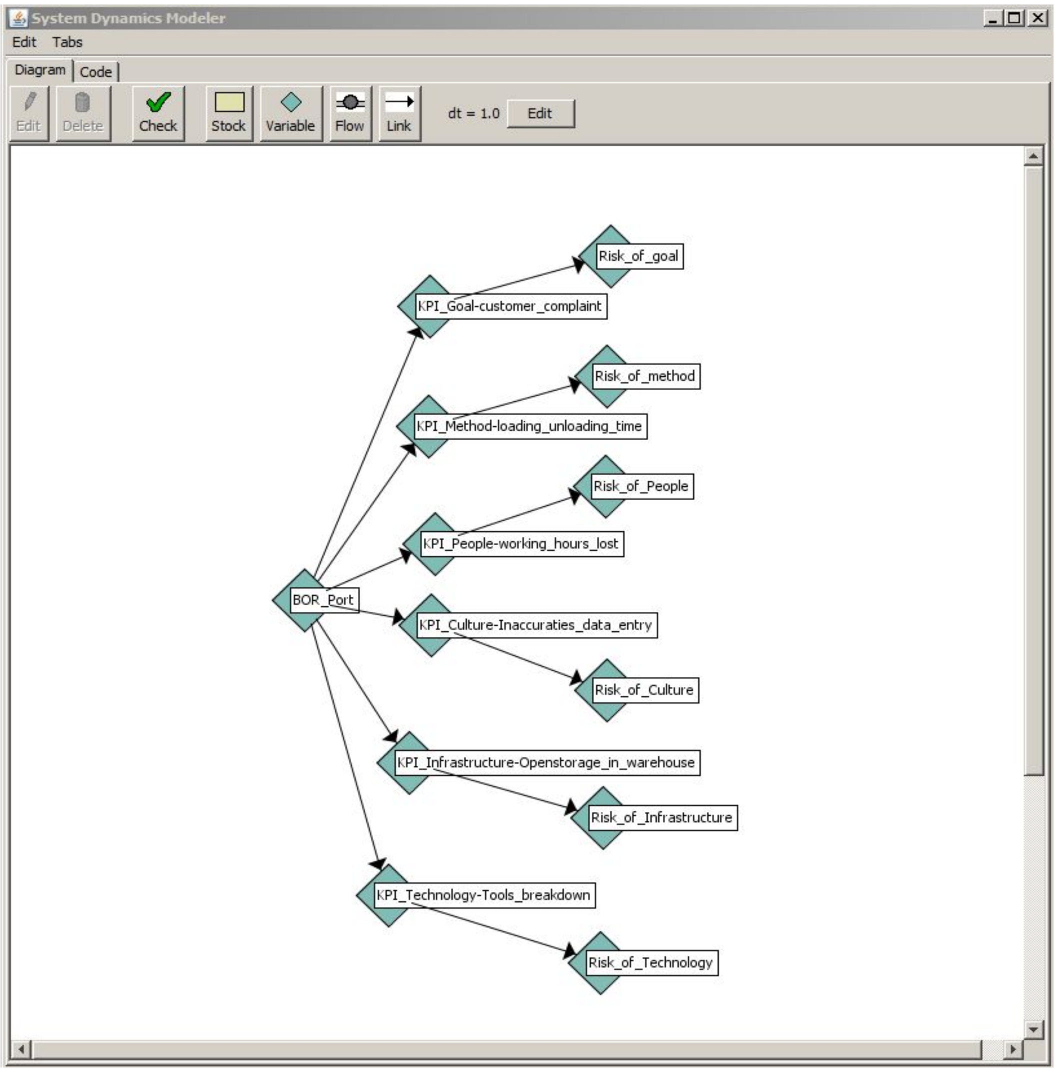


Figure 7.3 System dynamic modeller interface (Code in Appendix D)

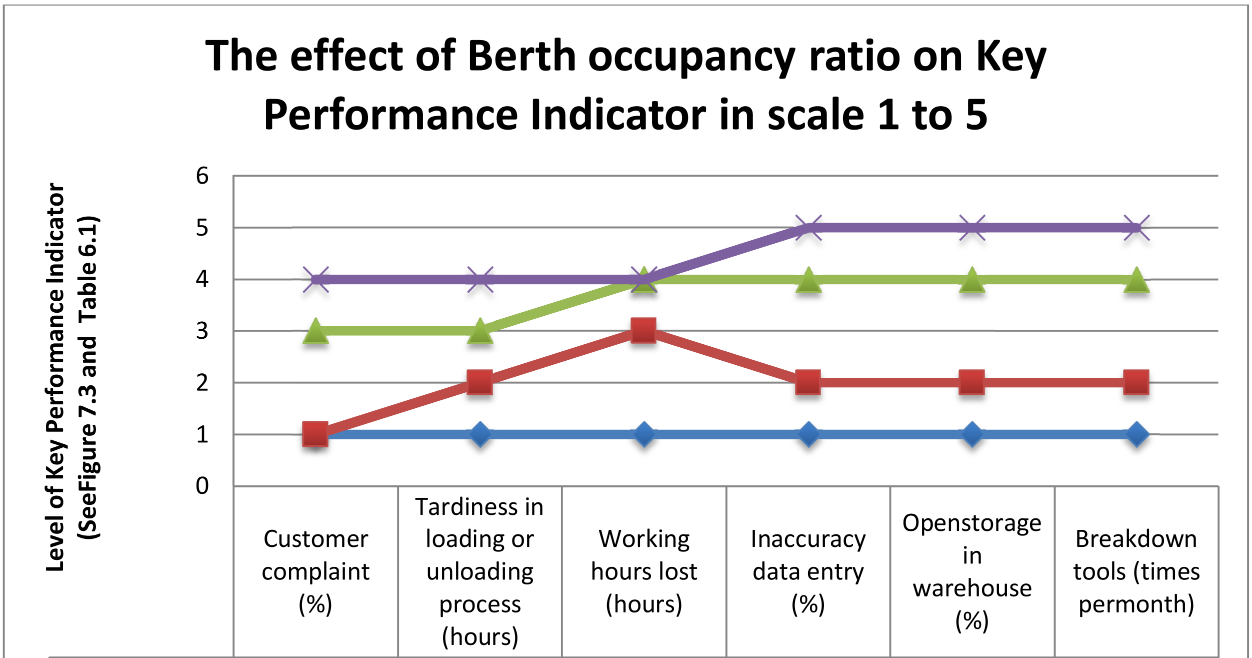
The interface of the simulation model in Appendix E provides the output of the simulation model from Figure 7.3, which represented the level of risk and the level of key performance indicators of the resilience dimension. The description of variables in the interface can be seen in Table 7.4. The models were run in 50000 ticks to observe verification of the variables in the code model. The number of ticks was determined by considering the consistency of output in the graph. By the time the model was tested, the output of the simulation model started showing consistent values at 38000 ticks. Thus, the results showed that the mode could be run in 50000 and the graphs showed constant results from the risk assessment and key performance indicators. The berth occupancy ratio on the system modeller slider on the interface was associated with the model. The minimum slider value is 0% and the maximum is 100%.

Table 7.4 Description of the variables and code at the interface of the simulation model

Variables' Code	Interface model	Descriptions
BOR_Port	BOR	Berth occupancy ratio of Port
KPI_Goal-customer_complaint	KPI Goal	Number of Customer Complaints
KPI_Method-loading_unloading_time	KPI Method	Lateness of the loading process to from trucks to ships by operators
KPI_People-working_hours_lost	KPI People	Number of working hours lost due to the delay in loading or unloading
KPI_Culture-Inacuraties_data_entry	KPI Culture	Inaccurate data entry by administration staff
KPI_Infrastructure-Openstorage_in_warehouse	KPI Infrastructure	The amount of excess space in the warehouse
KPI_Technology-Tools_breakdown	KPI Technology	Number of equipment breakdowns in loading or unloading per month
Risk _of_Goal	R_Goal	Risk in goal perspectives
Risk_of_Method	R_Method	Risk in method perspectives
Risk_of_People	R_People	Risk in people perspectives
Risk_of_Culture	R_Culture	Risk in culture perspectives
Risk_of_Infrastructure	R_Infrastructure	Risk in infrastructure perspectives
Risk_of_Technology	R_Technology	Risk in technology perspective perspectives

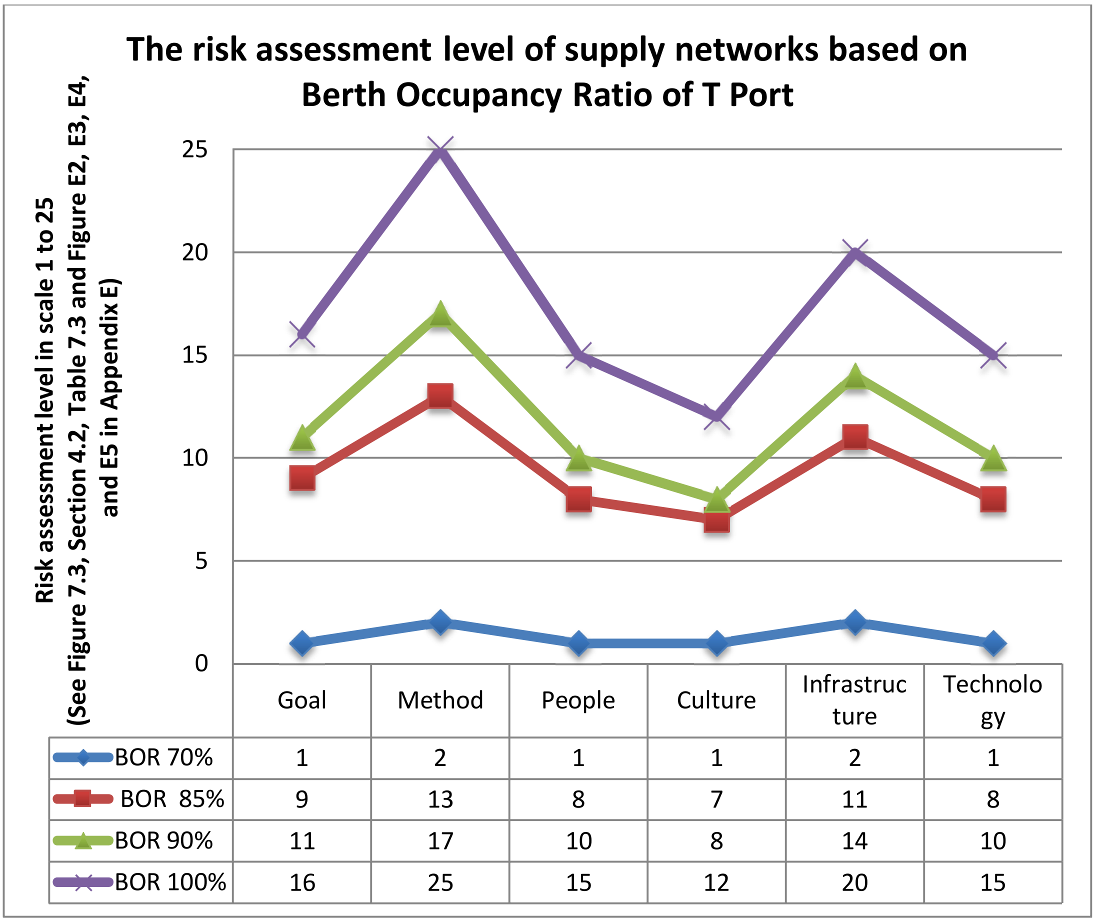
The model was translated to the monitor to show the results of the key performance indicator values and level of risk. The command "set up" and "go" on the monitor are used to run the simulation model. The command "set up" is to give orders to set up variable initial values and run a series of processes in the code. The command "go" is to execute or replicate a simulation model. The number of “ticks" or the replication process can be determined by users of the simulation. The number of "ticks" can also be used to determine and verify the model. If, during the process of replication of the model error does not occur, then the model is suggested to be valid or the code was running as was expected.

Figure 7.4, Figure 7.5, and Figure 7.6 provide a summary of simulation model output in four different values of the berth occupancy ratio. The results of the simulation model, key performance indicator values and risk, which is reflected on a monitor, could help the decision maker to conduct a risk assessment and evaluate key performance indicators in resilience assessment.



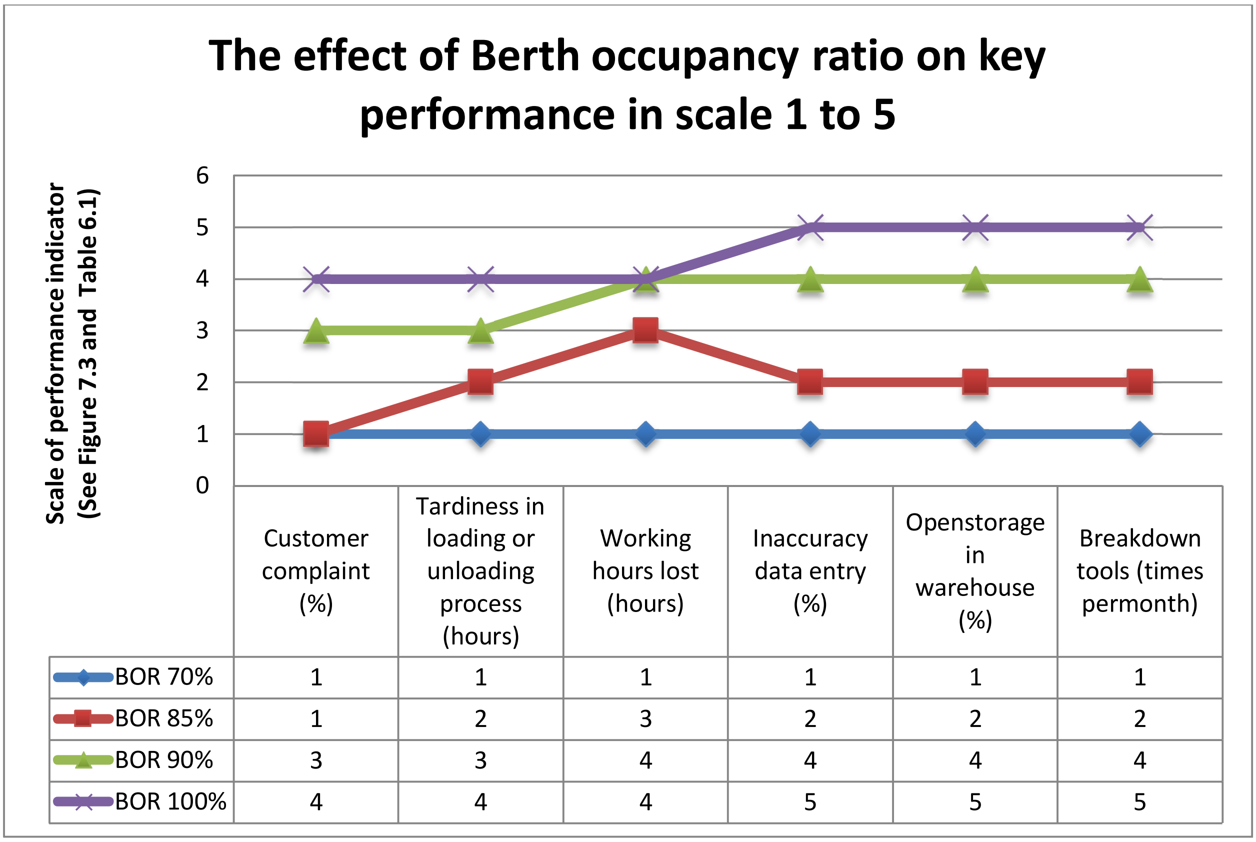
	Customer complaint (%)	Tardiness in loading or unloading process (hours)	Working hours lost (hours)	Inaccuracy data entry (%)	Openstorage in warehouse (%)	Breakdown tools (times permonth)
BOR 70%	1	1	1	1	1	1
BOR 85%	1	2	3	2	2	2
BOR 90%	3	3	4	4	4	4
BOR 100%	4	4	4	5	5	5

Figure 7.4 Relationship of the berth occupancy ratio to key performance indicator



	Goal	Method	People	Culture	Infrastructure	Technology
BOR 70%	1	2	1	1	2	1
BOR 85%	9	13	8	7	11	8
BOR 90%	11	17	10	8	14	10
BOR 100%	16	25	15	12	20	15

Figure 7.5 Relationship of the berth occupancy ratio to risk assessment level



	Customer complaint (%)	Tardiness in loading or unloading process (hours)	Working hours lost (hours)	Inaccuracy data entry (%)	Openstorage in warehouse (%)	Breakdown tools (times permonth)
BOR 70%	1	1	1	1	1	1
BOR 85%	1	2	3	2	2	2
BOR 90%	3	3	4	4	4	4
BOR 100%	4	4	4	5	5	5

Figure 7.6 The effect of the berth occupancy ratio on key performance indicator in scale 1 to 5 (See Table 6.1)

The fertiliser industry implements a specific delivery method based on regulations. Consequently, the supply network process must deal with critical risk in managing network flow and port availability. Thus, decision makers could use the information from simulation modelling to generate mitigation planning, performance assessment, planning and control of infrastructure utilities. For example: currently the berth occupancy ratio of the T-shaped port is between 85% and 96%. This indicated that the berth occupancy ratio was still higher than the target (70%). By using the simulation model the value of berth occupancy ratio could be changed into the desired value, so that the level of key performance indicators and risk could be predicted and target loading times could be minimized to reduce risk and increase supply network resilience. For example: the Department of Purchasing identified tardiness in unloading times as the highest risk. The shortest delay time was from two hours to more than eight hours. If delays in loading time were very high, it could influence delivery time, quality of product, people performance, and safety.

This model aided decision makers in assessing and predicting risk in their supply networks by changing the value of the berth occupancy ratio. Analysis of resilience assessment on the fertilizer industry supply networks can be determined based on the level of key performance indicators that were obtained from the output of the simulation results. In this case study, the level of resilience was inversely proportional to the level of the key performance indicators. For example, if the berth occupancy ratio was 90%, the interoperability dimensions: the number of customers who complained was four and inaccurate data entry was four. This shows the level of collaboration within the system supply networks was still low. Next on the dimensions of safety: loss of working hours was four and breakdown loading or unloading machinery was four. In addition, the dimension of reliability: tardiness in the process of loading and unloading was four. This indicates that the level of resilience of the fertilizer industry in continuity of the process was still too low. Fourth dimension, Availability: the availability of open storage for storing excess stocks of fertilizer also reached four which mean there was still plenty of fertilizer stock that had not been distributed due to the level of the port utility being low.

7.4 The stochastic simulation model with input of random level in the berth occupancy ratio

The next stage in simulation modelling was to design an experiment to observe the effect of berth occupancy ratio in random numbers. This experiment was applied to observe the fluctuation level of risk and resilience if the berth occupancy ratio changes unpredictably. In simulation code in Appendix D the variable of the berth occupancy ratio was set to a random number, so the value of the berth occupancy ratio would change automatically if the simulation was run, as shown in Appendix E. The output of the experiment in Table 7.5 and Table 7.6 indicates the impact of the berth occupancy ratio changes to the level of risk and key performance indicators. For example, if the berth occupancy ratio was 90%, the interoperability dimensions: the number of customers to complain was 0.27% or level 3 and the inaccurate data entry was 68% or level 4. This illustrates the level of collaboration within the system supply networks is low. Next, the dimensions of Safety: loss of working hours was 18 hours or level 4 and breakdown loading or unloading machinery was 4 times per month or level 4. In addition, the dimension of reliability: tardiness in the process of loading and unloading was 6 hours or level 4. This indicates that the level of resilience of the fertiliser industry in continuity with the process was low. The fourth dimension, Availability: the availability of open storage for storing excess stocks of fertiliser also reached 68% or level 4 which means there was still plenty of fertiliser stock that had not been distributed due to the level of the port utility being low.

Meanwhile, if the berth occupancy ratio was 78%, the interoperability dimensions: the number of customers to complain was 0.12% or level 1 and inaccurate data entry was 29% or level 2. This shows the level of collaboration within the system supply networks was high. Next, the level of Safety was moderate, since loss of working hours was 10 hours or level 3 and breakdown loading or unloading machinery was twice per month or level 2. In addition, the dimension of reliability: tardiness in the process of loading and unloading was 4 hours or level 2. This indicates that the level of resilience of the fertiliser industry in continuity of the process is moderate. The fourth dimension, Availability: the availability of open storage for storing excess stocks of fertiliser also reached 29% or level 2 which means the stock of fertiliser in the warehouses was sufficiently managed in fulfilling the demand.

Table 7.5 Output of simulation model: the risk assessment level

Time	**BOR**	**R-Goal**	**R-Method**	**R-People**	**R-Culture**	**R-Technology**	**R-Infrastructure**
x	y	y	y	y	y	y	Y
1	71	2	3	2	2	2	2
2	90	11	17	10	8	10	14
3	78	5	8	5	4	5	7
4	93	13	20	12	10	12	16
5	100	16	25	15	12	15	20
6	80	6	10	6	5	6	8
7	84	8	13	8	6	8	10
8	79	6	9	6	5	6	7
9	88	10	16	10	8	10	13
10	92	12	19	11	9	11	15

Table 7.6 Output of simulation model: the key performance indicators level

Time	**BOR**	**KPI Goal**	**KPI Method**	**KPI People**	**KPI Culture**	**KPI Technology**	**KPI Infrastructure**
x	y	y	y	y	y	y	Y
1	71	0.03	2	5	6	1	6
2	90	0.27	6	18	68	4	68
3	78	0.12	4	10	29	2	29
4	93	0.31	7	19	77	4	77
5	100	0.40	8	24	100	5	100
6	80	0.14	4	11	35	2	35
7	84	0.19	5	14	48	3	48
8	79	0.13	4	10	32	2	32
9	88	0.25	6	16	61	3	61
10	92	0.30	6	19	74	4	74

7.5 Design experiment of risk mitigation

The next step was analyzing the simulation into design experiments to implement some scenarios. The selection of variables in the scenario was based on the results of the model analysis of four departments in the fertiliser industry. The experiments were designed to determine the effect of changes in variables in the simulation results. The result could provide an overview for decision makers in making decisions for mitigation and risk reduction to improve supply network resilience. This section discusses the design experiment of the simulation model with four scenarios in four departments of the fertiliser industry. The simulation model adopted four levels of the mitigation plan to the system dynamic modeller as described in Section 4.3.4, with the berth occupancy ratio's variable being 69 + (((100 – 69) / (4 – 1) * (Mitigation – 1)). The scale of the Mitigation plan is defined from "slider= 1 to 4" in the simulation interface.

7.5.1 Mitigation plan by reducing risk

The first scenario applied the mitigation scenario of people and methods, in accordance with conceptual model improvement (Section 6.3). The fertiliser industry must conduct performance improvement of the loading operators while they were loading product from truck to ship, so that the risk caused by the process can be decreased. Moreover, working methods must be improved by prohibiting operators from using inappropriate tools. That rule was important to avoid damage in product quality and packaging. Thus, this scenario set the value of the mitigation plan at two (reduce). This change results in the level of risk assessment and key performance as described in Appendix E.

7.5.2 Mitigation plan by transferring risk to third party organisations

The fertiliser industry transfers risk by having insurance in place for raw materials and product safety. This policy was made to reduce the risk in transporting raw materials or products, for example: ships sink at sea caused by disaster or disruption, products lost from trucks while transporting from warehouses to distributors. In the simulation model, the variation in the mitigation plan was adjusted at three (Transfer), which was transfer of risk to a third party. The outputs of the simulation model in the second scenario are illustrated in Appendix E.

7.5.3 Mitigation plan by exploiting risk

The tardiness of loading or unloading was caused by delays in ships arriving in port and decreasing the technical conditions of loading/unloading equipment. This risk caused an impact on production operational disruption due to delays in the unloading activities of raw material from the ships. For example; the industry determined the risk mitigation by expanding the port's availability, increasing warehouse space and operating a bag conveyor system to accelerate the loading or unloading process and anticipate loading-unloading damage, improving ship loading, especially for conveyor belts and motor engines, to ensure the loading-unloading accessibilities. In the simulation model, the fourth mitigation plan was translated into level 4 of the mitigation scale. Appendix E describes an output scenario of three from the simulation model.

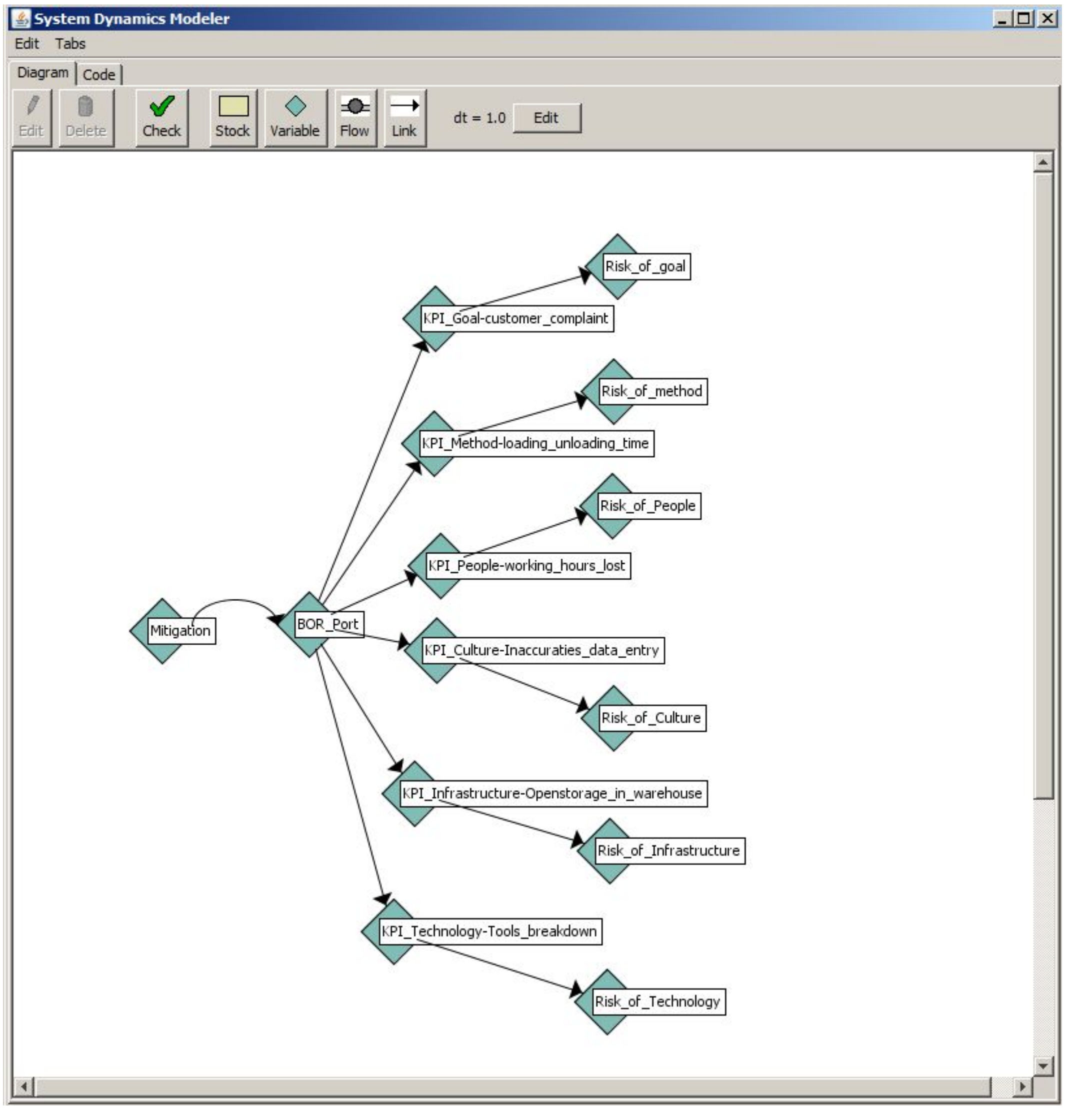


Figure 7.7 System dynamic modeller of the mitigation plan

7.5.4 Mitigation plan by avoiding risk

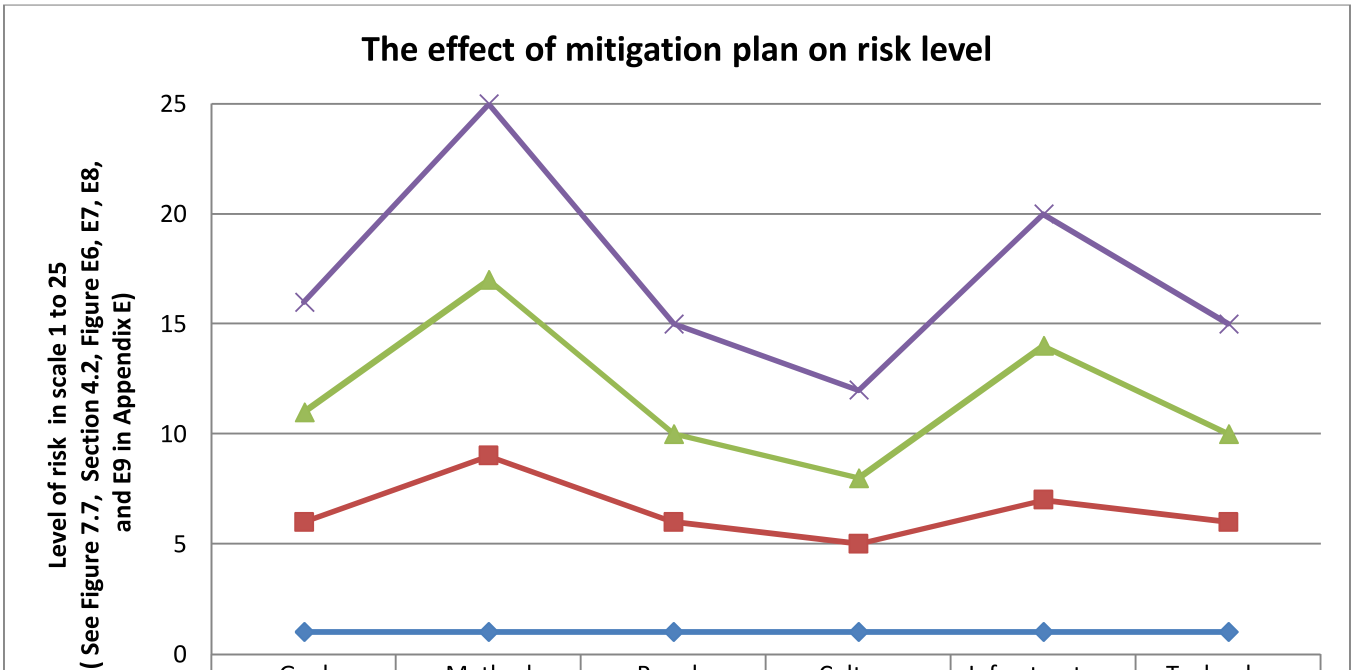
The fourth scenario was avoiding risk. In real conditions the fertiliser industry has not applied this mitigation plan. However, this research carried out this scenario to investigate the effect of the mitigation plan on resilience. The result of avoiding the risk scenario is described in Appendix E.

Figure 7.7, Figure 7.8, Figure 7.9, Figure 7.10, and Figure 7.11 represent the summary of the simulation model output that describes the effect of the four mitigation plans on the level of risk assessment and key performance indicators. For example: if the level of mitigation plan is three, then the berth occupancy ratio would be changed to 89.67%. These berth occupancy ratio changes will affect the level of risk_goal at 11, risk_method at 17, risk_people at 10, risk_culture at 8, risk_technology at 10 and risk_infrastructure at 14. Meanwhile, the effect of the berth occupancy ratio changes on the key performance indicators are: KPI_goal at 0.27%, KPI_method at 6 hours, KPI_people at 17 hours, KPI_culture at 67%, KPI_technology at 4 times and KPI_infrastructure at 67%. However, if the level of the mitigation plan is four, then the berth occupancy ratio would be changed to 100%. These berth occupancy ratio changes will affect the level of risk_goal at 16, risk_method at 25, risk_people at 15, risk_culture at 12, risk_technology at 15 and risk_infrastructure at 20, which indicated very high risk in the supply network. Meanwhile, the effect of the berth occupancy ratio changes on the key performance indicators reached the highest value, whereas: KPI_goal (customer complaints) at 0.40%, KPI_method (tardiness in loading or unloading in the port) at 8 hours, KPI_people (operators' working hours lost) at 24 hours, KPI_culture (inaccuracy entry data) at 100%, KPI_technology (machine breakdown) at 5 times and KPI_infrastructure (excess space in warehouses) at 100%.

By comparison with results in the previous two mitigation plans, the level of the berth occupancy ratio will remain steady at 69% if the decision makers establish level one or "avoid" as a strategy in the mitigation plan. As a result, the level of risk is one which indicates no risk or very low risk in the supply network. Similarly, the level of the key performance indicators reached the minimum level, which was KPI_goal (customer complaints) at 0.00%, KPI_method (tardiness in loading or unloading in the port) at 2 hours, KPI_people (operator working hours lost) at 4 hours, KPI_culture (inaccuracy entry data) at 0%, KPI_technology (machine breakdown) is only 1 time and KPI_infrastructure (excess space in warehouses) at 0%. The most optimum result was obtained from a scenario with the level of the mitigation plan at two (reduce).

The simulation results identified that "Avoid" was the best mitigation plan because it generates the lowest level of risk in all six perspectives.

However, the key people in the Risk Management Department argue that if the Indonesian fertiliser industry implements "Avoid" as the mitigation for risk, that means there are no operational and production activities in the industry. For this reason, the Indonesian fertiliser industry never carries out "Avoid" as a mitigation plan in real activity. So for the optimum result in mitigating risk, the second scenario, Reduce, was the most ideal scenario.



	Goal	Method	People	Culture	Infrastructure	Technology
Avoid	1	1	1	1	1	1
Reduce	6	9	6	5	7	6
Transfer	11	17	10	8	14	10
Exploit	16	25	15	12	20	15

Figure 7.8 Output of design experiments and the effect of the mitigation plan on risk assessment

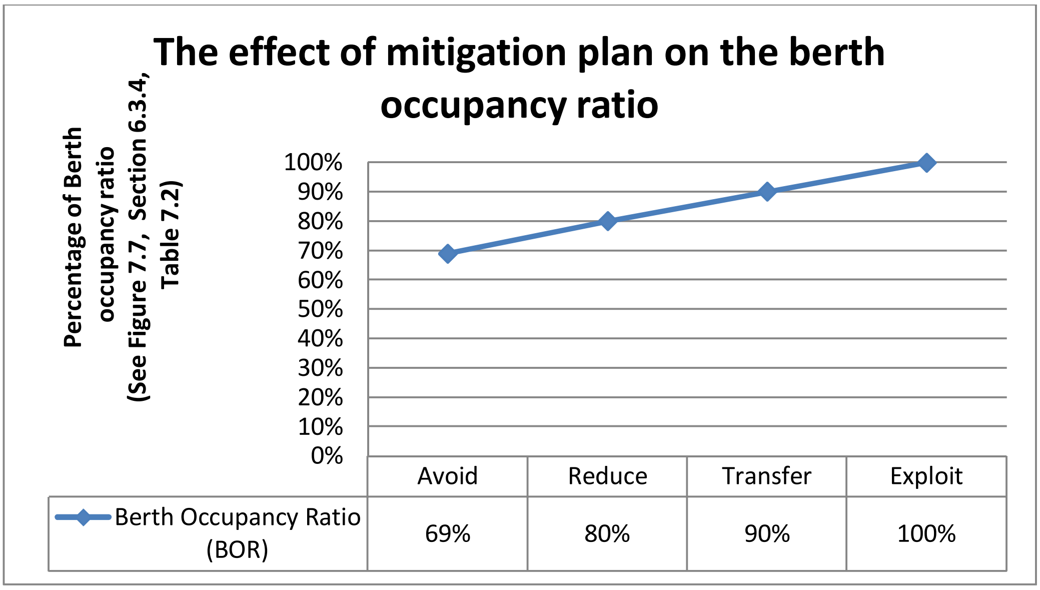
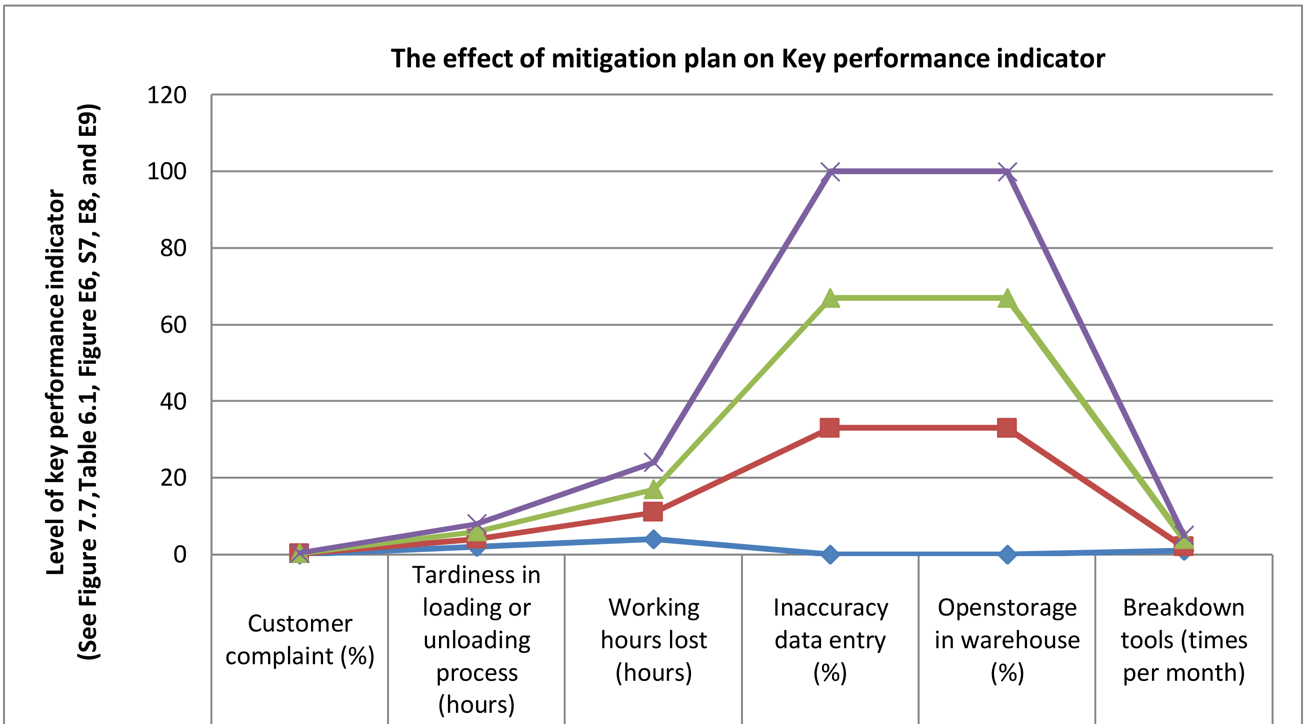
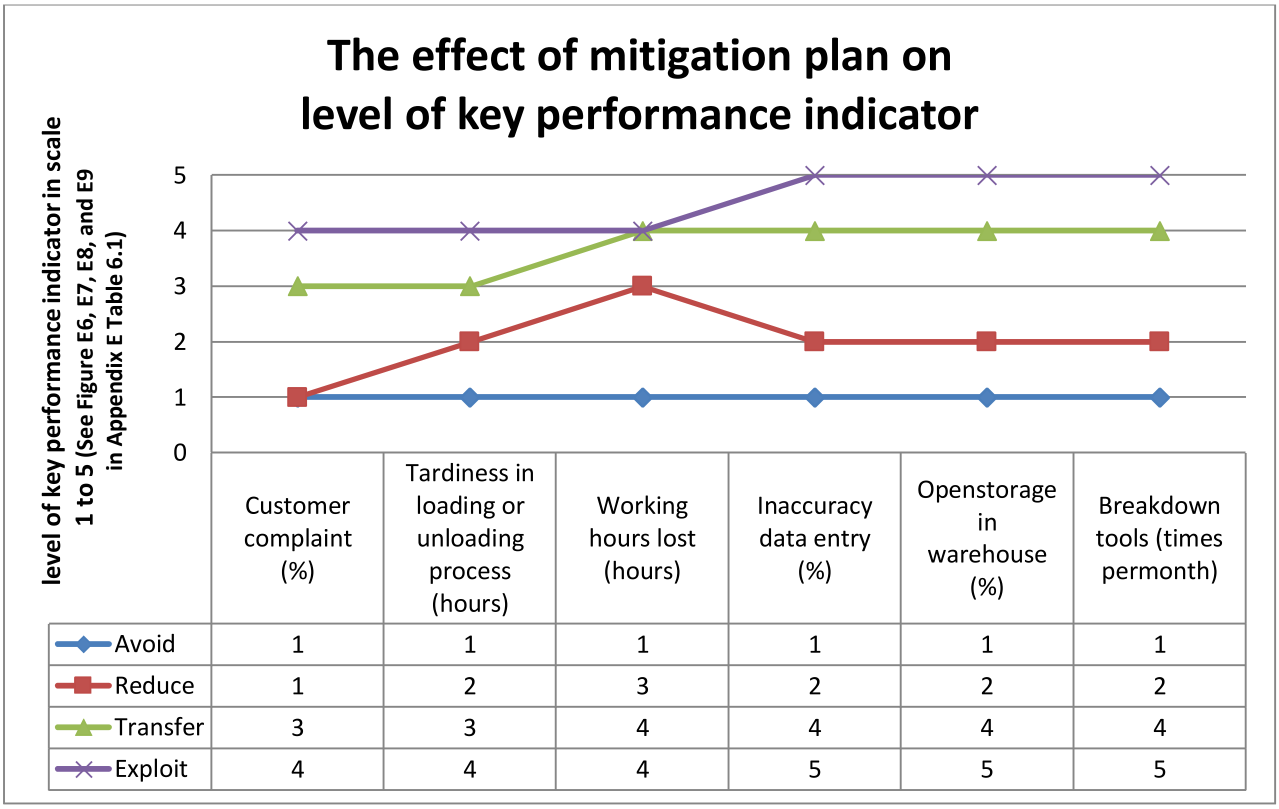


Figure 7.9 The effect of the mitigation plan on the berth occupancy ratio



	Customer complaint (%)	Tardiness in loading or unloading process (hours)	Working hours lost (hours)	Inaccuracy data entry (%)	Openstorage in warehouse (%)	Breakdown tools (times per month)
Avoid	0	2	4	0	0	1
Reduce	0	4	11	33	33	2
Transfer	0,3	6	17	67	67	4
Exploit	0,4	8	24	100	100	5

Figure 7.10 Output of design experiments and the effect of the mitigation plan on key performance indicators



	Customer complaint (%)	Tardiness in loading or unloading process (hours)	Working hours lost (hours)	Inaccuracy data entry (%)	Openstorage in warehouse (%)	Breakdown tools (times permonth)
Avoid	1	1	1	1	1	1
Reduce	1	2	3	2	2	2
Transfer	3	3	4	4	4	4
Exploit	4	4	4	5	5	5

Figure 7.11 Output of design experiments and the effect of the mitigation plan on key performance indicators on a scale of 1 to 5 (See Table 6.1)

7.6 Simulation modelling to manage material flow

Having discussed how to assess resilience in the fertiliser industry supply networks, this section addresses ways of reducing the tardiness in loading or unloading of material by managing material flow in the port as the fertiliser key supply network. This section presents a new application of the socio-technical system approach by applying it to a material flow system in the context of a broader supply network system (Utami et al., 2014b). Identification of key elements in the material flow system used the six perspectives of the Challenger and Clegg framework. The operational definitions of the six perspectives of material flow are:

a. Goal: to ensure the efficient flow of material through the port;

b. Procedure: standard operating procedures for material flow;

c. People: people in material flow;

d. Culture: administrative and production management process cycles;

e. Infrastructure: finished product warehouse and port loading area;

f. Technology: trucks as facilities for product distribution.

This research used the Enterprise Engineering Framework (McKay et al., 2009) to contextualize the different aspects of the research. The conceptual framework is summarised in Table 7.7.

Table 7.7 Conceptual frameworks for managing material flow in supply networks

	Define	**Develop**	**Deploy**
Purpose	How to manage material flow in the supply networks 1 To visualise product and process flows by using IDEF3		
Agency	The supply networks departments 2 To analyse the coordination between sales department, port departments and risk assessment department and to identify the biggest risk in material flow	To build conceptual and simulation modelling for managing material flow 4 To apply system dynamic and Agent based modelling	
Products and Services	Information availability for decision making process 3 To build prototype of simulation model for optimising material flow		How should the model be used for decision making? 5 To implement the model by using historical data from the fertiliser industry

The definitions of Table 7.7 are as follows:

<u>1. Define the purpose</u>

The first step was to define the purpose of building the tools or prototypes based on problems that existed in the system. The IDEF3 Process Capture Method (Li and C.Ying, 2009) was used in this thesis to visualise the processes and product flow in the fertiliser industry. As the focus of this research is on the influence of socio-technical changes, this study applies the IDEF-3 method to visualise product and process flows in order to better understand decision makers' perspectives. This can be seen from Figure 6.3 in Chapter 6 in box number 9. The Indonesian fertiliser industry needs to be resilient in order to deal with risk in the supply network, especially in the port area.

2. Define the agency

The second step was to define the system or departments in the material flow process, i.e. the Sales Department, the Risk Assessment Department and the Port Department. The fertiliser industry distributes products to consumers (farmers) based on government policy. The amount of fertiliser demand, delivery schedules, buffer stock and the amount of fertiliser to be shipped are dependent on government regulations that have been established previously. Thus, the industry applies a special delivery schedule that has been established by the Sales Departments; they are the Sales Department Region I which distributed fertiliser to the islands of Java and Bali; the Sales Department Region II which distributed fertiliser to the other islands (i.e. Kalimantan, Sumatra, Sulawesi, Nusa Tenggara and Papua). A further result of brainstorming with participants indicated that the greatest problem in material flow was maintaining operator performance in the unloading process of product from trucks into ships in the port area.

3. Define the outcome of the product or service

The third step was to define outcomes that would be generated to resolve the existing problems in the system. An outcome reported in this section is a prototype simulation model that is expected to help the decision maker in optimizing the process flow of material through the supply networks. By applying a socio-technical system approach and the enterprise engineering framework, the research assisted participants to determine the optimum value of variables in the supply network system to measure the loading time and the berth occupancy ratio. An agent-based simulation model was to be applied in this research.

4. Develop the tools or prototype

The fourth step was to determine how to achieve the outcome or prototype in step 3. This research applied agent-based model software to build models of material flow analysis. The product-handling operators are important agents in the material flow of the supply network. Therefore, their movements in processing loading or unloading were analysed. This research designed the agent-based modelling by using NetLogo 5.0.4 to visualise operator movement in handling the product from the trucks to the ships in the port.

5. Applying the tools to the case study

The case study was represented by a simulation model using historical data on material flow systems in the fertiliser supply network. Historical data from the fertiliser industry was used as input to the simulation model. Table 7.8 shows input variable names and values used in the agent-based model and Figure 7.12 illustrates a dynamic modeller of variables.

The flow of processes in the system modeller was arranged based on the flow of information and reporting procedure on the material flow process in the case study. The process was represented by a variable. For instance, administration time represents the process of reporting and recording the amount of products that will be distributed from warehouses to the trucks. This model assumed that the administration time was 24 hours. This variable was inserted as an input in the length of reporting process in the reporting cycle. The model assists decision makers to visualize the flow of information and material in the system by analysing and calculating the time for each variable.

Table 7.8 Variables and code of the agent-based model

Code/Slider	Value
Number-of-trucks	represent number of truck used, scale: 0 to 1000 (units)
Number-of-operators	represent number of people scale: 0 to 100 (person)
Number-of-stocks	represent number of products distributed, scale: 0 to 100000 (tons)
Number-of-ships	represent number of ships docked in the port, scale: 0 to 50 (units)
Number-of-warehouses	represent number of warehouses used, scale: 0 to 5 (units)
Number-of-departments	represent number of departments, scale: 0 to 30 (units)
Number-of-board_directors	represent number of decision makers, scale: 0 to 3 (person)

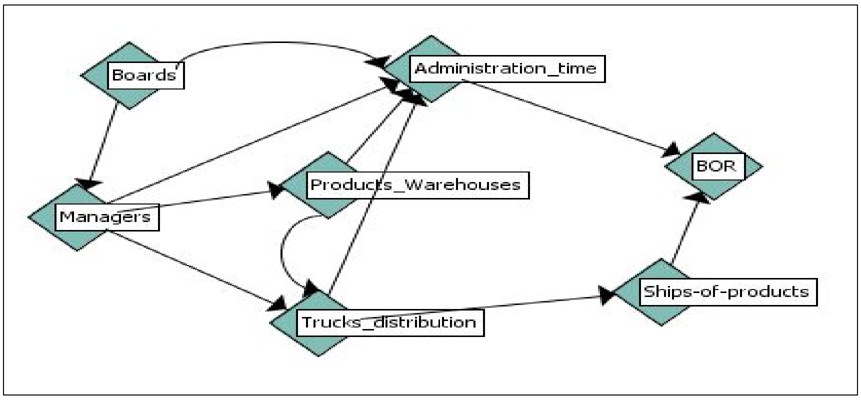


Figure 7.12 Material flow system cycle: administration and reporting process of material flow

The interfaces of the agent-based model developed for material flow optimization are illustrated in Figures E.11-E13 in Appendix E. Sliders at the interface of the model can be changed as the user desires. For example: the number of operators can be changed from zero to fifty or more. Sliders on the interface are used to set the values of the input variables. The graph shows the results of running the simulation model for loading time, number of operators, length of administration time, and of the berth occupancy ratio against an x-axis that represents time using NetLogo ticks. Face validation (Sargent, 2010; Liu et al., 2012) was used to validate the conceptual and simulation models. In the validation activities, people in the system were asked to review the model. In addition, the researcher conducted experiments using scenarios that changed variables in simulation modelling. An experiment was carried out to investigate the influence of variables changing to the loading time and the berth occupancy ratio.

The output of the simulation model in Table 7.9 presents the number of operators, the length of the material flow process and the percentage of berth occupancy ratio in five scenarios. Decision makers can use the output to determine the standard time of the loading process in order to achieve targets for the berth occupancy ratios. For instance, scenario one describes the berth occupancy ratio at 98.76%. The percentage will occur if decision makers employ fifteen operators in material flow and decide to use five trucks to transport fertiliser from three warehouses in the fertiliser industry to the port. As a result, administration time is 260 minutes and loading time is 531.60 minutes. On the other hand, in the second scenario, the berth occupancy ratio at 72.55% could be achieved if the material flow used 20 operators, 7 trucks and distributed fertiliser from one warehouse with the administration process at 200 minutes. By using those variables, loading time in port would be 401.05 minutes. These two scenarios show that the decision makers should increase the number of operators in order to decrease the berth occupancy ratio. However, as a further result of the simulation model, scenario five shows a different significant effect of variable changes on the berth occupancy ratio. The berth occupancy ratio declined from 98.76% in scenario one to 80.50% in scenario five. This percentage can be accomplished by employing 15 people and using six trucks and the decision makers should transport the fertiliser from two warehouses in order to minimize administration time and result in the same length of loading time as scenario one. Thus, scenario five is the best scenario to obtain the optimum value of variables and minimise the berth occupancy ratio. The results of the scenarios were used to inform the decision-makers in investigating the effects of their decisions in considering the impact of potential variable changes on the flow of materials within the port and achieve the optimum percentage of berth occupancy ratio.

Table 7.9 The output of the simulation model in five scenarios

Fertiliser (Tons)	Trucks (Unit)	Ware-houses (Unit)	Depart-ments (Unit)	Board Directors (Person)	Loading Time (Minute)	Opera-tors (Person)	Admin-Time (Minute)	BOR (%)
39696	5	3	3	2	531.60	15	260	98.76
40065	7	1	1	1	401.05	20	200	72.55
39747	10	4	6	1	664.42	12	420	94.20
40032	6	2	1	1	499.85	16	200	80.64
39999	6	2	1	2	531.15	15	220	80.50

7.7 Discussion

It was suggested that the issue of subsidised fertiliser shortages for farmers, especially in the planting season often occurs in Indonesia, and was due to a delay in supply from the industry to distributors. This issue is a major problem, since as a state-owned industry, the Indonesian fertiliser industry has a goal to achieve customer satisfaction. Results of interviews with decision makers in the Indonesian fertiliser industry found that delays in the supply of fertiliser to the distributors were due to a disturbance in the infrastructure.

Unloading of raw materials from suppliers and loading fertiliser from warehouses to the ships which will transport fertiliser to distributors, is carried out in the port area. These phenomenon lead to the port being an essential part of the infrastructure for stabilising the fertiliser supply network. Disturbances occurring in the port area will affect distribution and then also cause an impact on farmers as the end users of subsidised fertiliser. The Indonesian fertiliser industry defines the disturbance that causes negative impact, as a risk. Based on data collected, risks in the supply network are triggered by fluctuation of the port availability. The Indonesian fertiliser industry applies risk assessment to overcome this issue. The decision makers argue that by identifying risk, the cause of risk could be minimised. The report on risk assessment is being used as a reference to identify operational problems which occurred.

The supply network is a complex system because it consists of different components, such as human, equipment, information, and decision-making. Therefore, a comprehensive analysis of supply networks is needed in an effort to reduce risk and improve the resilience of supply networks. In this thesis, resilience is defined as the ability to respond to risk by maintaining social and technical resources to reduce and control risk.

This research generates an approach to assess the resilience of supply networks by synthesising information from the literature and the results of interviews with practitioners in the Indonesian fertiliser industry. The approach commences with a theoretical framework construction based on literature reviewed, as presented in Chapter 5. Then, the theoretical framework is applied to the case study by adjusting variables to operational definition from real world data. The result of this process is the conceptual model in Chapter 6. Next, the conceptual model is visualised into a simulation model in Chapter 7, in order to aid decision makers to easily understand and employ the approach. Table 7.10 describes the linking and translation of variable in the theoretical framework, conceptual model and simulation model.

Table 7.10 Translation of theoretical framework into conceptual and simulation model

Element of theoretical Framework (Figure 5.2)	Corresponding element in the conceptual model to support resilience assessment in supply networks (Figure 6.4)	Corresponding element in the conceptual model to support resilience assessment in Indonesian fertiliser industry supply networks (Figure 6.5)	Implementation of elements of (Figure 6.5 in the initial Simulation model (Figure 7.2) Simulation code: See Appendix D	Implementation of elements of (Figure 6.5 in the improved simulation model (Figure 7.3) Simulation code: See Appendix D
Infrastructure availability and changes	Infrastructure: Infrastructure elements Infrastructure in supply network	T-port Berth occupancy ration of T-port Loading /unloading time in T-port	Port	BOR_Port
- Risk - Impact	Supply network element	Supply network element	Risk in port For example: supplier phosphate	Risk_of_Method Risk_of_People Risk_of_Culture Risk_of_Goal Risk_of_Techno logy Risk_of_Infra Structure
- Risk identification - Risk analysis	The risk assessment in supply network	The risk assessment in supply network	Risk in port	
Risk assessment	The risk assessment in supply network	The risk assessment in supply network	Risk in port	
- Probability of risk - Degree of impact	The risk assessment aspect definition	The risk assessment aspect definition	Risk in port	
Information management	Information for decision making	Information for decision making	Goal of port efficiency	BOR_Port
Risk mitigation	Risk mitigation	Risk mitigation	Risk in port	Mitigation

Continues on next page

Table 7.10 Continued

Element of theoretical Framework (Figure 5.2)	Corresponding element in the conceptual model to support resilience assessment in supply networks (Figure 6.4)	Corresponding element in the conceptual model to support resilience assessment in Indonesian fertiliser industry supply networks (Figure 6.5)	Implementation of elements of (Figure 6.5 in the initial Simulation model (Figure 7.2) Simulation code: See Appendix D	Implementation of elements of (Figure 6.5 in the improved simulation model (Figure 7.3) Simulation code: See Appendix D
Resilience supply network	Resilience assessment	Resilience assessment	KPI	KPI
Key performance indicator	Resilience indicator	Customer complaint Inaccuracies data entry Working hours lost Breakdown tools Tardiness loading/unloading process Open storage in warehouse	For example: KPI I; truck available & truck needed	KPI_Goal-customer_complaint KPI_People-working_hours_lost KPI_Culture-Inacuraties_data_entry KPI_Technology-Tools_breakdown KPI_Infrastructure-Openstorage_in_warehouse KPI_Method-loading_unloading_time
Resilience dimension	Interoperability Safety Reliability Availability	Interoperability Safety Reliability Availability	Interoperability: people & training Safety: Maintenance and culture maintenance Reliability: port expansion & delivery method Availability: Truck availability & sub contract	Output of simulation model (Appendix E)
Strategy	Decision making element	Decision making element	Goal of port efficiency	Example application of strategy and controlling see Section 7.6
Controlling	Information for decision making	Information for decision making	KPI	
Constraints and resources identification: Operational definition of risk and key performance indicators by applying the six perspectives of socio-technical system (Figure 5.2)	Socio technical element in the risk assessment Distribution region	Socio technical element in the risk assessment Distribution region	Change rate	

The approach must be validated to ensure that it satisfies the decision makers' requirements. The results of validation activities showed that the approach is deemed valid because it achieved the validation criteria.

Recap of the validation results is as follows:

1. The resilience assessment approach was in accordance with the industry's goal and aids decision makers in achieving goals. The key performance indicators identified were based on decision makers' requirements. The goal, as one of the key performance indicators, is to maintain or achieve a targeted level of customer satisfaction. This definition was determined based on the Indonesian fertiliser industry's goal, to achieve customers' satisfaction.

2. The data required were available in the industry. The data used in this approach was key people's answers to the semi-structured questionnaire and supported by historical data available such as, the risk assessment report, the port management report, and the annual report.

3. The approach aids decision makers in predicting the level of risk and it can be used as a reference in determining the risk management strategy for the future. Outputs of the simulation model provide the level of risk in six components of key performance indicators. This output can be used by decision makers to predict the level of risk based on berth occupancy ratio fluctuation.

4. The result of the approach can be used as a material for internal controls in order to support the operational activities. The approach can aid decision makers in reviewing the effect of infrastructure fluctuation on the supply network performance. By translating business process into the conceptual model, the approach helps decision makers to evaluate the current level of resilience as internal control.

5. The output of the approach can be used to review the business plan, such as the expansion plan of the infrastructure facilities or optimising the allocation of human resources and technology. This criterion can be achieved by applying a stochastic model in the design experiment of the simulation model. The output of the simulation model can aid decision makers to optimise resource allocation in order to maintain material flow in the port area. The results of the resilience assessment can be used to reflect the current level of resilience as a reference in establishing a business plan.

Even though the model was generated to solve a specific problem in the Indonesian fertiliser industry, this model can also be generalised and applied to other industries, by adjusting the variables in the model. More importantly, availability of data to support this model is a main requirement in order to apply the approach.

7.8 Summary

The simulation model reported in this chapter was an implementation of the conceptual model from Chapter 6. Input of the simulation model was the historical data from the case study. The simulation model in this research was built using software NetLogo 5.0.4. The output of the simulation model could be used to help decision makers to analyse the risks and assess resilience in the Indonesian fertiliser industry supply network. Output from the model can be used as input to execution of the simulation model.

This research presents a new resilience assessment approach that includes human and technical factors in supply network operation flows. Outputs of the simulation model showed the effect varying values in the material flow system on the berth occupancy ratio of the port. The model can assist decision makers in improving the material flow system in order to reduce loading time and determine the percentage of berth occupancy ratio in the port. The standard time for the loading process, as the output of the simulation model, can be used as information to determine and reduce target loading times and the number of operators needed to accomplish the material flow process. In addition, this model can be used to aid decision makers in assessing and predicting material flow performance in their supply networks. The model was reviewed with the key people in the Indonesian fertiliser industry who confirmed that the model was suitable to be used to assess resilience in the Indonesian fertiliser industry.

Chapter 8
Conclusions and Recommendation for Future Research

Supply network failures in the Indonesian fertiliser industry have a serious negative impact on agricultural production especially for small and medium sized farms. These failures arise from risks, particularly in the transport system and its infrastructure. Improving supply network resilience reduces the impact of risks and so improves the situation of the small and medium sized farms in Indonesia.

The aim of this research was to propose and evaluate an approach for assessing the resilience of Indonesian supply networks to changes in infrastructure availability. A theoretical framework, based on a synthesis of literature and interviews with industry practitioners, was generated. Key performance indicators of resilience were defined by incorporating the six perspectives of the socio-technical systems (goals, people, procedures, culture, infrastructure and technology) into a theoretical framework. The theoretical framework was used to inform the construction of a conceptual model that was populated with data from a real-world case study. A simulation model was then built to translate the conceptual model into a practical application. The simulation model was used to investigate the results of resilience assessment in different scenarios and predict levels of risk.

This research contributes to the need to identify requirements to build improved agility and flexibility into resilience strategies as reported by the World Economic Forum in 2013 (Agenda Industry, 2013). According to this report, more than 80% of companies had concerns related to supply chain resilience. This research provides an approach that can be used to aid identification of key performance indicators of resilience in supply networks. The findings of this research can be used to help managers predict the level of risk in supply networks and in determining resource allocation strategies to maintain material flow. Moreover, the design of the resilience assessment approach considered the needs of managers and other decision makers, making the approach feasible for adoption within industry and use by managers.

The research has potential benefits for policy makers, especially the Ministry of Agriculture and the Ministry of Industry of Indonesia, in providing a systematic way of analysing and assessing risk in the supply network of subsidised fertiliser. The approach could also be used by the Ministry of

Natural Resources in managing the subsidised gas supply network, and by the Ministry of Trade in managing the subsidised rice supply network. The simulation model established in this study could also be used as a tool to assess the current condition of a supply network, and its output used as a baseline in the planning of future supply networks.

8.1 Contribution to knowledge

The contribution to knowledge is reported here against the objectives given in Chapter 1.

Objective (1): To characterise key dimensions of resilience based on the literature.

The definition of supply network resilience used in this research was, "the ability of a network to respond to disturbance by maintaining social and technical resources to reduce and control risk." Resilience assessment methods and tools are needed to help managers to predict the level of risk and resilience in the supply network. This research focused on the availability of a port. The following aspects of socio-technical systems were introduced to the key people in the Indonesian fertiliser industry: goal, process or procedure, culture, technology, building, and people. Discussion with the key people led to the conclusion that the six aspects could be used as key performance indicators in assessing resilience. Key performance indicators were identified from qualitative data (collected through interviews with the key industry stakeholders) and quantitative data (historical reports from the Indonesian fertiliser industry).

Resilience dimensions were defined from literature reviewed and interviews with key people. The following resilience dimensions were identified through this research.

- Interoperability: integration of a diverse collection of sub-systems to collaborate in order to achieve the overall goal of the system.
- Safety: the ability to protect against failure or damage.
- Reliability: continuity in achieving targets.
- Availability: the availability of resources in dealing with system changes.

Objective (2): to define a case study of the Indonesian fertiliser industry for use in the assessment of the resilience approach proposed.

As an archipelago country, the geographic structure of Indonesia influences its supply network performance. Over 50% of the population of Indonesia are farmers (50.21%) (The Indonesian Statistics Centre Bureau, 2013), and the availability of fertiliser is critical to farmers, especially during the planting season. The Indonesian fertiliser industry, which produces subsidised fertiliser for small and medium sized farms, is an important industry to support the welfare of the farmers. In 2011, the Indonesian fertiliser industry reported a lack of subsidised fertiliser available to farmers during planting time due to delays in the distribution of fertiliser from the industry to farmers. This problem was caused by delays in the transportation system. The main infrastructure of the transport system is the port. Delays in the port had a detrimental impact on the resilience of the supply network. Thus, an in-depth study of the Indonesian fertiliser industry supply network was proposed to enable managers to improve the performance of the supply network by assessing supply network resilience related to infrastructure availability changes.

The port management of the Indonesian fertiliser industry uses the berth occupancy ratio as a measure of port availability. The berth occupancy ratio target is 70%, based on the United Nations Conference on Trade and Development-UNCTAD, where berth occupancy ratios higher than 70% were regarded as a sign of congestion, while lower than 70% signified under-utilization of the port. Monthly berth occupancy ratios of the Indonesian fertiliser industry's port from June to August 2013 were 90.94%, 84.95% and 86.71% respectively. These data indicate that there was congestion in the port area. Based on interviews with key people, the congestion led to delays in the distribution of fertilisers from the industry, ultimately to farmers.

Objective (3): to identify key requirements for an approach for assessing the resilience of Indonesian fertiliser industry supply networks to infrastructure changes.

Results from interviews with supply network managers highlighted five requirements for the resilience assessment approach that was to be established as part of this research.

1) The assessment needed to accommodate the goal of the supply network, in this case, to deliver fertiliser to farmers.
2) The approach should use data that is already available to users and their organisations.

3) The approach should aid decision makers in predicting supply network risk and be useful in exploring future risk management strategies.

4) The output of the approach should provide information to inform auditing processes and reporting of operational activities.

5) The output of the approach should inform the adjustment of business plans, such as expansion plans for infrastructure facilities or optimising the allocation of human resources and technology.

Objective (4): to propose an approach for assessing the resilience of Indonesian fertiliser industry supply networks to infrastructure changes.

A theoretical framework was established based on a synthesis of literature and interviews with industry practitioners. The theoretical framework was verified and validated through the construction of conceptual and simulation models. The conceptual model was populated with data from a real-world case study taken from the Indonesian fertiliser industry. A simulation model was then built to translate the conceptual model into a practical application. The simulation model was used to investigate the results of resilience assessment in different scenarios and predict levels of risk. The approach accommodates social and technical factors in the supply network system.

Objective (5): to evaluate the proposed approach using the case study and a prototype software implementation.

The approach was evaluated in two simulation prototype models. The first simulation model was presented to key people in the Indonesian fertiliser industry. Based on discussions with these people, the suitability of the first simulation model (see Figure 7.2) was confirmed. However, the user interface of the model needed improvement. Specifically, they suggested that presentation of the variables might be rearranged so they were more readable for users. The researcher improved the model, then this was again evaluated with the key people who suggested adding a new variable for the model such as product safety, because the Indonesian fertiliser industry was starting to consider product safety as an important factor. This highlighted a need for flexibility in the simulation model established in this research, because adding a new variable would require corresponding changes to the conceptual and simulation model and additional case study data.

8.2 Limitations of this research

Limitations of this research are categorised into four key areas: research method used, choice of case study, data analysis, and verification and validation of models in this research are discussed in this section.

8.2.1 Research method

The case study method narrowed down the scope of the research by focusing on the particular case of the Indonesian fertiliser industry supply network. This was necessary because this research resolve a specific process for Indonesian fertiliser industry, but it means that further work would be needed to evaluate the wider applicability of the proposed approach. Two semi-structured questionnaires were used to collect data. One was used to identify the requirements of decision makers for an approach to assess resilience. The second questionnaire was used as a tool to verify and validate the approach. Results of interviews based on the questionnaire were mainly qualitative. The researcher used additional quantitative information, from historical data in industry and government reports.

8.2.2 Choice of case study

This research analysed the port as the main infrastructure facility in the supply network. The Indonesian fertiliser industry is governed by the Indonesian government so the structure of the supply network tends to be stable and is managed by government regulations. The geographical characteristics of Indonesia influence the supply network structure and flow. Thus, the resilience assessment approach generated in this research is likely to be applicable to other supply networks, which have similar geographical characteristics as Indonesia. Further work would be needed to explore its wider applicability.

Data availability was one of the criteria used to ensure that the resilience assessment approach could be applied practically. This research used two reports from the Indonesian fertiliser industry: the Risk Assessment and the Port Management. Key performance indicators and dimensions of resilience in the resilience assessment were defined based on these reports and confirmed with key people in the industry. Comparable reports would be needed if the approach were applied to other supply networks and sectors.

8.2.3 Data analysis

This research applied interpolation functions to quantify levels of risk, and these were then used as input in the simulation model. Design experiments of four mitigation scenarios were developed to explore the level of future risk. The interpolation functions that were developed against the historical data from the real supply network system could be used to predict the level of resilience in the conceptual and simulation models. However, more work is potentially needed to assess whether the resilience assessment approach could be reliably applied by different people in other situations.

Even though the interpolation functions in this research used minimum and maximum levels of historical data from the fertiliser industry, it could provide precise prediction of the risk assessment and key performance indicator levels in the models. However, the measurement and prediction process of risk assessment and quantification of the key performance indicators in the research could have been improved by using spline function approximation. This method has the advantage of allowing a curve to be defined which can improve the precision of approximation (Jeffrey, 2005).

The NetLogo 5.0.4 software agent-based simulation was used to build a dynamic agent based model. A combination of agent-based and discrete event simulation could be applied to improve the performance of the simulation model. The combination of two kinds of simulation method could help in presenting broader and more detailed information on the supply network elements, and material and information flows.

8.2.4 Verification and validation of models

The key decision-makers who participated in the data collection process were from four departments. Verification and validation of the models was carried out through interviews with the same participants for each model (see Section 3.2.3). The involvement of key decision makers from other departments in the Indonesian fertiliser industry could have been possible if the researcher had been given more time and the necessary permissions. The involvement of experts from academia as verifiers and validators of the models would have also been important. It could be very useful to obtain views from both sides: practitioners and academia.

The conceptual model (see Chapter 6) and simulation model (see Chapter 7) were generated based on the theoretical framework (see Chapter 5). As a result, any limitations in the theoretical framework would manifest themselves in the subsequent models and, therefore, in the results.

Validation of the conceptual and simulation models used the face validity method. The key people in the Indonesian fertiliser industry were asked to review the models by responding to the validation and verification questionnaire (see Appendix C). Implementation of this validation method involved a combination of other validation methods from Sargent (2010). This included the following:

- Animation method: results from the operation of the simulation model were displayed graphically when the simulation model ran.
- Degenerate test: designing experimental scenarios based on four mitigation plans from historical data in the Indonesian fertiliser industry.
- Event method: comparing the influence of risk level with the berth occupancy ratio level.
- Operational graphic: output from the simulation model was presented graphically in the interface of the simulation model (see Section 7.2.2).
- Traces: variables from the simulation model can be traced in the simulation code. The code could also be changed based on the design experiment in the scenarios (see Appendix D).

Historical data (from the Risk Assessment report and the Port Management report) were used to validate conceptual and simulation models. Then the key people were asked to review the output of the model. The simulation model was evaluated by being run with several replications of the berth occupancy ratio level (See Section 7.2.1). Sargent suggested other verification and validation methods that could be implemented in the future work.

8.3 Directions for future research

The theoretical framework was generated based on interviews and synthesis of the literature. The interviews were carried out with key decision-makers from the Risk Management Department, the Port Management Department, The Procurement Department, Sales Department Region I, and Sales Department Region II in the Indonesian fertiliser industry. This resulted in the elements of the theoretical framework being in accordance with their views. The inclusion of a wider range of decision-makers representing a wider range of stakeholders would likely change the elements of the theoretical framework. People who could be involved in the interviews include the key people from the Production Department, the Maintenance Department, and the Human Resources Department.

The research analysed the key performance indicators based on six perspectives of the socio-technical framework. As recommended by the World Economic Forum (Agenda Industry, 2013), to establish a resilient supply network in today's globalised and interconnected world, resilience assessment must involve other factors, such as economic, social, environmental and governmental. Risks in a supply network have a strong relationship with vulnerabilities in operational activities. The supply network system must share responsibility and resilience management with other departments in the industry and with private and public sectors, such as government, financial institutions and local communities. Collaboration with other organisations could help industry to prepare for and respond to a broad range of potential disruptions in the future. For this reason, further research could extend the key performance indicators to include other factors such as product quality, product safety, finance, and policy to develop the resilience assessment approach in order to support the Indonesian industry competing in the ASEAN Free Trade Area 2016.

Currently, Indonesia has a large number of small and medium sized enterprises, which support the Indonesian economy. Indonesia has a unique characteristic of geographical area. This characteristic also influences the supply network resilience in small and medium sized companies. The research could be used to assess their supply network resilience, including small and medium sized companies. In the short term, the resilience assessment introduced in this research could be developed by adding new variables related to social, economic, and environmental factors.

This research found that material handling in the port area is a crucial problem that leads to risk in the supply network. In the medium term (6-18 months) time frame, research could be continued in re-designing standard operating procedures to improve the material-handling system in the port area. The Indonesian fertiliser industry could be chosen as a case study.

Based on findings in this research that risk in the port area was caused by operators being unable to carry out standard operating procedures in the port area, in the longer term, sustainable design of material flow in the port could be addressed. Such research could analyse the influence of operators' behaviour on material flow performance.

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Appendix A
Semi-structured Questionnaire

The Assessment of resilience in Indonesian Supply networks

My Name is Issa and I am currently a doctoral candidate at School of Mechanical Engineering, University of Leeds United Kingdom. I am conducting research in to the topic "The Assessment of Resilience in Indonesian Supply networks."
This research is intended to help organizations to analyse and evaluate their resilience in supply networks. The questionnaire is designed to be best answered by the participant who have responsible for risk and performance in supply network in your organization. The research participants are decision makers in Indonesia supply network, i.e. supply network managers in industries. Moreover, the person should preferably have background knowledge on supply networks performance and the adoption of Logistic regulation 26 the government of Indonesia.
Most of the questions in the questionnaire simply require you to tick the appropriate answer (box). The questionnaire should take you approximately fifteen to thirty minutes to complete. I would like to inform that participants will take no risks being involved in this research since confidentiality would be fully guaranteed and this research will be used only for academic purposes.
The potential benefits of this research for the participants are the participants will know the resilience of supply network at their industry. In addition they can plan the supply networks strategy to improve supply networks performance and minimize risks in uncertainty environment. Moreover, the result will give contribution to Indonesian economic development.
Thank you for your time and cooperation in completing this questionnaire

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General Information

Organization name:
(Optional)

Please tick your level in your organization

- ☐ Owner (You are the owner of the organization or industries)
- ☐ Top level manager (You have responsibility and job description as Top Level manager)
- ☐ Middle manager (You have responsibility and job description as Middle manager)
- ☐ Low manager (You have responsibility and job description as Low manager)
- ☐ Staff (You have responsibility and job description as staff)
- ☐ Others: ______

Please tick your function in your organization

- ☐ Purchasing (Your organization or department buys raw material from supplier)
- ☐ Marketing (Your organization or department sells product of your organization)
- ☐ Manufacturing (Your organization or department produces product)
- ☐ Finance/credit (Your organization or department has the responsibility in finance)
- ☐ Distribution (Your organization or department distributes products)
- ☐ Transportation (Your organization or department transports products)
- ☐ Quality (Your organization or department inspects products)
- ☐ Product development (Your organization or department develops products)
- ☐ Researcher (Your organization or department carry out research in supply networks)
- ☐ Social and community development (Your organization or department develops and supports community)
- ☐ Others: ______

Please tick type of your product in your organization

- ☐ Make to stock (Your organization produces mass production)
- ☐ Make to order (Your organization produces product based on order from consumers)

Where are location of your stakeholders?

(You can tick more than one option and please explain your stakeholders' location in the box bellow)

- ☐ Madura Island
- ☐ East Java
- ☐ Java Island
- ☐ Indonesia
- ☐ Southeast Asia
- ☐ Asia
- ☐ International
- ☐ Please explain location of your stakeholders: ☐

How many employees does your organization have?

- ☐ None
- ☐ 1-10
- ☐ 11-100
- ☐ 101-250
- ☐ 251-1000
- ☐ 1001 over

The risks in Indonesian Supply networks

What is your organization role in supply network?

- ☐ Supplier (Your organization supply raw material to industries)
- ☐ Distributor (Tour organization distributes finished products)
- ☐ Retailer (Your organization sells finished products)
- ☐ Manufacture (Your organization produces products)
- ☐ Warehouse (Your organization stores finished product)
- ☐ Agent (Your organization stores and distributes finished product from distributors to end consumers)
- ☐ End customers (your organization uses the finished products)
- ☐ Exporter (Your organization exports finished product)

☐ Transportation provider (Your organization provides transportation services for industries and distributors)

☐ Collector (Your organization collects raw material from farmers

☐ Farmer (You grow and harvest the herb plants/raw materials)

☐ Others: ☐

What is your organization's adoption stage for Regulation 26, 2012 about Blue print of Indonesian logistic systems?
(Please thick only one option)

☐ Has not adopted and is not considering

☐ Is considering the adoption

☐ Has decided to adopt in future

☐ Has adopted

What are the crucial factors that influence the supply networks?
(You can thick more than one option and please give brief explanation in the box bellow)

☐ Infrastructure of transportation and distribution

☐ Information technology and communications

☐ Regulation and policy

☐ Human resources

☐ Institutional/organizational issue

☐ Logistic service providers

☐ Environmental (e.g. climate change)

☐ Financial

☐ Commodity

☐ Sustainable relationship

☐ Oder fulfilment cycle time

☐ Proximity (Geography, Electric, Organization)

☐ Social issues

☐ Geography

☐ Others: ☐

Please give your brief explanation regarding in the following questions:

1. What is the influence of relationship with suppliers in your supply networks?
2. How many suppliers do you have and where are their locations?
3. How many distributors do you have and where are their locations?
4. How many costumers do you have and where are their locations?
5. How do you transport and distribute your raw materials and products?
6. How long have your organization had relationship with suppliers, distributors and customers?
7. How do you measure the performance of supply networks?
8. What are the most important factors in supply networks performance?
9. How do you identify the risk in supply networks?
10. What is the influence of infrastructure availability and changes in supply networks performance?
11. How does the Indonesian government support supply networks in term of infrastructure availability and changes?
12. How does the Non-governmental organization (NGO/WHO) support supply networks in term of infrastructure availability and changes?
13. How does the financial institution support supply networks in term of infrastructure availability and changes?
14. How does the researcher institutions support supply networks in term of infrastructure availability and changes?

Appendix B
List of risk in the Indonesian fertiliser industry supply network

Table B.1 Risks in the supply of raw material

No	Risk	Cause	Description	Impact	Mitigation	Score		Risk assessment
						Probability	Impact	(D × P)
1	Queuing of the ships in docking and unloading in T shaped port and destination port	Loading point to truck	- Sea siltation - Unreliable unloading equipment: equipment leaks - The arrival of the ship is not on schedule - Lack of power checker - Lack of unloading personnel and forklift	- Delay of loading from port to truck or train - Raw material loses - Delay in raw materials supply affect the production rate - Accelerating equipment damage	- Adding checker - Adding loading/ unloading labor and forklift - Adding transportation facilities (truck, train, ships) - Preventive maintenance - Ship arrival scheduling - Preparing reliability of unloading facilities	3	2	6
2	Port expansion	Lack of pier capacity	Dock expansion to increase capacity of pier storage. This project takes more than one year.	- Production operations disturbance	- reconditioning loading and unloading equipment - continuing dock dredging - Planning of human resources fulfillment and CSU operator	4	4	16

Risks in the supply of raw material (Continued)

3	Traffic congestion on the highway	Road/ Infrastructure capacity	Traffic congestion on the highway from port to fertiliser industry	- Delay in raw materials supply affect the production rate - Target is not achieved - Incurred relocation cost	- Adding transportation facilities (truck, train, ships) - Adding drivers	4	4	16
4	Raw materials, merchandise and chemicals substance be delivered late	- Changes in material requirement planning - Changes in production and marketing planning - Transportation facilities	unpredictable demand, changes in demand of raw material Difficulty to get freight	- Stock out of raw material - raw material cannot be used as planned - Operational and marketing activities disrupted - Procurement department did not obtain competitive prices for raw material	- Coordination with production department and distributors - Procurement planning based on production and marketing planning - Forecast the world economic condition in the future - Long term contract with transportation service provider	4	4	16
5	Dependence on a supplier	- The pattern of purchasing - Lack of information about suppliers	- brand of raw materials from one source / supplier - No price comparison - Referring to a specific brand /	- The price is expensive and weak negotiating position	- The pattern of direct election for suppliers - Tender / auction is limited to several suppliers - Exchange of information between	2	2	4

			Designating existing brand		plant fertiliser, searching from the internet - Generalization of products specification (giving some reference brand in PR)			
6	Purchase from many suppliers (multi-sourcing)	- The amount of raw material - Type of raw material	- large amounts of raw material requirement -the purchased goods assortment	Quality goods inconsistent / varied -occur crowded at port / demurrage	-coordination with the Department of Laboratory and process to perform lab tests. And check the composition of raw materials and other supporting materials that are used - buy alternative raw material substitution	2	2	4
7	Unsafe delivery of raw material	-unqualified forwarder -Terms of Delivery in Purchasing Order	Forwarder-election by supplier Filing insurance policy after the goods arrive at the port of destination of goods lost	Loss of goods, loss to the company establish contract with qualified forwarder	Selectively apply insurance policy before the goods are dispatched	3	1	3
8	Procurement services late	The work plan Evaluation Requireme nts	- Evaluation of techniques - Procurement department designate specific brands - Owner Estimates less	-Evaluation of technical user for too long - suppliers cannot meet the requirements (single supplier) relocation budget - Create a common specification OE refers to the time-limits	Create a common specification order estimates refers to the time-limits	2	2	4

Table B.2 Risks in the Port Department

No	Risk	Cause	Impact	Mitigation planning	Impact	Probability	Risk
1	Demurrage in loading activity	Unloading equipment and conveyor leaks	Loss of raw materials, the environment becomes dirty, thus speeding up raw material unloading equipment failure	Repair or replace the unloading improving preventive maintenance increasing the frequency of cleaning tools	3	2	6
2	Delay in loading activity	The arrival of the ship is not in accordance with procedures	Incurring demurrage delayed of raw materials supply that can affect the rate of production	Ship arrival schedule prepare the reliability of loading equipment increase operational costs	4	4	16
3	Damage to equipment	Sling off and grab corrosion/leak, wheel and rail boggle corrosion	Delay in unloading activity	Preventive maintenance	3	5	15
4	Damage to equipment and dock	Chain and pen broken due to corrosion and lack of capacity	Damaging the ship and the dock the collision	Periodic inspection and gradual improvement	4	4	16
5	Interruptions in operation	Continuous ship un-loader (CSU): - Vertical screw, flight bearing and cover bearing worn out, shaft intermediate screw horizontal broken	Demurrage, vibration, interrupt loading and unloading activity	Time based management, Spare part preparation	4	4	16

6	conveyor system disruption	Broken conveyor belt / roller jams, tail, head pulley broken and structure / walk and way corroded	Demurrage Workplace accident	Spare part preparation Maintenance	4	4	16
7	Impaired equipment	Dock pole corroded due to poor functioning of cathode protection	Corroded pilings cause shorter equipment functions	Repair the corroded pier pole	5	1	5
8	Damage to equipment docks, morning dolphin because accidentally made to collide ships	- dolphin morning accidentally made to collide ships - the weather: heavy rain when demand is high fertiliser supply - queuing and congestion ships to dock and loading / unloading at the T shaped port T and the destination port	The dock security system does not work	Replacement/repair morning dolphin	5	3	15
9	Impaired dock operations	Capacity of ships 25,000 DWT cause silting of sea in the dock area	Ships have difficulty to dock at port	Dragging the port	3	5	15

Table B.3 Risk in The Sales Department Region I

No	Risk	Cause	Description	Impact	Mitigation	Score		Risk assessment
						Probability	Impact	(D × P)
1	Queuing of the ships in docking and unloading in T shaped port and destination port	Loading point from trucks to ships	- Sea siltation - Unreliable unloading and loading equipment: equipment leaks - The departure of the ship is not on schedule - Lack of power checker - Lack of unloading personnel and forklift	- Delay of unloading from truck to port - Delay in fertiliser distribution affect stock availability in DC - Customers complaint - Waiting time in order fulfillment process	- Adding checker - Adding loading/ unloading labor and forklift - Adding transportation facilities (truck, train, ships) - Preventive maintenance - Ship departure scheduling - Preparing reliability of unloading facilities	4	4	16
2	Port expansion	Lack of pier capacity	Dock expansion to increase capacity of pier storage. This project takes more than one year.	- Delay in fertiliser distribution affect stock availability in DC - Customers complaint - Waiting time in order fulfillment process	- Utilize other ports located around the fertiliser industry for loading fertiliser into the ships - Conducting surveys and data collection of delivery time in dock located on outside of Java region. Delivery time is measured from loading activities in the fertiliser industry to farmers (Line IV). It is	5	3	15

					calculated to determine the optimal amount of buffer stock in DC. - To strive for fertiliser as a priority item in loading process destination ports - conduct socialization of the dock expansion project to farmers - To support farmers in identifying the needs of fertiliser in the group definitive plan			
3	Traffic congestion on the highway	Road/ Infrastructure capacity	Traffic congestion on the highway from fertiliser industry to DC, distributors, retailer and farmers	- Target is not achieved	- Adding transportation facilities (truck, train, ships) - Add truck drivers - Establish a better delivery planning - conduct internal coordination between distribution manager, risk management manager and marketing manager	3	5	15
4.	New bridge construction	New bridge construction	Construction of new bridge in region I	- caused changes in the regional shipping lines of fertiliser - changes in delivery time - changes in	- Establish a better delivery planning - conduct internal coordination between distribution manager, risk management manager and	3	2	6

				determination of truck capacity and buffer stock in DC	marketing manager			
5	Stock of fertiliser in open storage	Excessive inventory	Over stock of due to limitation of warehouse capacity. the fertiliser is kept in open storage	- A number of fertiliser damaged due to sun and rain in open storage	- Fertiliser stored in open storage and distributed first	4	2	8
6	Data of fertiliser stock in warehouse does not reflect the real condition of fertiliser availability	Reporting system	- Losing of stock records -Less of supervision - Delays in receiving reports of stock from distributor centers, distributors, retailer to the fertiliser industry	Inaccuracy in decision-making process in sales and distribution department	-Stock-opname conducted only once per month by the officials warehouses - Stock opname conducted only once in every 6 months by warehouses manager of the fertiliser industry	3	2	6
7	Fertiliser damaged or shrink in distribution centers	Terms handling	The provisions are not implemented e.g.: - Use hook - Warehouse area is dirty - re bag time is longer	- Consumer complaint - Brand image decreased significantly	-Establish procedures for handling fertiliser in distribution centres and carefully monitor the implementation	4	1	4
8	The monitoring system of delivery activity has	The monitoring system	Lack of reporting facilities New warehouse have not yet had on line / not	Inaccurate decision making in sales and distribution	Preparing online reporting tool	3	2	6

	not been optimal.		installed the online program for stock report. computer-trouble					
9	Original fertiliser less weight	Fertiliser weight in bag is less than standard	Packing in the bagging unit production fertiliser weight in bag is less than standard	Consumers complaint brand image decrease significantly Loss of delivery time lead to re bag costs	Internal coordination with production department to determine in bag weight standard of fertiliser	3	2	6
10	Fertiliser is lost in delivery process to distribution center	Monitorin g stock in delivery process	Fertiliser is lost in delivery process to distribution centre monitoring stock in delivery process	The amount of fertiliser decreased when it loaded in distribution centre. the fertiliser is loss in delivery process Loss of fertiliser delivered to distribution centre Loss of delivery time	Establish contract to manage the amount of fertiliser during delivery process	3	1	3
11	Excessive stock in the fertiliser industry due to climate change	Excessiv e stock in the fertiliser industry	Climate change	Operating cost increase open storage cause fertiliser potential damage	Keep fertiliser in open storage in the fertiliser industry Decide over capacity delivery and storage in decision center	4	2	8
12	Damage/shri nkage of fertiliser in the fertiliser industry warehouse	Torn fertiliser bag	Lack quality of plastic bag nails pallet torn	consumer complaint brand image decrease	Coordination with the Department of Procurement of raw materials in order to provide good quality fertiliser bag replace nails pallet with	5	1	5

					plastic pallet			
13	Stock out in the fertiliser industry	Stock out in the fertiliser industry warehouse due to unavailability transportation facilities	Unavailable transportation facilities Changes in sales plan Discrepancy between delivery schedule with actual delivery activities Limitation of fertiliser stock in distribution center	Consumer complaint Target not achieved Relocation costs Establish safety stock procedure	-configure better delivery plan -internal coordination with the Department of sales and department of production	5	1	5
14	Stock out in distribution centres	Stock out in distribution centres due to insufficient transportation facilities availability	Unavailable stock in the fertiliser industry warehouse - changes in selling plan - Discrepancy between delivery schedule with actual delivery activities	Limitation of fertiliser stock in distribution center Consumer complaint Target not achieved Relocation costs -	- Establish safety stock procedure -Configure better delivery plan -Internal coordination with the Department of Sales and Department of Production -	5	1	5

Table B.4 Risk in The Sales department region II

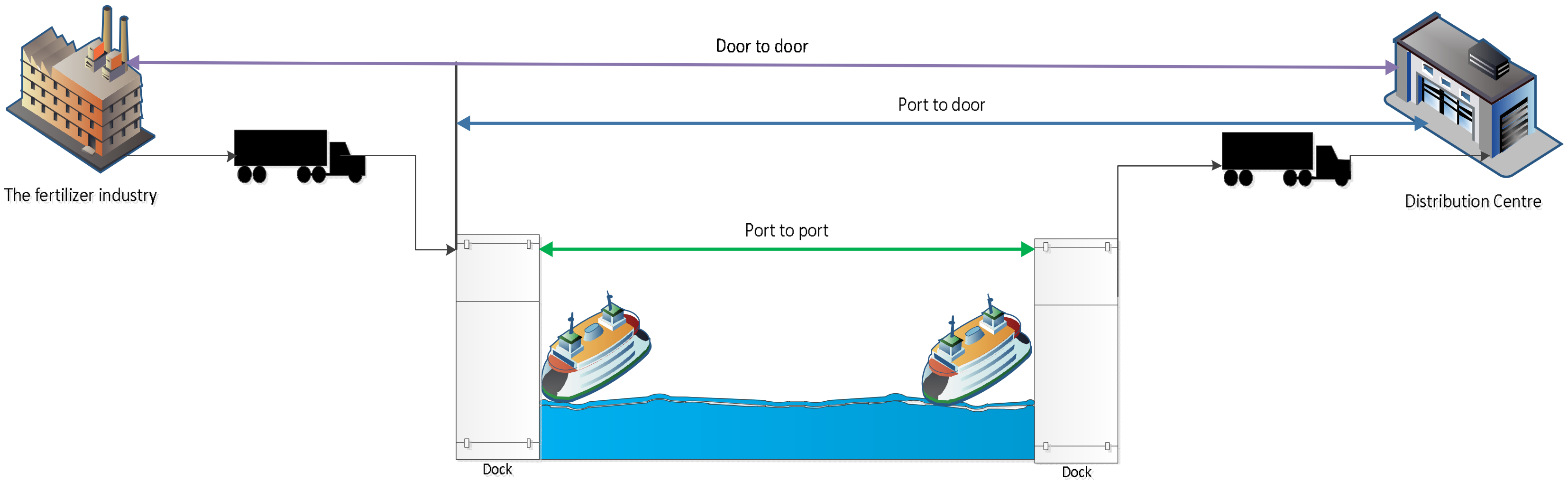
No	Risk	Cause	Description	Impact	Mitigation	Score		Risk assessment
						Probability	Impact	(D × P)
1	Queuing of the ships in docking and unloading in T shaped port and destination port	Loading point from trucks to ships	- Sea siltation - Unreliable unloading and loading equipment: equipment leaks - The departure of the ship is not on schedule - Lack of power checker - Lack of unloading personnel and forklift	- Delay of unloading from truck to port - Delay in fertiliser distribution affect stock availability in DC - Customers complaint - Waiting time in order fulfillment process	- Adding checker - Adding loading/ unloading labor and forklift - Adding transportation facilities (truck, train, ships) - Preventive maintenance - Ship departure scheduling - Preparing reliability of unloading facilities	5	3	15
2	Port expansion	Lack of pier capacity	Dock expansion to increase capacity of pier storage. This project takes more than one year.	- Delay in fertiliser distribution affect stock availability in DC - Customers complaint - Waiting time in order fulfillment process	- Utilize other ports located around the fertiliser industry for loading fertiliser into the ships - Conducting surveys and data collection of delivery time in dock located on outside of Java region. Delivery time is measured from loading activities in the fertiliser industry to farmers (Line IV). It is	5	3	15

					calculated to determine the optimal amount of buffer stock in DC. - To strive for fertiliser as a priority item in loading process destination ports - conduct socialization of the dock expansion project to farmers - To support farmers in identifying the needs of fertiliser in the group definitive plan			
3	Traffic congestion on the highway	Road/ Infrastructure capacity	Traffic congestion on the highway from fertiliser industry to DC, distributors, retailer and farmers	- Target is not achieved	- Adding transportation facilities (truck, train, ships) - Add truck drivers - Establish a better delivery planning - conduct internal coordination between distribution manager, risk management manager and marketing manager	3	5	15

4	New bridge construction	New bridge construction	Construction of new bridge in region I	- caused changes in the regional shipping lines of fertiliser - changes in delivery time - changes in determination of truck capacity and buffer stock in DC	- Establish a better delivery planning - conduct internal coordination between distribution manager, risk management manager and marketing manager - changes in infrastructure facilities changes	3	2	6
5	Bridge repair	Bridge repair because of disasters and maintenance	Bridge repair in particular time	- caused changes in the regional shipping lines of fertiliser - changes in delivery time - changes in determination of truck capacity and buffer stock in DC	- Re planning shipping capacity - Transportation route changing - Measure delivery planning - Conduct internal coordination between distribution manager, risk management manager and marketing manager	3	5	15
6	Road repair	Road repair because of disasters and maintenance	Road repair in particular time	- caused changes in the regional shipping lines of fertiliser - changes in delivery time - changes in determination of truck capacity and buffer stock in DC	- Establish a better delivery planning - Re planning shipping capacity - Transportation route changing - Re measure delivery planning - conduct internal coordination between distribution manager,	3	5	15

					risk management manager and marketing manager			

Terms in distribution in the fertiliser industry



Appendix C
Verification and validation questionnaire

UNIVERSITY OF LEEDS

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Checklist

Validation and verification of conceptual and simulation model

I. Conceptual Model			
1. Model representation			
a. Model is Complete	☐ Low	☐ Medium	☐ High
b. Mode is Correct	☐ Low	☐ Medium	☐ High
c. Model is minimal	☐ Low	☐ Medium	☐ High
d. Model is understandable	☐ Low	☐ Medium	☐ High
e. Mode is extendable	☐ Low	☐ Medium	☐ High
f. Overall representation	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
2. Model process flow			
a. Entities	☐ Low	☐ Medium	☐ High

b. Variables	☐ Low	☐ Medium	☐ High
c. Entities relationship	☐ Low	☐ Medium	☐ High
d. Overall process	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
Recommendation:			
Validation Level	☐ Low	☐ Medium	☐ High
II. Simulation Model			
1. Model interface			
a. Monitor display	☐ Low	☐ Medium	☐ High
b. Colour	☐ Low	☐ Medium	☐ High
c. Variable layout	☐ Low	☐ Medium	☐ High
d. Plot and diagram	☐ Low	☐ Medium	☐ High
e. Running appearance	☐ Low	☐ Medium	☐ High
f. Overall interface	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
2. Parameter			
a. Lead time	☐ Low	☐ Medium	☐ High
b. Delivery time	☐ Low	☐ Medium	☐ High
c. Infrastructure facilities	☐ Low	☐ Medium	☐ High
3. Key performance indicator			

a. Interoperability	☐ Low	☐ Medium	☐ High
b. Safety	☐ Low	☐ Medium	☐ High
c. Reliability	☐ Low	☐ Medium	☐ High
d. Availability	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
Recommendation:			
Validation Level	☐ Low	☐ Medium	☐ High
III. Design Experiment			
Scenario A			
1. Sufficient information and data to present realistic scenario	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
2. Scenario motivation to achieve goal	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
3. Resources available to run the scenario	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			

Recommendation:			
Scenario B			
1. Sufficient information and data to present realistic scenario	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
2. Scenario motivation to achieve goal	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
3. Resources available to run the scenario	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
Recommendation:			

Scenario C			
1. Sufficient information and data to present realistic scenario	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
2. Scenario motivation to achieve goal	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
3. Resources available to run the scenario	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
Recommendation:			
Scenario D			
1. Sufficient information and data to present realistic scenario	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			

2. Scenario motivation to achieve goal	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
3. Resources available to run the scenario	☐ Low	☐ Medium	☐ High
Please give your comment and suggestion:			
Final recommendation			

Name of participant :

Date :

Signature :

Appendix D
Simulation model Code

D.1. Validated of simulation modelling

```
;; System dynamics model globals
globals [
  ;; size of each step, see SYSTEM-DYNAMICS-GO
  dt
]

;; Initializes the system dynamics model.
;; Call this in your model's SETUP procedure.
to system-dynamics-setup
  reset-ticks
  set dt 1.0
end

;; Step through the system dynamics model by performing next iteration of Euler's method.
;; Call this in your model's GO procedure.
to system-dynamics-go

  ;; compute variable and flow values once per step
  let local-BOR_Port BOR_Port
  let local-KPI_Method-loading_unloading_time KPI_Method-loading_unloading_time
  let local-Risk_of_method Risk_of_method
  let local-Risk_of_goal Risk_of_goal
  let local-KPI_Goal-customer_complaint KPI_Goal-customer_complaint
  let local-KPI_People-working_hours_lost KPI_People-working_hours_lost
  let local-Risk_of_People Risk_of_People
  let local-KPI_Culture-Inaccuraties_data_entry KPI_Culture-Inaccuraties_data_entry
  let local-KPI_Infrastructure-Openstorage_in_warehouse KPI_Infrastructure-Openstorage_in_warehouse
  let local-KPI_Technology-Tools_breakdown KPI_Technology-Tools_breakdown
  let local-Risk_of_Culture Risk_of_Culture
  let local-Risk_of_Infrastructure Risk_of_Infrastructure
  let local-Risk_of_Technology Risk_of_Technology

  tick-advance dt
end

;; Report value of variable
to-report BOR_Port
  report BOR
end
```

```
;; Report value of variable
to-report KPI_Method-loading_unloading_time
  report 2 + (((8 - 2) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_method
  report 1 + (((25 - 1) / (8 - 2))  * (KPI_Method-loading_unloading_time - 2))
end

;; Report value of variable
to-report Risk_of_goal
  report (1 + (((16 - 1) / (0.4 - 0))  * (KPI_Goal-customer_complaint - 0)))
end

;; Report value of variable
to-report KPI_Goal-customer_complaint
  report 0 + (((0.4 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_People-working_hours_lost
  report 4 + (((24 - 4) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_People
  report 1 + (((15 - 1) / (24 - 4))  * (KPI_People-working_hours_lost - 4))
end

;; Report value of variable
to-report KPI_Culture-Inaccuraties_data_entry
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Infrastructure-Openstorage_in_warehouse
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Technology-Tools_breakdown
  report 1 + (((5 - 1) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_Culture
  report 1 + (((12 - 1) / (100 - 0))  * (KPI_Culture-Inaccuraties_data_entry - 0))
end
```

```
;; Report value of variable
to-report Risk_of_Infrastructure
  report 1 + (((20 - 1) / (100 - 0))  * (KPI_Infrastructure-Openstorage_in_warehouse -
0))
end

;; Report value of variable
to-report Risk_of_Technology
  report 1 + (((15 - 1) / (5 - 1))  * (KPI_Technology-Tools_breakdown - 1))
end

;; Plot the current state of the system dynamics model's stocks
;; Call this procedure in your plot's update commands.
to system-dynamics-do-plot
end
to setup
  ca
  system-dynamics-setup    ;; defined by the System Dynamics Modeler
end

to go
  if ticks >= times-of-simulation [stop]
  system-dynamics-go       ;; defined by the System Dynamics Modeler
  do-plot
end

to do-plot
  set-current-plot "Score of risk"
  set-current-plot-pen "R-Goal"
  plotxy ticks Risk_of_goal
  set-current-plot-pen "R-Method"
  plotxy ticks Risk_of_method
  set-current-plot-pen "R-Technology"
  plotxy ticks Risk_of_technology
  set-current-plot-pen "R-People"
  plotxy ticks Risk_of_people
  set-current-plot-pen "R-Culture"
  plotxy ticks Risk_of_culture
  set-current-plot-pen "R-Infrastructure"
  plotxy ticks Risk_of_infrastructure
  set-current-plot "Key Performance Indicator"
  set-current-plot-pen "KPI_Goal"
  plotxy ticks KPI_Goal-customer_complaint
  set-current-plot-pen "KPI_Method"
  plotxy ticks KPI_Method-loading_unloading_time
  set-current-plot-pen "KPI_People"
  plotxy ticks KPI_People-working_hours_lost
  set-current-plot-pen "KPI_Culture"
  plotxy ticks KPI_Culture-Inaccuraties_data_entry
```

```
  set-current-plot-pen "KPI_Technology"
  plotxy ticks KPI_Technology-Tools_breakdown
  set-current-plot-pen "KPI_Infrastructure"
  plotxy ticks KPI_Infrastructure-Openstorage_in_warehouse
  system-dynamics-do-plot
 end
```

A.2 Validated simulation modelling with BOR in random number

```
;; System dynamics model globals
globals [
  ;; size of each step, see SYSTEM-DYNAMICS-GO
  dt
]

;; Initializes the system dynamics model.
;; Call this in your model's SETUP procedure.
to system-dynamics-setup
  reset-ticks
  set dt 1.0
end

;; Step through the system dynamics model by performing next iteration of Euler's method.
;; Call this in your model's GO procedure.
to system-dynamics-go

  ;; compute variable and flow values once per step
  let local-BOR_Port BOR_Port
  let local-KPI_Method-loading_unloading_time KPI_Method-loading_unloading_time
  let local-Risk_of_method Risk_of_method
  let local-Risk_of_goal Risk_of_goal
  let local-KPI_Goal-customer_complaint KPI_Goal-customer_complaint
  let local-KPI_People-working_hours_lost KPI_People-working_hours_lost
  let local-Risk_of_People Risk_of_People
  let local-KPI_Culture-Inaccuraties_data_entry KPI_Culture-Inaccuraties_data_entry
  let local-KPI_Infrastructure-Openstorage_in_warehouse KPI_Infrastructure-Openstorage_in_warehouse
  let local-KPI_Technology-Tools_breakdown KPI_Technology-Tools_breakdown
  let local-Risk_of_Culture Risk_of_Culture
  let local-Risk_of_Infrastructure Risk_of_Infrastructure
  let local-Risk_of_Technology Risk_of_Technology

  tick-advance dt
end

;; Report value of variable
to-report BOR_Port
  report BOR
```

```
end

;; Report value of variable
to-report KPI_Method-loading_unloading_time
  report 2 + (((8 - 2) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_method
  report 1 + (((25 - 1) / (8 - 2))  * (KPI_Method-loading_unloading_time - 2))
end

;; Report value of variable
to-report Risk_of_goal
  report (1 + (((16 - 1) / (0.4 - 0))  * (KPI_Goal-customer_complaint - 0)))
end

;; Report value of variable
to-report KPI_Goal-customer_complaint
  report 0 + (((0.4 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_People-working_hours_lost
  report 4 + (((24 - 4) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_People
  report 1 + (((15 - 1) / (24 - 4))  * (KPI_People-working_hours_lost - 4))
end

;; Report value of variable
to-report KPI_Culture-Inaccuraties_data_entry
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Infrastructure-Openstorage_in_warehouse
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Technology-Tools_breakdown
  report 1 + (((5 - 1) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_Culture
  report 1 + (((12 - 1) / (100 - 0))  * (KPI_Culture-Inaccuraties_data_entry - 0))
```

```
end

;; Report value of variable
to-report Risk_of_Infrastructure
  report 1 + (((20 - 1) / (100 - 0))  * (KPI_Infrastructure-Openstorage_in_warehouse -
0))
end

;; Report value of variable
to-report Risk_of_Technology
  report 1 + (((15 - 1) / (5 - 1))  * (KPI_Technology-Tools_breakdown - 1))
end

;; Plot the current state of the system dynamics model's stocks
;; Call this procedure in your plot's update commands.
to system-dynamics-do-plot
end

to setup
  ca
  set BOR 70
  system-dynamics-setup    ;; defined by the System Dynamics Modeler
end

to go
  set BOR random-poisson 80
  if ticks >= times-of-simulation [stop]
  system-dynamics-go       ;; defined by the System Dynamics Modeler
  do-plot
end

to do-plot
  set-current-plot "Score of risk"
  set-current-plot-pen "R-Goal"
  plotxy ticks Risk_of_goal
  set-current-plot-pen "R-Method"
  plotxy ticks Risk_of_method
  set-current-plot-pen "R-Technology"
  plotxy ticks Risk_of_technology
  set-current-plot-pen "R-People"
  plotxy ticks Risk_of_people
  set-current-plot-pen "R-Culture"
  plotxy ticks Risk_of_culture
  set-current-plot-pen "R-Infrastructure"
  plotxy ticks Risk_of_infrastructure
  set-current-plot-pen "BOR"
  plotxy ticks BOR_Port
  set-current-plot "Key Performance Indicator"
  set-current-plot-pen "KPI_Goal"
  plotxy ticks KPI_Goal-customer_complaint
```

```
  set-current-plot-pen "KPI_Method"
  plotxy ticks KPI_Method-loading_unloading_time
  set-current-plot-pen "KPI_People"
  plotxy ticks KPI_People-working_hours_lost
  set-current-plot-pen "KPI_Culture"
  plotxy ticks KPI_Culture-Inaccuraties_data_entry
  set-current-plot-pen "KPI_Technology"
  plotxy ticks KPI_Technology-Tools_breakdown
  set-current-plot-pen "KPI_Infrastructure"
  plotxy ticks KPI_Infrastructure-Openstorage_in_warehouse
  set-current-plot-pen "BOR"
  plotxy ticks BOR_Port
  system-dynamics-do-plot
 end
```

A.2. Simulation model code of Mitigation plan

```
;; System dynamics model globals
globals [
  ;; size of each step, see SYSTEM-DYNAMICS-GO
  dt
]

;; Initializes the system dynamics model.
;; Call this in your model's SETUP procedure.
to system-dynamics-setup
  reset-ticks
  set dt 1.0
end

;; Step through the system dynamics model by performing next iteration of Euler's method.
;; Call this in your model's GO procedure.
to system-dynamics-go

  ;; compute variable and flow values once per step
  let local-BOR_Port BOR_Port
  let local-KPI_Method-loading_unloading_time KPI_Method-loading_unloading_time
  let local-Risk_of_method Risk_of_method
  let local-Risk_of_goal Risk_of_goal
  let local-KPI_Goal-customer_complaint KPI_Goal-customer_complaint
  let local-KPI_People-working_hours_lost KPI_People-working_hours_lost
  let local-Risk_of_People Risk_of_People
  let local-KPI_Culture-Inaccuraties_data_entry KPI_Culture-Inaccuraties_data_entry
  let local-KPI_Infrastructure-Openstorage_in_warehouse KPI_Infrastructure-Openstorage_in_warehouse
  let local-KPI_Technology-Tools_breakdown KPI_Technology-Tools_breakdown
  let local-Risk_of_Culture Risk_of_Culture
  let local-Risk_of_Infrastructure Risk_of_Infrastructure
  let local-Risk_of_Technology Risk_of_Technology
  let local-Mitigation Mitigation
```

```
  tick-advance dt
end

;; Report value of variable
to-report BOR_Port
  report 69 + (((100 - 69) / ( 4 - 1)) * (Mitigation - 1))
end

;; Report value of variable
to-report KPI_Method-loading_unloading_time
  report 2 + (((8 - 2) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_method
  report 1 + (((25 - 1) / (8 - 2))  * (KPI_Method-loading_unloading_time - 2))
end

;; Report value of variable
to-report Risk_of_goal
  report (1 + (((16 - 1) / (0.4 - 0))  * (KPI_Goal-customer_complaint - 0)))
end

;; Report value of variable
to-report KPI_Goal-customer_complaint
  report 0 + (((0.4 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_People-working_hours_lost
  report 4 + (((24 - 4) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_People
  report 1 + (((15 - 1) / (24 - 4))  * (KPI_People-working_hours_lost - 4))
end

;; Report value of variable
to-report KPI_Culture-Inaccuraties_data_entry
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Infrastructure-Openstorage_in_warehouse
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Technology-Tools_breakdown
```

```
  report 1 + (((5 - 1) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_Culture
  report 1 + (((12 - 1) / (100 - 0))  * (KPI_Culture-Inaccuraties_data_entry - 0))
end

;; Report value of variable
to-report Risk_of_Infrastructure
  report 1 + (((20 - 1) / (100 - 0))  * (KPI_Infrastructure-Openstorage_in_warehouse -
0))
end

;; Report value of variable
to-report Risk_of_Technology
  report 1 + (((15 - 1) / (5 - 1))  * (KPI_Technology-Tools_breakdown - 1))
end

;; Report value of variable
to-report Mitigation
  report Mitigation_plan
end

;; Plot the current state of the system dynamics model's stocks
;; Call this procedure in your plot's update commands.
to system-dynamics-do-plot
end

to setup
  ca
  system-dynamics-setup    ;; defined by the System Dynamics Modeler
end

to go
  if ticks >= times-of-simulation [stop]
  system-dynamics-go       ;; defined by the System Dynamics Modeler
  do-plot
end

to do-plot
  set-current-plot "Score of risk"
  set-current-plot-pen "R-Goal"
  plotxy ticks Risk_of_goal
  set-current-plot-pen "R-Method"
  plotxy ticks Risk_of_method
  set-current-plot-pen "R-Technology"
  plotxy ticks Risk_of_technology
  set-current-plot-pen "R-People"
  plotxy ticks Risk_of_people
```

```
  set-current-plot-pen "R-Culture"
  plotxy ticks Risk_of_culture
  set-current-plot-pen "R-Infrastructure"
  plotxy ticks Risk_of_infrastructure
  set-current-plot "Key Performance Indicator"
  set-current-plot-pen "KPI_Goal"
  plotxy ticks KPI_Goal-customer_complaint
  set-current-plot-pen "KPI_Method"
  plotxy ticks KPI_Method-loading_unloading_time
  set-current-plot-pen "KPI_People"
  plotxy ticks KPI_People-working_hours_lost
  set-current-plot-pen "KPI_Culture"
  plotxy ticks KPI_Culture-Inaccuraties_data_entry
  set-current-plot-pen "KPI_Technology"
  plotxy ticks KPI_Technology-Tools_breakdown
  set-current-plot-pen "KPI_Infrastructure"
  plotxy ticks KPI_Infrastructure-Openstorage_in_warehouse
  system-dynamics-do-plot
 end
```

A.3 Code of simulation modelling of Mitigation plan scenario

```
;; System dynamics model globals
globals [
  ;; size of each step, see SYSTEM-DYNAMICS-GO
  dt
]

;; Initializes the system dynamics model.
;; Call this in your model's SETUP procedure.
to system-dynamics-setup
  reset-ticks
  set dt 1.0
end

;; Step through the system dynamics model by performing next iteration of Euler's
method.
;; Call this in your model's GO procedure.
to system-dynamics-go

  ;; compute variable and flow values once per step
  let local-BOR_Port BOR_Port
  let local-KPI_Method-loading_unloading_time KPI_Method-loading_unloading_time
  let local-Risk_of_method Risk_of_method
  let local-Risk_of_goal Risk_of_goal
  let local-KPI_Goal-customer_complaint KPI_Goal-customer_complaint
  let local-KPI_People-working_hours_lost KPI_People-working_hours_lost
  let local-Risk_of_People Risk_of_People
  let local-KPI_Culture-Inaccuraties_data_entry KPI_Culture-Inaccuraties_data_entry
```

```
 let local-KPI_Infrastructure-Openstorage_in_warehouse KPI_Infrastructure-Openstorage_in_warehouse
 let local-KPI_Technology-Tools_breakdown KPI_Technology-Tools_breakdown
 let local-Risk_of_Culture Risk_of_Culture
 let local-Risk_of_Infrastructure Risk_of_Infrastructure
 let local-Risk_of_Technology Risk_of_Technology
 let local-Mitigation Mitigation

 tick-advance dt
end

;; Report value of variable
to-report BOR_Port
 report 69 + (((100 - 69) / ( 4 - 1)) * (Mitigation - 1))
end

;; Report value of variable
to-report KPI_Method-loading_unloading_time
 report 2 + (((8 - 2) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_method
 report 1 + (((25 - 1) / (8 - 2))  * (KPI_Method-loading_unloading_time - 2))
end

;; Report value of variable
to-report Risk_of_goal
 report (1 + (((16 - 1) / (0.4 - 0))  * (KPI_Goal-customer_complaint - 0)))
end

;; Report value of variable
to-report KPI_Goal-customer_complaint
 report 0 + (((0.4 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_People-working_hours_lost
 report 4 + (((24 - 4) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_People
 report 1 + (((15 - 1) / (24 - 4))  * (KPI_People-working_hours_lost - 4))
end

;; Report value of variable
to-report KPI_Culture-Inaccuraties_data_entry
 report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end
```

```
;; Report value of variable
to-report KPI_Infrastructure-Openstorage_in_warehouse
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Technology-Tools_breakdown
  report 1 + (((5 - 1) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_Culture
  report 1 + (((12 - 1) / (100 - 0))  * (KPI_Culture-Inaccuraties_data_entry - 0))
end

;; Report value of variable
to-report Risk_of_Infrastructure
  report 1 + (((20 - 1) / (100 - 0))  * (KPI_Infrastructure-Openstorage_in_warehouse -
0))
end

;; Report value of variable
to-report Risk_of_Technology
  report 1 + (((15 - 1) / (5 - 1))  * (KPI_Technology-Tools_breakdown - 1))
end

;; Report value of variable
to-report Mitigation
  report Mitigation_plan
end

;; Plot the current state of the system dynamics model's stocks
;; Call this procedure in your plot's update commands.
to system-dynamics-do-plot
end
to setup
  ca
  system-dynamics-setup    ;; defined by the System Dynamics Modeler
end

to go
  if ticks >= times-of-simulation [stop]
  system-dynamics-go       ;; defined by the System Dynamics Modeler
  do-plot
end

to do-plot
  set-current-plot "Score of risk"
  set-current-plot-pen "R-Goal"
```

```
  plotxy ticks Risk_of_goal
  set-current-plot-pen "R-Method"
  plotxy ticks Risk_of_method
  set-current-plot-pen "R-Technology"
  plotxy ticks Risk_of_technology
  set-current-plot-pen "R-People"
  plotxy ticks Risk_of_people
  set-current-plot-pen "R-Culture"
  plotxy ticks Risk_of_culture
  set-current-plot-pen "R-Infrastructure"
  plotxy ticks Risk_of_infrastructure
  set-current-plot "Key Performance Indicator"
  set-current-plot-pen "KPI_Goal"
  plotxy ticks KPI_Goal-customer_complaint
  set-current-plot-pen "KPI_Method"
  plotxy ticks KPI_Method-loading_unloading_time
  set-current-plot-pen "KPI_People"
  plotxy ticks KPI_People-working_hours_lost
  set-current-plot-pen "KPI_Culture"
  plotxy ticks KPI_Culture-Inaccuraties_data_entry
  set-current-plot-pen "KPI_Technology"
  plotxy ticks KPI_Technology-Tools_breakdown
  set-current-plot-pen "KPI_Infrastructure"
  plotxy ticks KPI_Infrastructure-Openstorage_in_warehouse
  system-dynamics-do-plot
  end
```

A.4 Code of simulation modelling of Mitigation plan scenario

```
;; System dynamics model globals
globals [
  ;; size of each step, see SYSTEM-DYNAMICS-GO
  dt
]

;; Initializes the system dynamics model.
;; Call this in your model's SETUP procedure.
to system-dynamics-setup
  reset-ticks
  set dt 1.0
end

;; Step through the system dynamics model by performing next iteration of Euler's method.
;; Call this in your model's GO procedure.
to system-dynamics-go

  ;; compute variable and flow values once per step
  let local-BOR_Port BOR_Port
  let local-KPI_Method-loading_unloading_time KPI_Method-loading_unloading_time
  let local-Risk_of_method Risk_of_method
```

```
  let local-Risk_of_goal Risk_of_goal
  let local-KPI_Goal-customer_complaint KPI_Goal-customer_complaint
  let local-KPI_People-working_hours_lost KPI_People-working_hours_lost
  let local-Risk_of_People Risk_of_People
  let local-KPI_Culture-Inaccuraties_data_entry KPI_Culture-Inaccuraties_data_entry
  let local-KPI_Infrastructure-Openstorage_in_warehouse KPI_Infrastructure-Openstorage_in_warehouse
  let local-KPI_Technology-Tools_breakdown KPI_Technology-Tools_breakdown
  let local-Risk_of_Culture Risk_of_Culture
  let local-Risk_of_Infrastructure Risk_of_Infrastructure
  let local-Risk_of_Technology Risk_of_Technology
  let local-Mitigation Mitigation

  tick-advance dt
end

;; Report value of variable
to-report BOR_Port
  report 69 + (((100 - 69) / ( 4 - 1)) * (Mitigation - 1))
end

;; Report value of variable
to-report KPI_Method-loading_unloading_time
  report 2 + (((8 - 2) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_method
  report 1 + (((25 - 1) / (8 - 2))  * (KPI_Method-loading_unloading_time - 2))
end

;; Report value of variable
to-report Risk_of_goal
  report (1 + (((16 - 1) / (0.4 - 0))  * (KPI_Goal-customer_complaint - 0)))
end

;; Report value of variable
to-report KPI_Goal-customer_complaint
  report 0 + (((0.4 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_People-working_hours_lost
  report 4 + (((24 - 4) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_People
  report 1 + (((15 - 1) / (24 - 4))  * (KPI_People-working_hours_lost - 4))
end
```

```
;; Report value of variable
to-report KPI_Culture-Inaccuraties_data_entry
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Infrastructure-Openstorage_in_warehouse
  report 0 + (((100 - 0) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report KPI_Technology-Tools_breakdown
  report 1 + (((5 - 1) / ( 100 - 69)) * ( BOR_Port - 69))
end

;; Report value of variable
to-report Risk_of_Culture
  report 1 + (((12 - 1) / (100 - 0))  * (KPI_Culture-Inaccuraties_data_entry - 0))
end

;; Report value of variable
to-report Risk_of_Infrastructure
  report 1 + (((20 - 1) / (100 - 0))  * (KPI_Infrastructure-Openstorage_in_warehouse -
0))
end

;; Report value of variable
to-report Risk_of_Technology
  report 1 + (((15 - 1) / (5 - 1))  * (KPI_Technology-Tools_breakdown - 1))
end

;; Report value of variable
to-report Mitigation
  report Mitigation_plan
end

;; Plot the current state of the system dynamics model's stocks
;; Call this procedure in your plot's update commands.
to system-dynamics-do-plot
end
to setup
  ca
  set Mitigation_plan 1
  system-dynamics-setup    ;; defined by the System Dynamics Modeler
end
```

```
to go
  set Mitigation_plan random-poisson 3
  if ticks >= times-of-simulation [stop]
  system-dynamics-go       ;; defined by the System Dynamics Modeler
  do-plot
end

to do-plot
  set-current-plot "Score of risk"
  set-current-plot-pen "R-Goal"
  plotxy ticks Risk_of_goal
  set-current-plot-pen "R-Method"
  plotxy ticks Risk_of_method
  set-current-plot-pen "R-Technology"
  plotxy ticks Risk_of_technology
  set-current-plot-pen "R-People"
  plotxy ticks Risk_of_people
  set-current-plot-pen "R-Culture"
  plotxy ticks Risk_of_culture
  set-current-plot-pen "R-Infrastructure"
  plotxy ticks Risk_of_infrastructure
  set-current-plot "Key Performance Indicator"
  set-current-plot-pen "KPI_Goal"
  plotxy ticks KPI_Goal-customer_complaint
  set-current-plot-pen "KPI_Method"
  plotxy ticks KPI_Method-loading_unloading_time
  set-current-plot-pen "KPI_People"
  plotxy ticks KPI_People-working_hours_lost
  set-current-plot-pen "KPI_Culture"
  plotxy ticks KPI_Culture-Inaccuraties_data_entry
  set-current-plot-pen "KPI_Technology"
  plotxy ticks KPI_Technology-Tools_breakdown
  set-current-plot-pen "KPI_Infrastructure"
  plotxy ticks KPI_Infrastructure-Openstorage_in_warehouse
  system-dynamics-do-plot
 end
```

A.5 Code of Material flow simulation modelling

```
;; System dynamics model globals
globals [
  ;; size of each step, see SYSTEM-DYNAMICS-GO
  dt
]

;; Initializes the system dynamics model.
;; Call this in your model's SETUP procedure.
to system-dynamics-setup
  reset-ticks
  set dt 1.0
```

```
end

;; Step through the system dynamics model by performing next iteration of Euler's method.
;; Call this in your model's GO procedure.
to system-dynamics-go

  ;; compute variable and flow values once per step
  let local-Boards Boards
  let local-Managers Managers
  let local-Products_Warehouses Products_Warehouses
  let local-Trucks_distribution Trucks_distribution
  let local-Ships-of-products Ships-of-products
  let local-Administration_time Administration_time
  let local-BOR BOR

  tick-advance dt
end

;; Report value of variable
to-report Boards
  report Number-of-board_directors
end

;; Report value of variable
to-report Managers
  report Number-of-departments
end

;; Report value of variable
to-report Products_Warehouses
  report Number-of-warehouses
end

;; Report value of variable
to-report Trucks_distribution
  report Number-of-trucks
end

;; Report value of variable
to-report Ships-of-products
  report Number-of-ships
end

;; Report value of variable
to-report Administration_time
  report (Boards + Managers + Products_Warehouses + Trucks_distribution) * 20
end

;; Report value of variable
```

```
to-report BOR
  report (((Ships-of-products * 110) * ((number-of-stocks / (number-of-operators * 5))
* 20) + administration_time) / (625 * 30 * 24))
end

;; Plot the current state of the system dynamics model's stocks
;; Call this procedure in your plot's update commands.
to system-dynamics-do-plot
end
breed [operators operator]
breed [trucks truck]
breed [ships ship]
breed [warehouses warehouse]
breed [departments department]
breed [board_directors board_director]

operators-own [loading_target
              unloading_target
              risk_assessment
  ]

to setup
  clear-all
  set number-of-operators 25
  set number-of-board_directors 1
  set number-of-trucks 10
  set number-of-warehouses 2
  set number-of-departments 3
  set number-of-ships 30
  set number-of-stocks 400000
  set-default-shape operators "person service"
  set-default-shape ships "boat"
  set-default-shape trucks "truck"
  set-default-shape warehouses "house colonial"
  set-default-shape departments "house ranch"
  set-default-shape board_directors "house"

  create-trucks number-of-trucks
    [ setxy 10 random-ycor ]

  create-ships number-of-ships
    [setxy 16 random-ycor]

  create-warehouses number-of-warehouses
    [setxy 0 random-ycor]

  create-departments number-of-departments
    [setxy -5 random-ycor]

  create-board_directors number-of-board_directors
```

```
    [setxy -10 0]


  create-operators number-of-operators [
    setxy 11 random-ycor
    set loading_target one-of ships
    set unloading_target one-of trucks
    set risk_assessment one-of departments
    face loading_target
  ]
  reset-ticks
end

to go
  time
  if ticks >= times-of-simulation [stop]
  set number-of-operators random-poisson 15
  set number-of-board_directors random-poisson 2
  set number-of-trucks random-poisson 7
  set number-of-warehouses random-poisson 2
  set number-of-departments random-poisson 2
  set number-of-ships random-poisson 30
  set number-of-stocks random-poisson 40000
  ask operators [
  if distance loading_target = 0
  [ set loading_target one-of ships
    face loading_target ]
  ifelse distance loading_target < 1
  [ move-to unloading_target
    set unloading_target one-of trucks ]
  [ fd 1 ]
]
  tick
  if ticks >= number-of-stocks [ stop ]
  do-plot
end

to time
  ask operators
   [ show number-of-stocks / (number-of-operators * 5) ]
end

to do-plot
  set-current-plot "Material Flow"
  set-current-plot-pen "Loading time"
  plotxy ticks number-of-stocks / (number-of-operators * 5)
  set-current-plot-pen "operators"
  plotxy ticks number-of-operators
  set-current-plot-pen "Adm_time"
  plotxy ticks Administration_time
```

```
  set-current-plot-pen "BOR"
  plotxy ticks BOR

  set-current-plot "The number of others elements"
  set-current-plot-pen "Trucks"
  plotxy ticks number-of-trucks
  set-current-plot-pen "ships"
  plotxy ticks number-of-ships
  set-current-plot-pen "Warehouses"
  plotxy ticks number-of-warehouses
  set-current-plot-pen "departments"
  plotxy ticks number-of-departments
  set-current-plot-pen "Board directors"
  plotxy ticks number-of-board_directors
end
```

Appendix E
Variable and interface of simulation model

Table E.1 Input variable of simulation modelling

MODEL SETTINGS													
Preventive maintenance	Expansion	Number-of-trucks	Trucks needed	Tools maintenance	Trucks	Changes rate	Supplier phosphate unloading time	Scheduling	Sub-contract	Delivery method	Infrastructure-fac-ind	People-performance	Training-act
16	16	25	45	10	55	0.5	25	25	15	10	10	25	15

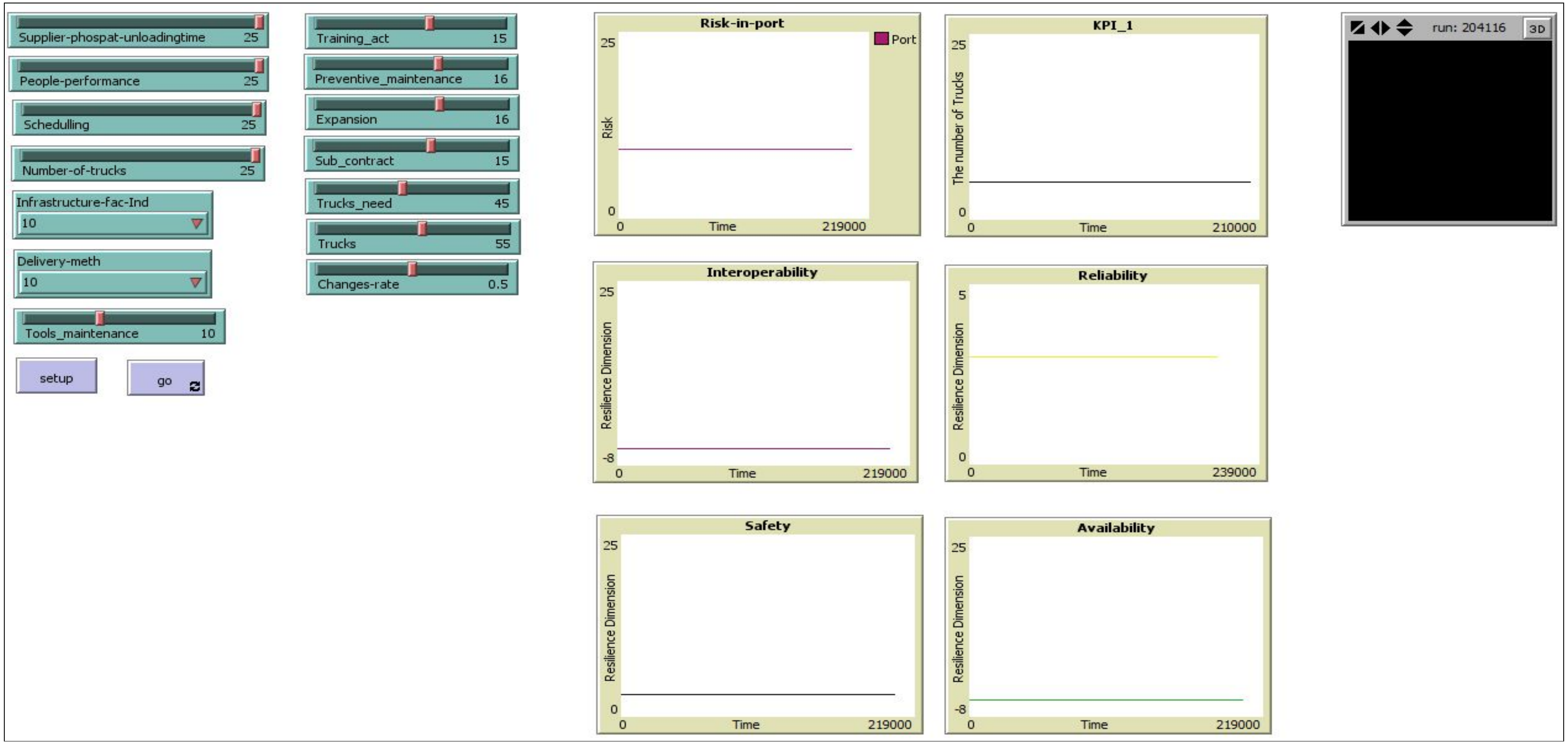

Figure E.1 Interface of simulation modelling of the resilience assessment of supply networks in 204116 run times

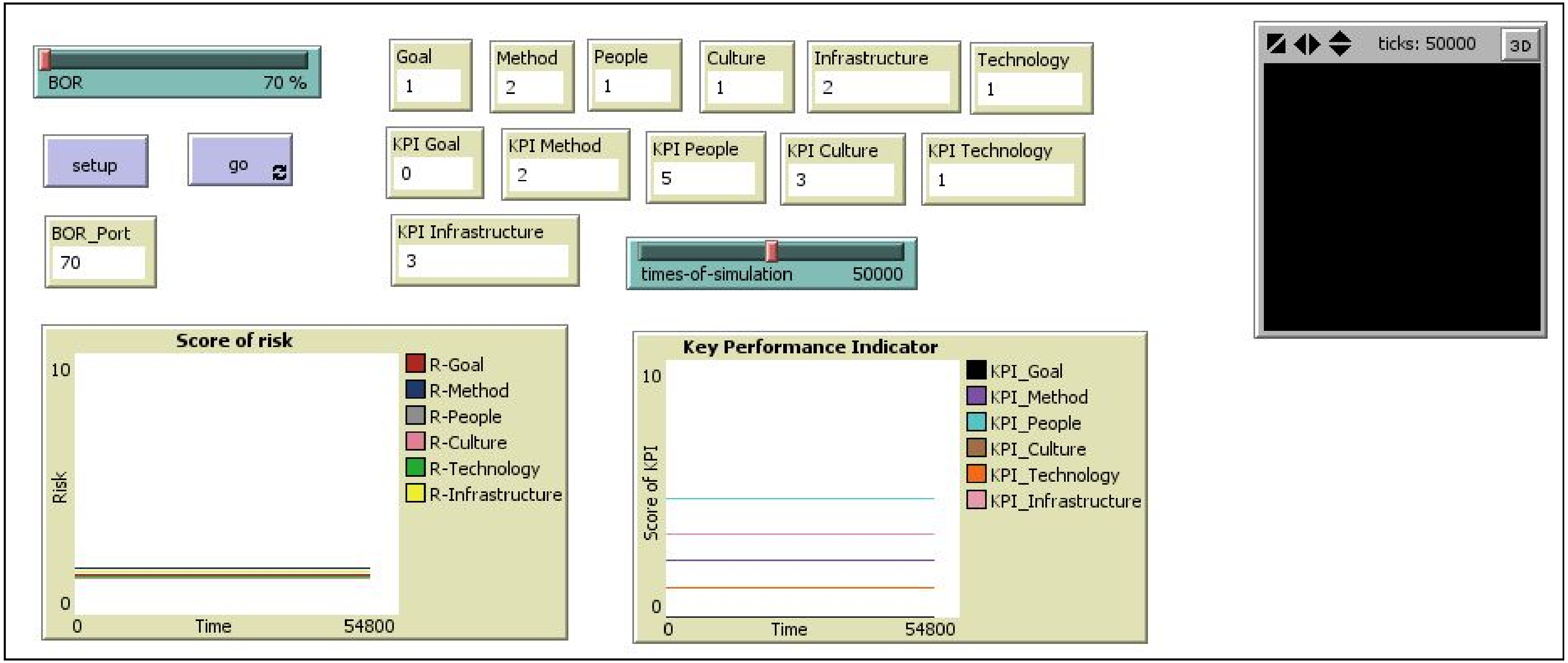

Figure E.2 The output of the simulation model in Berth Occupancy Ratio 70%

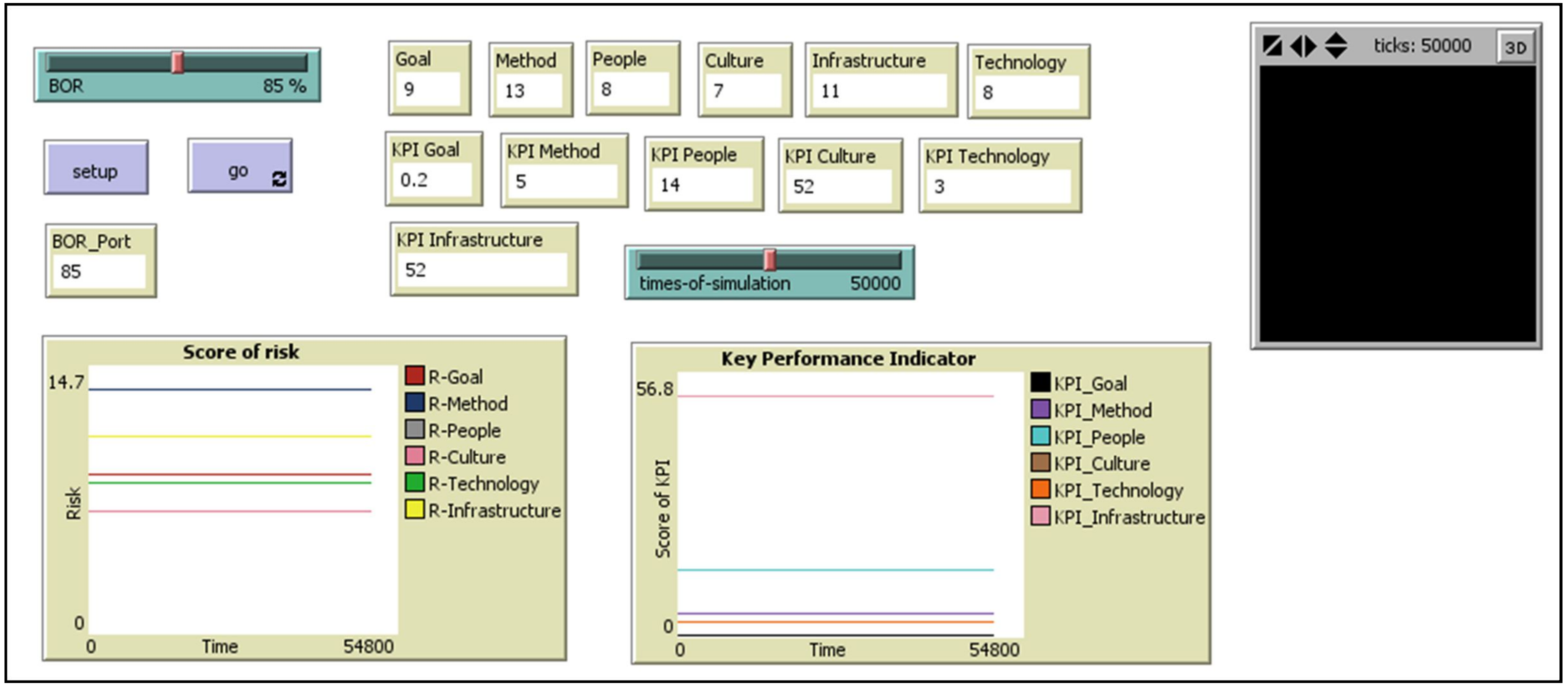

Figure E.3 The output of the simulation model in Berth Occupancy Ratio 85%

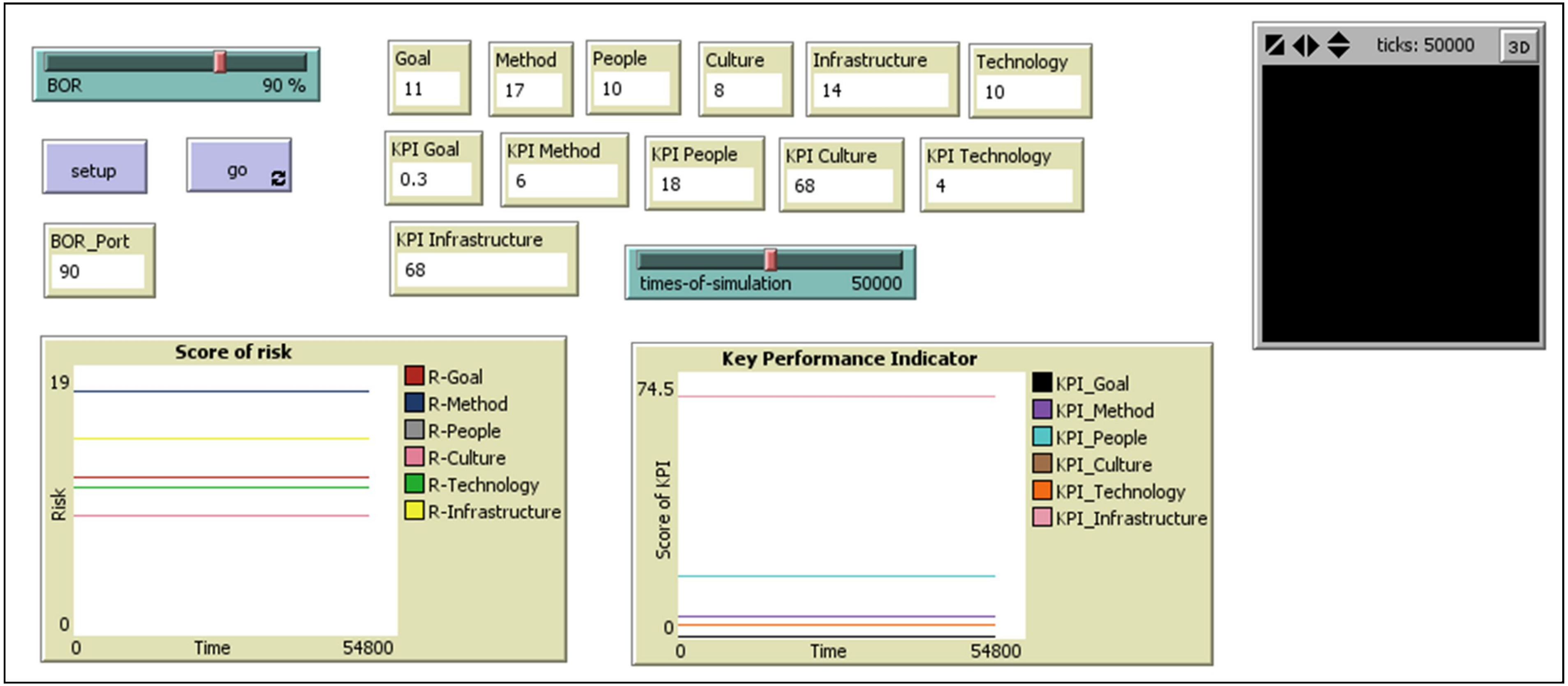

Figure E.4 The output of the simulation model in Berth Occupancy Ratio 90%

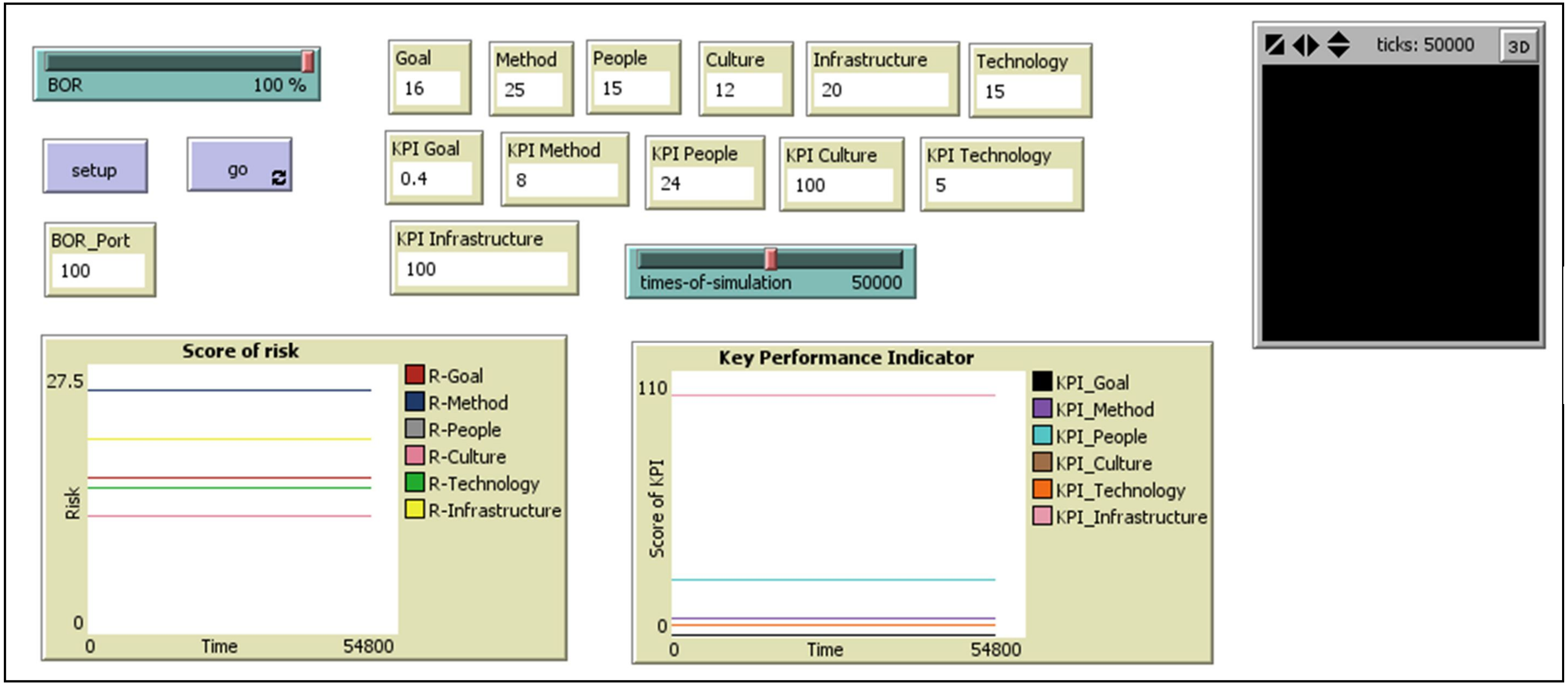

Figure E.5 The output of the simulation model in Berth Occupancy Ratio 100%

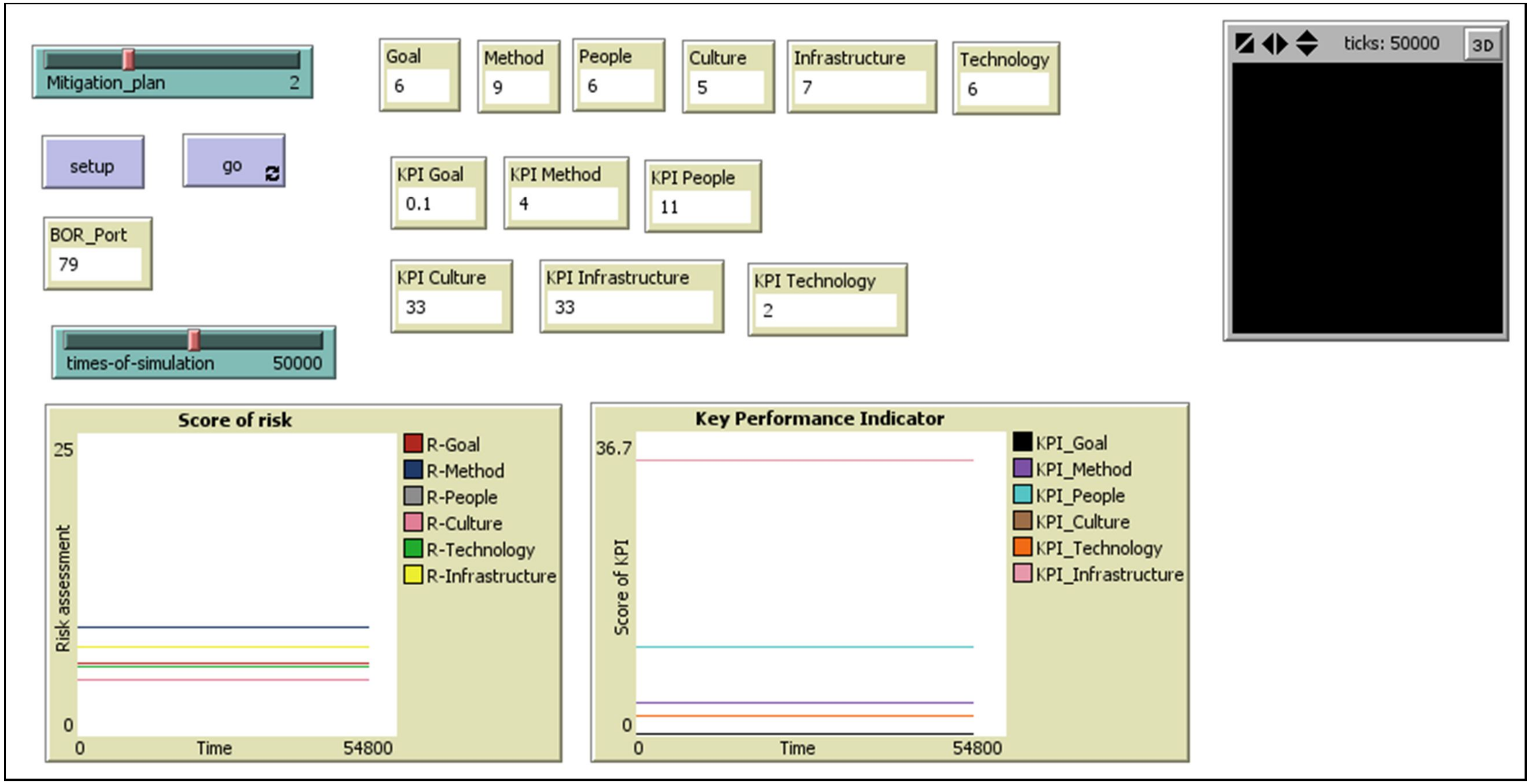

Figure E.6 Scenario of mitigation plan: reduce

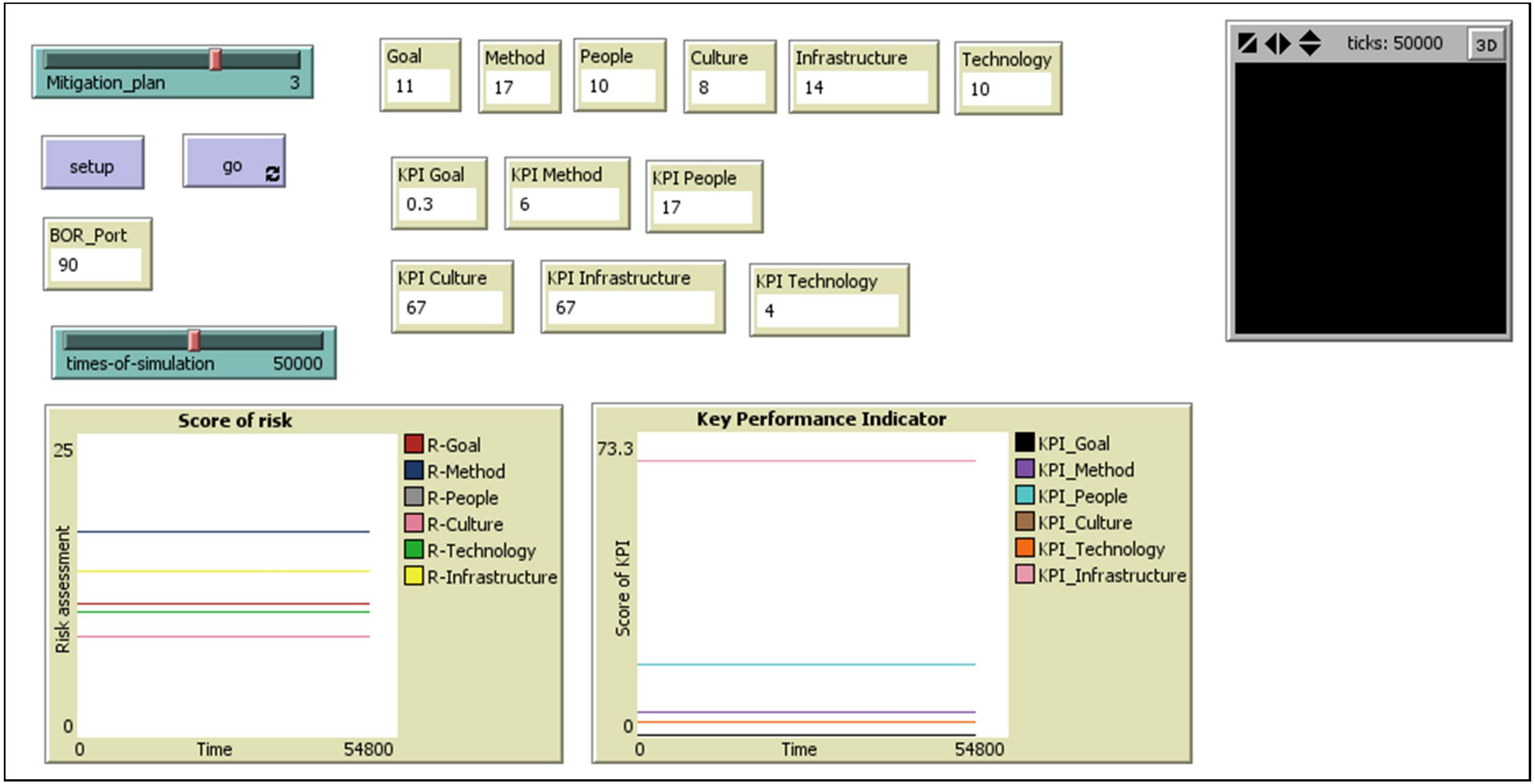

Figure E.7 Scenario of mitigation plan: transfer

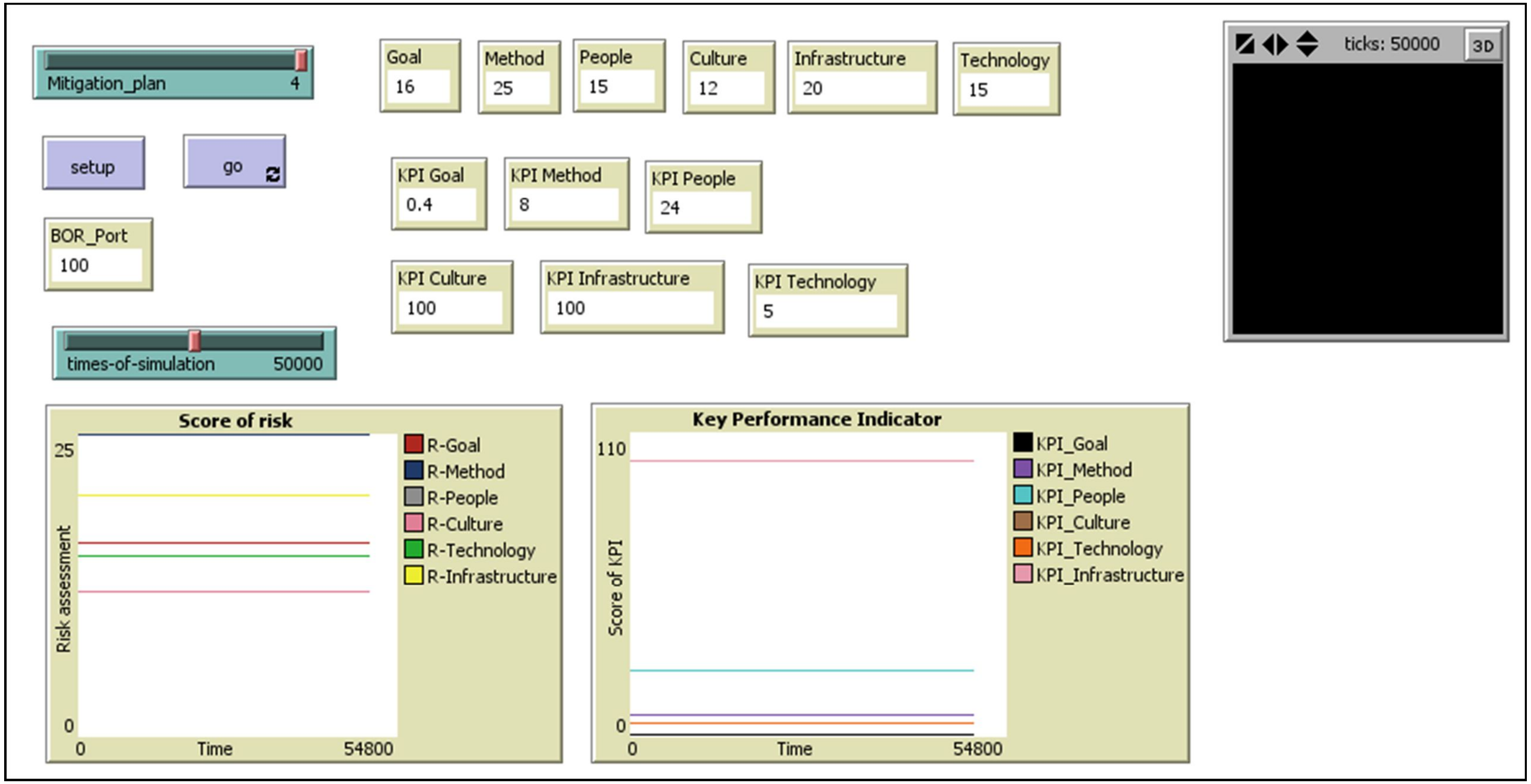

Figure E.8 Scenario of mitigation plan: exploit

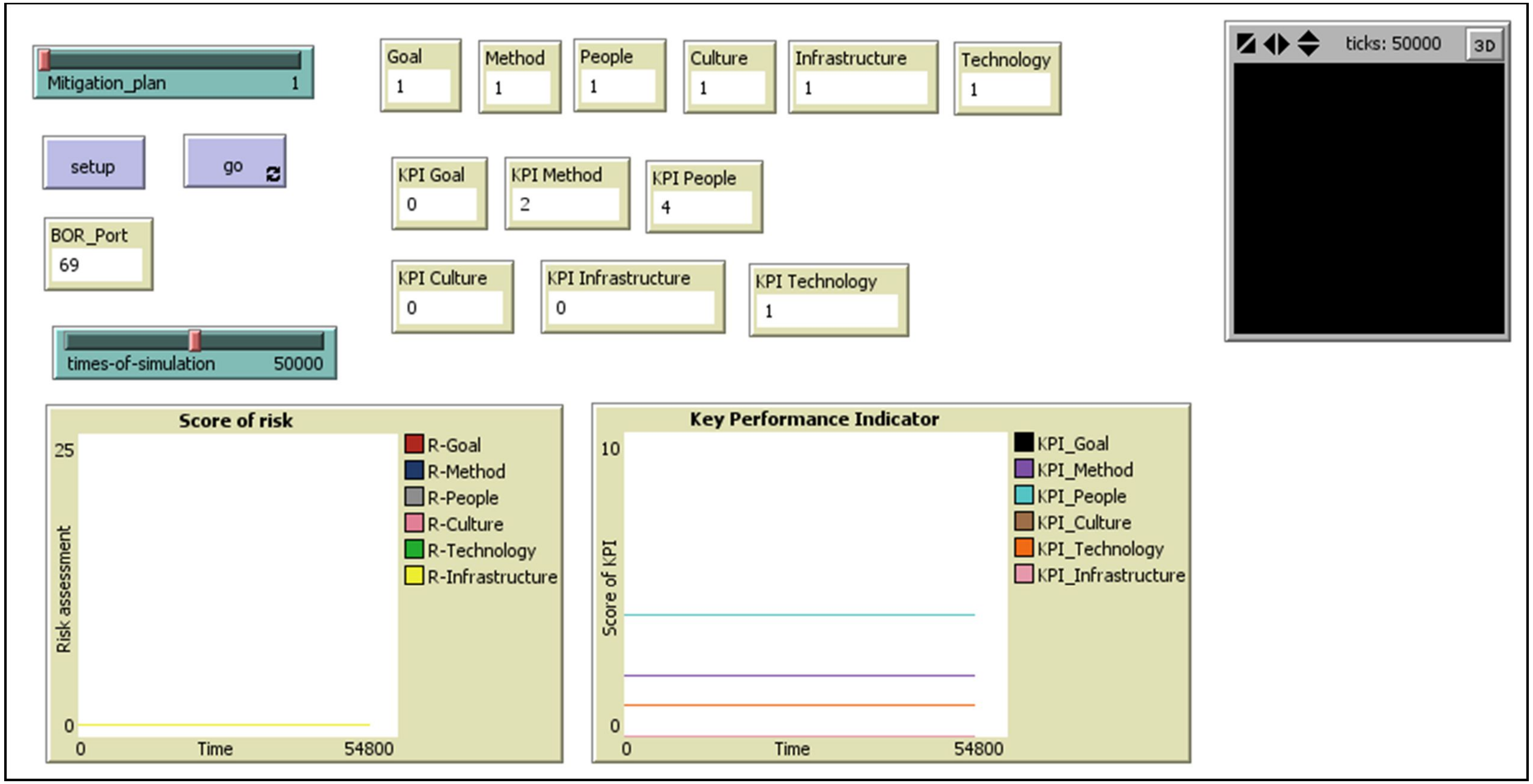

Figure E.9 Scenario of mitigation plan: avoid

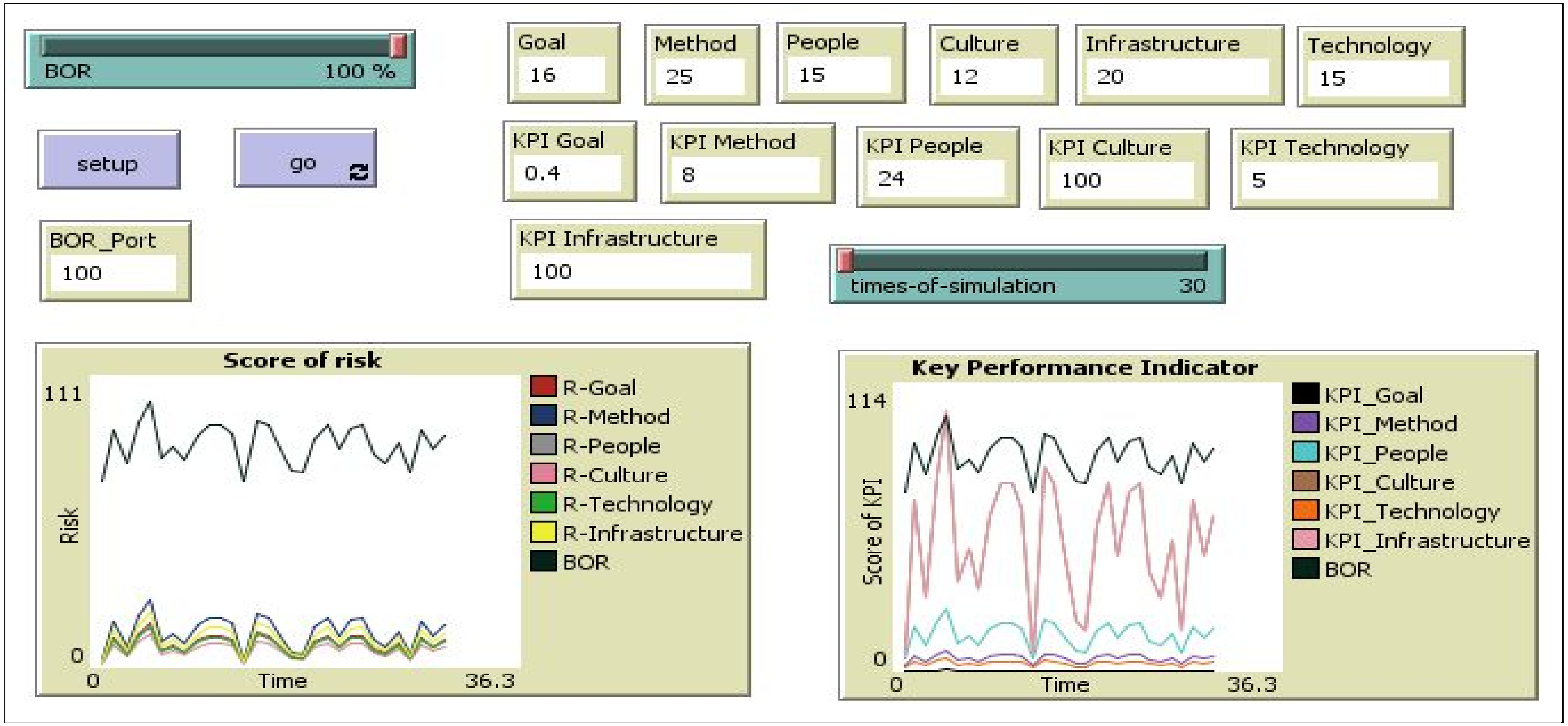

Figure E.10 The interface of simulation model

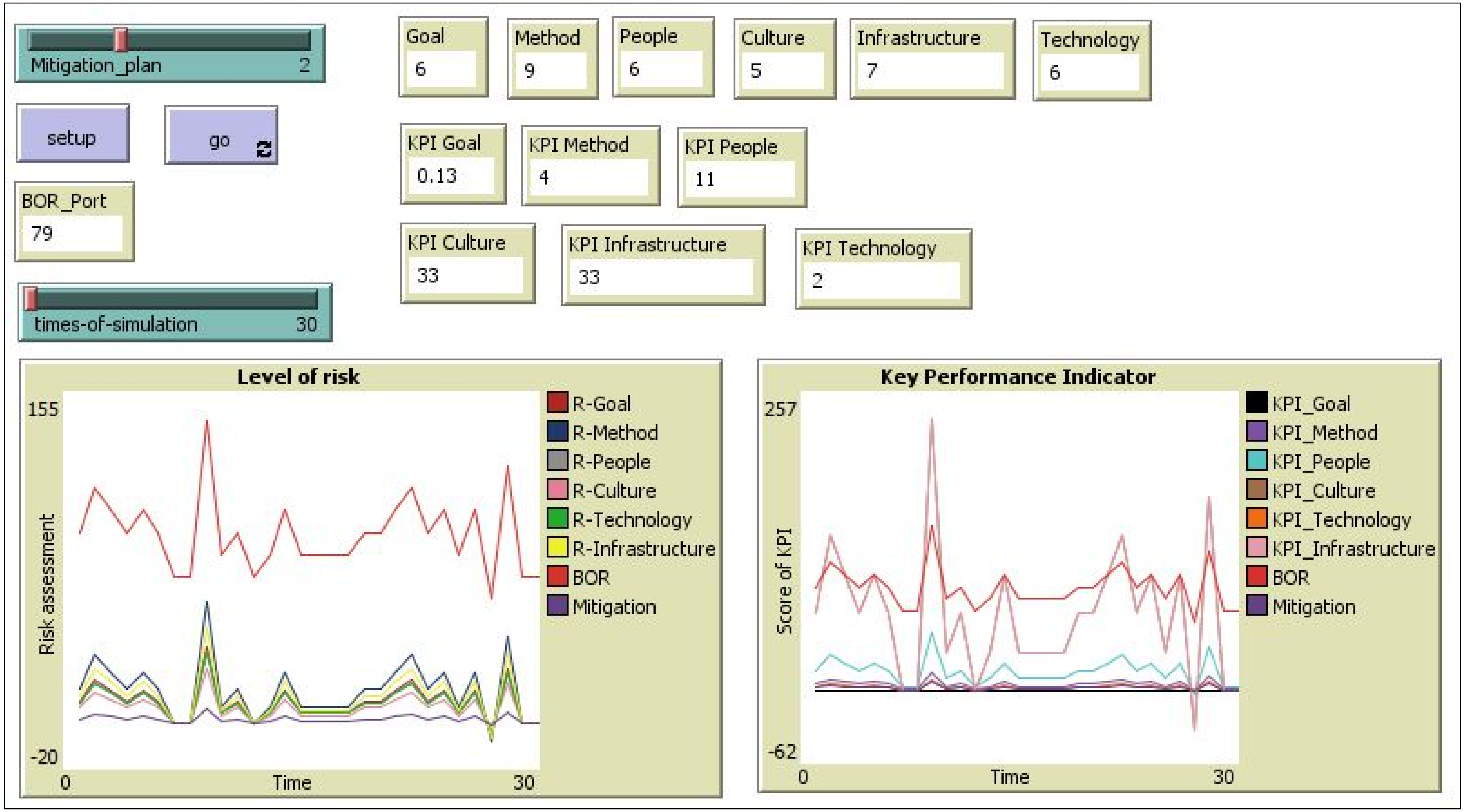

Figure E.11 The interface of the simulation model with a random level of mitigation plan

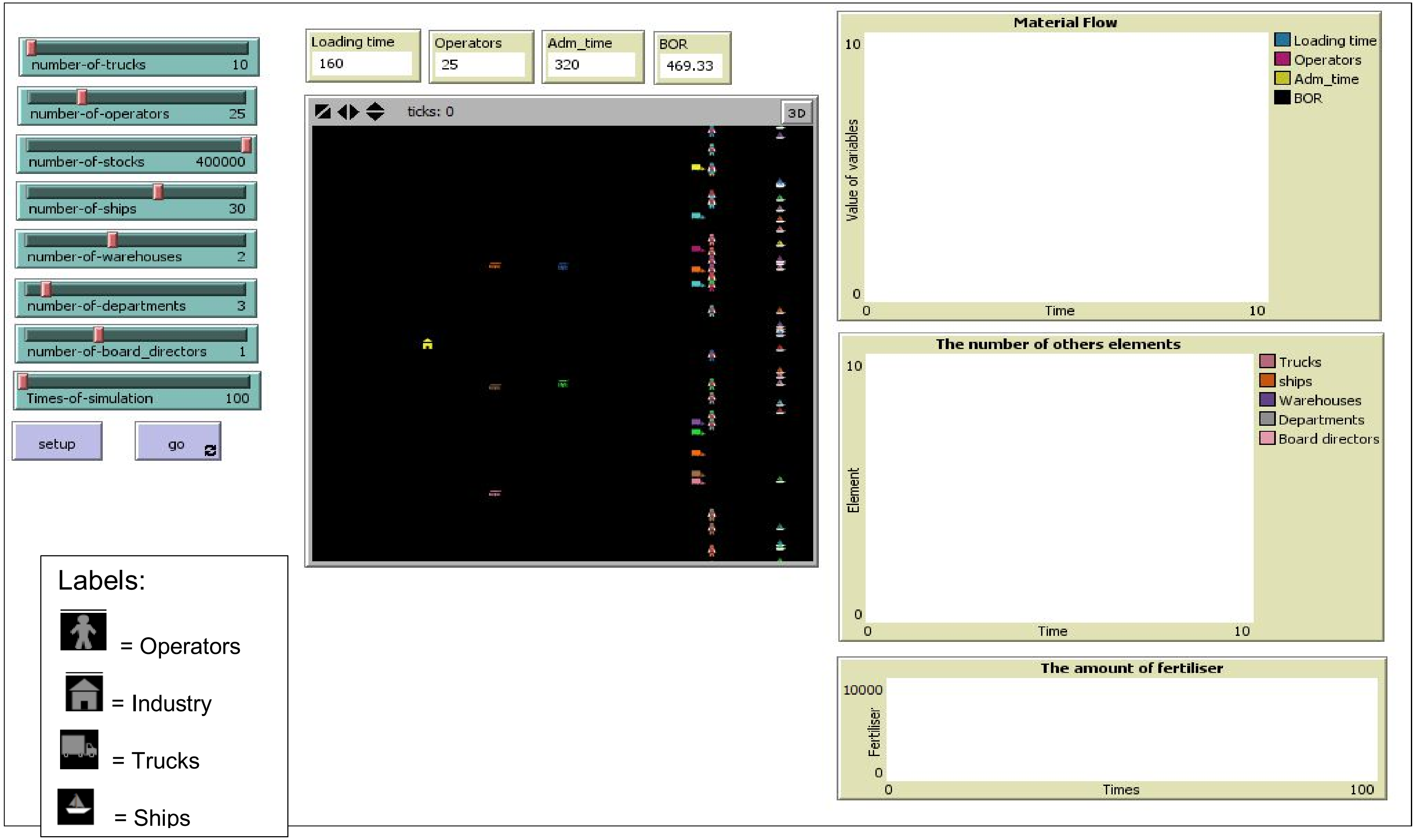

Figure E.12 The initial step of the simulation model: people are close to truck and they are ready to handle product from trucks to ships.

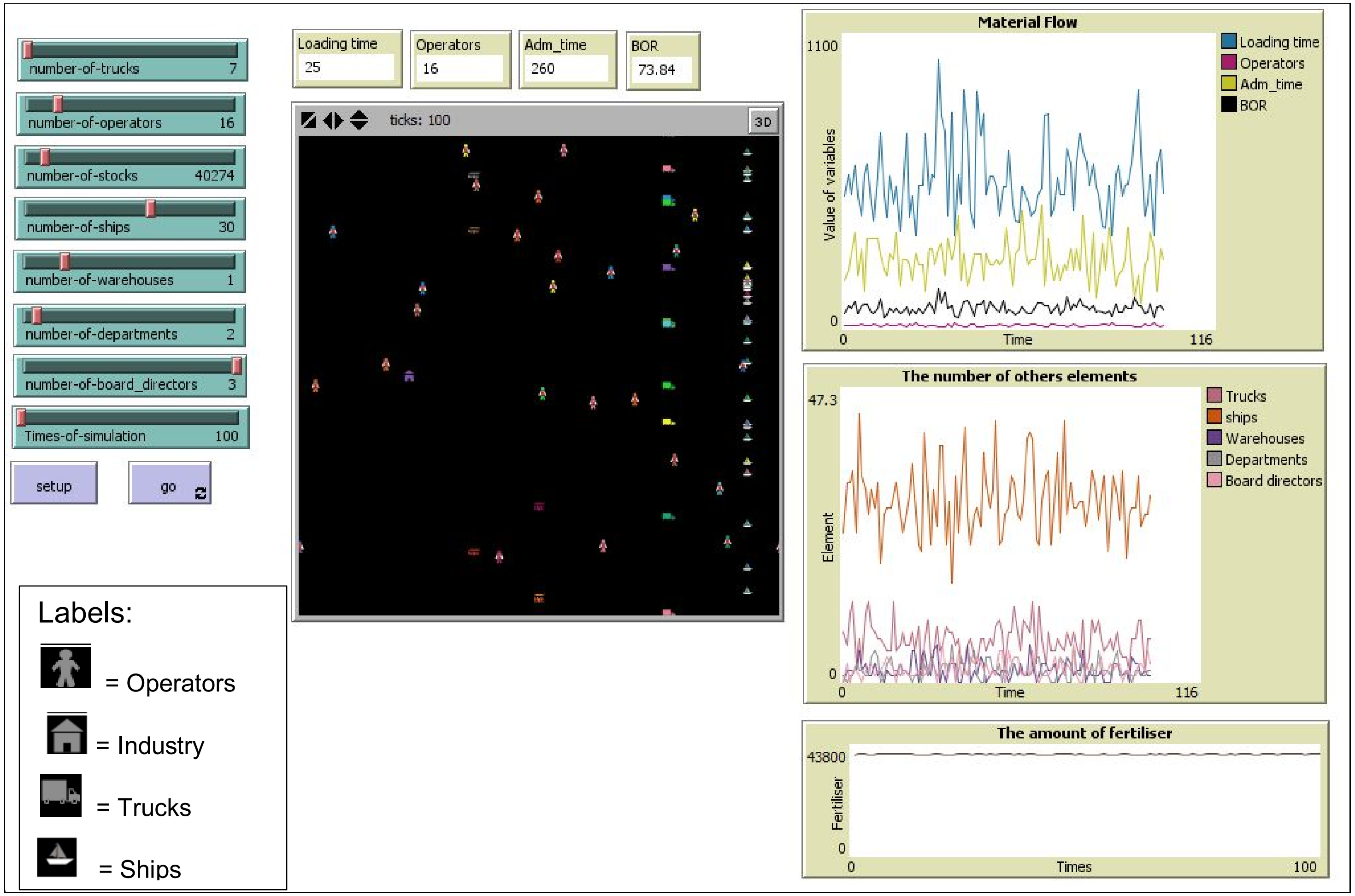

Figure E.13 The interface of the material flow simulation model

Appendix F
Table data populated

Table data population of conceptual model by using Express G. The tables were built by using Microsoft access 2007

Supply_networks_elements	
ID	Supply_networks_elements
1	Supplier_ammonia
2	Supplier_Phospat
3	Supplier_sulfur
4	Supplier_plastic_bags
5	The_fertiliser_industry
6	Distribution_centre_1
7	Distribution_centre_2
8	Distribution_centre_3
9	Distribution_centre_4
10	Distribution_centre_5
11	Distribution_centre_n
12	Distributor_1
13	Distributor_2
14	Distributor_3
15	Distributor_4
16	Distributor_5
17	Distributor_6
18	Distributor_7
19	Distributor_8
20	Distributor_9
21	Distributor_10
22	Distributor_n
23	Retailer_1
24	Retailer_2
25	Retailer_3
26	Retailer_4
27	Retailer_5
28	Retailer_6
29	Retailer_7
30	Retailer_8

Supply_networks_elements	
ID	Supply_networks_elements
31	Retailer_9
32	Retailer_10
33	Retailer_n
34	Farmers
35	Road
36	Rail_road
37	Port
38	Bridge
39	Risk_goals
40	Risk_procedures
41	Risk_culture
42	Risk_technology
43	Risk_building
44	Risk_people
45	Mitigation_goals
46	Mitigation_procedures
47	Mitigation_culture
48	Mitigation_technology
49	Mitigation_building
50	Mitigation_people
51	Decision_making
52	Resilience_assessment
53	Interoperability
54	Safety
55	Reliability
56	Availability

The_assessment_of_risk		
ID	Supply_networks_elements	Socio_technical_components
1	37	39, 40, 41, 42, 43, 44
2	35	39, 40, 41, 42, 43, 44
3	5	39, 40, 41, 42, 43, 44
4	36	39, 40, 41, 42, 43, 44
5	38	39, 40, 41, 42, 43, 44
6	11	39, 40, 41, 42, 43, 44
7	22	39, 40, 41, 42, 43, 44
8	33	39, 40, 41, 42, 43, 44

Decision_making_of_risk_mitigation			
ID	Supply_networks_elements	Socio_technical_components	The_decision_making
1	51	45, 46, 47, 48, 49, 50	52

Reports

Supply_networks_flow

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13:27:25

ID	Infrastructure_facilities	Origin	Destination
1	1	35, 37	5
2	2	35, 37	5
3	3	35, 37	5
4	4	35	5
5	5	35, 36	6
6	5	35, 36, 38	7
7	5	35, 36, 37, 38	8
8	5	35, 36, 37, 38	9
9	5	35, 36, 37, 38	10
10	5	35, 36, 37, 38	11
11	6	35, 37, 38	12
12	6	35, 37, 38	13
13	6	35, 37, 38	14
14	6	35, 37, 38	15
15	6	35, 37, 38	16
16	6	35, 37, 38	17
17	6	35, 37, 38	18
18	6	35, 37, 38	19
19	6	35, 37, 38	20
20	6, 7	35, 36, 37	21
21	8, 9, 10, 11	35, 36, 37, 38	22
22	12	35, 38	23
23	12	35, 38	24

24	12	35, 38	25
25	13	35, 38	26
26	13	35, 38	27
27	13	35, 38	28
28	12	35, 38	29
29	12	35, 38	30
30	14	35, 38	31
31	14	35, 38	32
32	13, 14, 15, 16, 17, 18, 19, 20, 21, 22	35, 36, 37, 38	33

The_assessment_of_risk

24 July 2014 13:31:11

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ID	Socio_technical_components	Supply_networks_elements
1	37	39, 40, 41, 42, 43, 44
2	35	39, 40, 41, 42, 43, 44
3	5	39, 40, 41, 42, 43, 44
4	36	39, 40, 41, 42, 43, 44
5	38	39, 40, 41, 42, 43, 44
6	11	39, 40, 41, 42, 43, 44
7	22	39, 40, 41, 42, 43, 44
8	33	39, 40, 41, 42, 43, 44

Decision_making_of_risk_mitigation

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ID	Socio_technical_components	Supply_networks_elements	The_decision_making
1	51	45, 46, 47, 48, 49, 50	52

The_assessment_of_resilience

24 July 2014 13:31:30

ID	Resilience_indicator	Socio_technical_components
1	52	53, 54, 55, 56