The resilience assessment of supply networks: A case study from the Indonesian Fertilizer Industry

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Abstract. The complexity of infrastructure availability changes leads to problems in supply networks. Consequently, supply networks need to become resilient to complex systems. This paper proposes a conceptual framework for assessing the resilience of supply networks to changes in infrastructure availability. A socio-technical system approach was integrated with an enterprise-engineering framework to design a resilience assessment framework. The framework aims to aid decision makers in assessing supply networks by considering the six perspectives of socio-technical systems. A case study from the fertilizer industry in Indonesia was used to evaluate the framework. The case study analysis identified port availability as the most important infrastructure facility that influences supply networks resilience in Indonesia. A simulation model was used to explore the effect of port availability on supply networks risk and resilience. By using the simulation model, decision makers can predict the level of risk and key performance indicators in order to assess resilience dimensions.

Keywords: resilience, risk assessment, port availability, simulation modelling

1. Introduction

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 internal organisation's operational system but also customers' satisfaction. The risk in supply networks is caused by numerous disruptions, for example: transportation infrastructure failures triggered 6% in supply chain and transport networks disruptions and as a dynamic environment, there is crucial need to review risk management practices to support strategic decision making to establish risk mitigation methods [1]. Resilience is important when considering the interconnectedness in supply networks, where risk and disruption can have significant impact globally. Therefore, to survive, supply networks must be resilient [2] and assess their resilience periodically. In order for resilience assessment aid supply networks to be successful, they need to deal with risk by making resilience part of the supply networks in day-to-day operations [3]. Hence, decision makers and researchers must concern themselves with development of risk assessment as a fundamental practical approach to create resilient supply networks.
In the current era of global markets, ports are important infrastructure facilities for the sustainability of supply networks [4], [5]. Thus this study presents a conceptual model of how to use 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. This study focuses on the effect of a port's utilisation on level of risk and resilience in the supply networks with the case study on the Indonesian fertilizer industry as an example of conceptual model application.

The structure of this paper is as follows: Section 2 provides a review of the literature to identify resilience definition and theoretical framework. The methodology used in this research is explained in Section 3. The results of the case study analysis are described in Section 4. Section 5 presents the conceptual model for assessing supply network resilience, while Section 6 describes simulation modelling for applying the framework in the case study and the results of the resilience assessment. Finally, Section 7 presents the conclusion and contribution of this research to knowledge.

2. Defining resilience

Resilience is a concept that has had many definitions, depending on the areas of application. Several studies proposed the concept of resilience and its measurement in physical infrastructure facilities [6], [7], [8]. The resilience of physical infrastructure is important and most visible during and after a natural disaster (earthquake, flood, and drought), which disturb the performance of these facilities. However, organisations also have to manage their resilience (for example: supply networks failures) in order to deal with competitiveness and maintain customers satisfaction [3]. There are still few studies on measuring supply networks resilience. In contrast to the well-established supply networks design, where the research issues and types of problems have been established during the last two decades, research in supply networks resilience by considering dynamic analysis and control of risk have so far received little systematic consideration. Although many studies consider possible stochastic scenarios or perturbations by quantifying the probability and impact of risk, they do not include any suggestions on how to proceed in the case of disturbance or disruptions [9]. Hence, this paper proposes to measure the resilience of supply networks to changes in infrastructure availability. The definition of resilience used in this reseach is the ability the ability to recover quickly from risks and infrastructure facility changes to achieve expected target. Measurement of resilience will enable organisations to identify how resilient their supply networks are and what the supply networks can do to improve their resilience.

This paper argues that resilience assessment and identification need to be addressed from the decision makers' perspective in supply networks because the decision makers are definitely knowledgeable and understand real activities and operational events in the supply network. In addition, they can define critical criteria in resilience assessment based on historical data and experiences and supply networks resilience affects supply networks performance [2]. Hence, this paper aims to develop and evaluate a tool for assessing the resilience of supply networks to changes in infrastructure availability based on decision makers' requirements and focus on the effect of infrastructure facility changes by considering risk.

2.1. The risk assessment in supply networks

Supply networks should be resilient to vulnerable or negative effects of risk. Resilience is the ability to recover from the disturbance through the development of responsiveness, capabilities, redundancy and flexibility [10]. Disruptions in the supply network affect not only an organization's operational system but also all supply networks components. Tuncel and Alpan [11] defined 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 [8] formulated the quantitative definition of supply-chain risk as: Risk = ($P_{Loss} \times I_{Loss}$), where risk is the function of the probability (P) of loss and the significance of its consequences (I) [8]. 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 [8], [12].

2.2. Socio-technical system

The Socio-technical approach is a method to give equal weight to social and technical issues when systems are being designed [13]. This approach recognizes that any organisation, or part of it, is made up of a set of interacting sub-systems. Thus, any organisation has goals, vision and value, employs people with capabilities, mind sets and attitudes, working in physical infrastructure, using technologies and tools, working with processes and practices, and sharing certain cultural assumptions and norms [14], [15]. The socio-technical framework identifies potential threats in systems so the system can be made more resilient. A socio-technical perspective could be extended to supply network systems by considering interconnection and involvement of people or organisations (end-users, managers, technologists, human factor specialists, trade unionists, suppliers, government) in system design process [15]. In this study, application of socio-technical framework to configure resilience assessment in supply networks could be applied in the resilience assessment cycle.

2.3. Theoretical framework

A theoretical framework in Figure 1 has been generated to represent resilience assessment comprehensively. The framework suggests that resilience assessment in supply networks is a collaboration of different processes in some specific sequence. The processes have five steps of analysis 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 assess resilient supply networks, strategy planning and implementation of the resilience methodology, and controlling the strategy by comparing targets and achievement of performance. Key performance indicators (KPI) and resilience dimensions have been defined in order to determine resilience metrics. The resilience dimensions are Interoperability: integration of a diverse subsystem to collaborate in order to achieve goal, Safety: the ability to protect against failure or damage, Reliability: continuity in achieving targets, and Availability: the availability of resources in dealing with system changes.

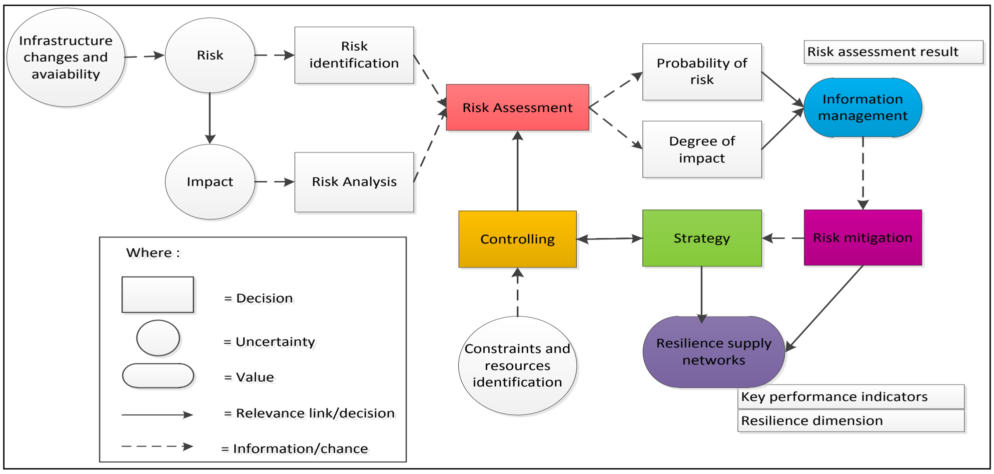

Figure 1 Theoretical framework of resilience assessment in supply network

3. Methodology

A combination of case study and simulation approach was used. A case study approach investigates a contemporary phenomenon in depth and within real life [16], while a simulation approach constructs an artificial system within relevant information and data from the case study [17]. A simulation approach permits observation of the dynamic behaviour of a system and is useful for understanding future conditions. Due to the complexity of supply infrastructure networks, a holistic case study is conducted in an in-depth case study of one particular industry. The fertilizer industry in Indonesia 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.

Table 1 Enterprise engineering framework for assessing resilience

	Define	Develop	Deploy
Purpose	Assess resilience of Indonesia supply network		
Agency	Indonesian fertilizer industry	Conceptual framework and simulation modelling for assessing resilience of supply network	
Products and services	Decision making tools to support supply network decision makers		How should we assess the resilience of supply network

This research used the Enterprise Engineering Framework [18] to visualize sources, criteria and models of the assessment of resilience in supply networks. As shown in Table 1, the purpose is to create a tool to assess the resilience of supply networks with a case study of industry as the agency which served as the intended organization that applies developed framework or tools to serve the purpose of defining supply networks resilience assessment with the focus on infrastructure changes and availability in order to achieve customer satisfaction.

3.1. Data collection

Yin [16] identified six sources to collect data for the case study analysis: documentation, archival records, interviews, direct observations, participants' observation and physical artefacts. Data sources for this study were collected by conducting fieldwork research in the fertilizer industry in Indonesia. A semi structured questionnaire was used to collect information and data.
The questions were:
(1) Who are key suppliers of your organization?
(2) For each of key supplier:
 (a) What do they supply?
 (b) How do you use it?
 (c) Where is the supplier of the products factory located?
 (d) How is it transported?
 (e) What are the infrastructure facilities they need?
 (f) Where does the interviewee think the biggest risks are?
(3) Who are key consumers?
(4) For each of key consumers:
 (a) What do they buy?
 (b) How do you use it?
 (c) Where is the consumer of the product(s) located?
 (d) How is it transported?
 (e) What are the infrastructure facilities they need?
 (f) Where does the interviewee think the biggest risks are?

Before conducting interviews, researchers explained to the participants the definitions and clarified information that addressed the answers. The researcher recorded the answers and available data that have been given by participants to support the information. The participants are key people who have tasks and responsibilities in supply networks management.

4. Case study analysis

This paper presents the fertilizer industry in Indonesia as a case study to assess the resilience in supply networks. As an agrarian country, the fertilizer industry is a significantly important industry to support agricultural development. The main product of the Indonesian fertilizer industry is subsidized fertilizers that are distributed to small and medium income farmers throughout Indonesian. However, the fertilizer industry supply networks in Indonesia tend to be at risk due to changes in infrastructure availability.

The supply networks in the fertilizer industry are a special case because overall supply networks elements are ruled by government regulations. The elements of the fertilizer industry supply networks are the fertilizer industry, distribution centres, distributors, with retailers and farmers as the end consumers. In order to support supply networks flow, the fertilizer industry has its own port, namely T-port that is located near the industry. The decision makers in the fertilizer industry understand that port availability has a significant influence on supply networks' resilience. The risk assessment department of the industry reported strategic risks related to the supply networks 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 fertilizer industry. This report provides evidence that the infrastructure availability, especially the port, causes a major impact on the resilience of supply networks. Therefore, the assessment of supply networks risk is an increasingly important stage to achieve targets and to improve the fertilizer industry resilience and performance.

4.1. Key performance indicators of resilience assessments

In this study, key performance indicators (KPIs) were defined by taking account of supply networks performance, resilience assessment and infrastructure availability. The researcher worked with decision makers to understand their requirements by using the house of quality matrix [19]. Meanwhile, six socio-technical perspectives (goal, method, people, culture, infrastructure and technology) [15] have been applied to identify the KPIs. The decision makers suggested that in order to achieve and maintain supply network resilience, the fertilizer industry should concern itself with risk reduction. Customer satisfaction, as the fertilizer industry's primary goal, could be achieved by considering and managing not only physical facilities but also coordination of high quality human resources. Further, T-port, as the infrastructure facility that influences the supply networks in loading or unloading gain significant effect on risk and resilience in the supply networks. The fertilizer industry uses Berth Occupancy Ratio (BOR) to measure port availability. One important component in BOR is loading or unloading time. Hence, this study suggested that BOR significantly influence risk and resilience in supply networks.
Key performance indicators that have been identified in this study are as follows:

1) KPI for Goal: Customer Complaint: the target established by industry for customer complaint is from 0 % to 0.4%.
2) KPI for method: lateness in the loading process from trucks to ships by operators. The lowest value was 2 hours and the highest value was 8 hours.
3) KPI for people: the number of working hours lost due to the delay in loading or unloading. The lowest value is 4 hours the highest value is 24 hours.
4) KPI for culture: inaccurate data entry by administration staff. The lowest value was 0% and the highest was 100%.
5) KPI for infrastructure: Amount of excess space in warehouse. This KPI lowest value was 0 % and the highest value was 100%.
6) KPI for technology: Number of equipment breakdowns in loading or unloading per month. The industry assigns a breakdown at least once per month and a maximum of five times per month or more.

5. Conceptual modeling of the resilience assessment

A model should be developed for a specific purpose or application and its validity determined with respect to that purpose [20]. The conceptual model configuration is an important stage in model building with the main objective being to transfer data from a real world system into a model language. A conceptual model is an abstract model of reality which is platform independent [21]. In this paper, a conceptual model has been designed to subsequently translate the real supply network into a more detailed system-level. A conceptual model of resilience assessment in the Indonesian supply network was drawn by using EXPRESS G notation [22] as illustrated in Figure 2. The model consists of entities and attributes. The entities are the main concepts of the theoretical frameworks, which are the supply network, infrastructure facilities, the risk assessment, decision making process and resilience assessment. The attributes are information and entities definitions.

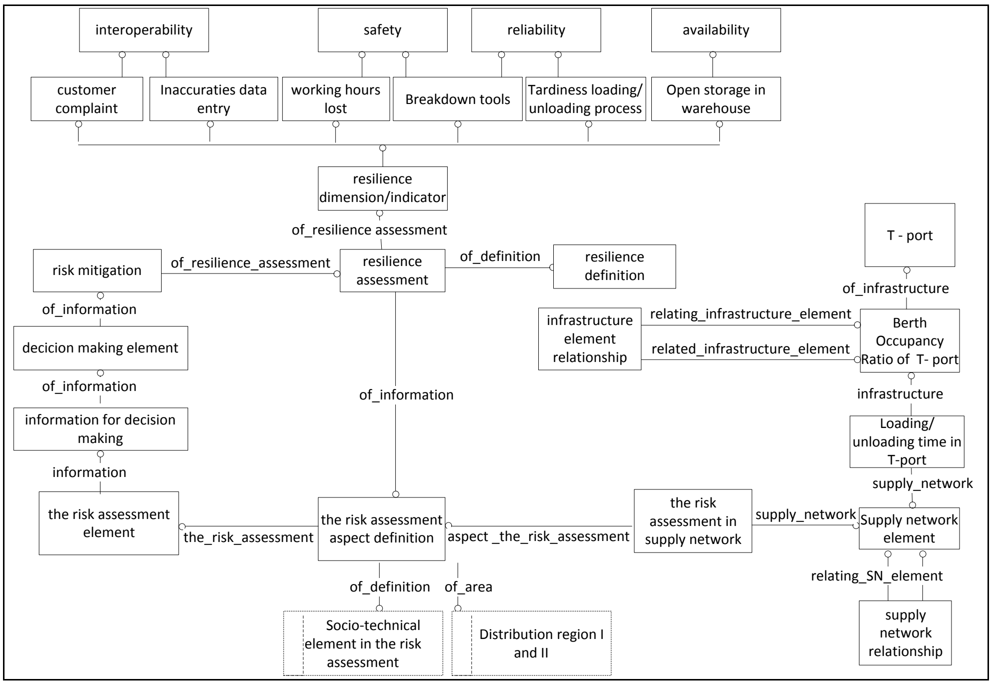

Figure 2 Conceptual modelling of the assessment of resilience of supply network

Key performance indicators were divided into six socio-technical system perspectives. Since the fertilizer industry has a standard value in determining the lowest and highest values of key performance indicators, this study adopted the interpolation calculation [23] as shown Equation (1) to calculate the relationship between the value of the KPI and BOR.

Interpolation formula of key performance indicators is as follows:

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

BOR_c = standard value of berth occupancy ratio in the fertilizer 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

The risk level for each perspectives of the socio-technical system was calculated after determining key performance indicators. Calculation of risk levels also adopted interpolation formula as shown in Equation (2) to determine the relationship between the value of berth occupancy ratio and level of risk. Data of input in the simulation model was determined based on data collected from the industry. The level of risk assessment 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 $= 1 + \frac{(Re - Rc)}{(KPIe - KPIc)} \times (KPId - KPIc)$ Equation (2)

BOR_c = standard value of berth occupancy ratio in the fertilizer 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

6. Simulation modeling of the resilience assessment

A simulation model is a computerized version of a conceptual model [21]. Simulation is an effective tool in representing the behaviour of systems in the real world by using computer programming. This paper used Netlogo 5.0.4 to build a resilience assessment model and significantly represent the effect of infrastructure changes in supply networks resilience. Netlogo 5.0.4 provides code and variable that can help model developers to build systems based on purposes dynamically.
Figure 3 shows the simulation modeler code the effect of BOR on risk assessment and key performance indicators. The variables and code programming of simulation model are shown in table 2. The Six perspectives of the socio-technical system have been integrated in the model to help decision makers to measure key performance indicators value and risk assessment. The interface of the simulation model in Figure 4 illustrates the level of risk and key performance indicators as the output of the simulation model.

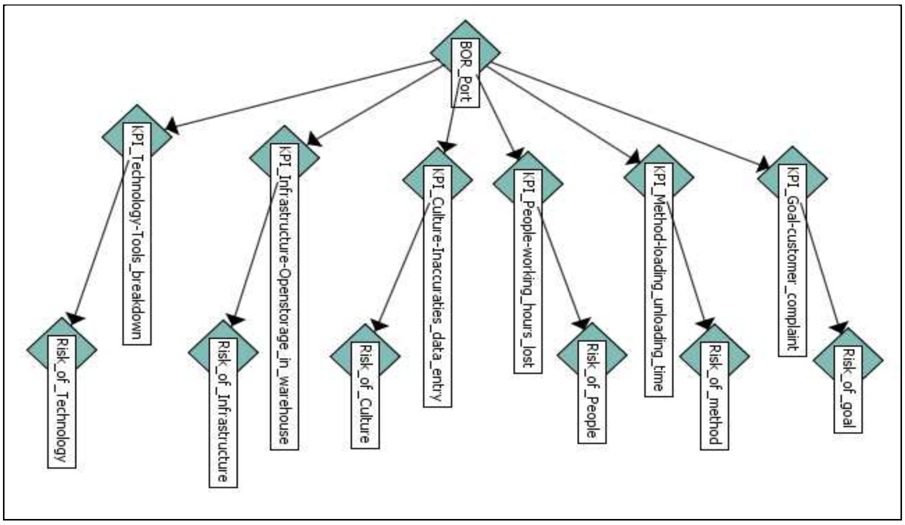

Figure 3 System modeler of resilience assessment

Table 2 Description of variables and code in simulation modeling

Variables' Code in Figure 3	Interface model in Figure 4	Descriptions
BOR_Port	BOR	Bert occupancy ratio of Port
KPI_Goal-customer_complaint	KPI Goal	Number of Customer Complaint
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

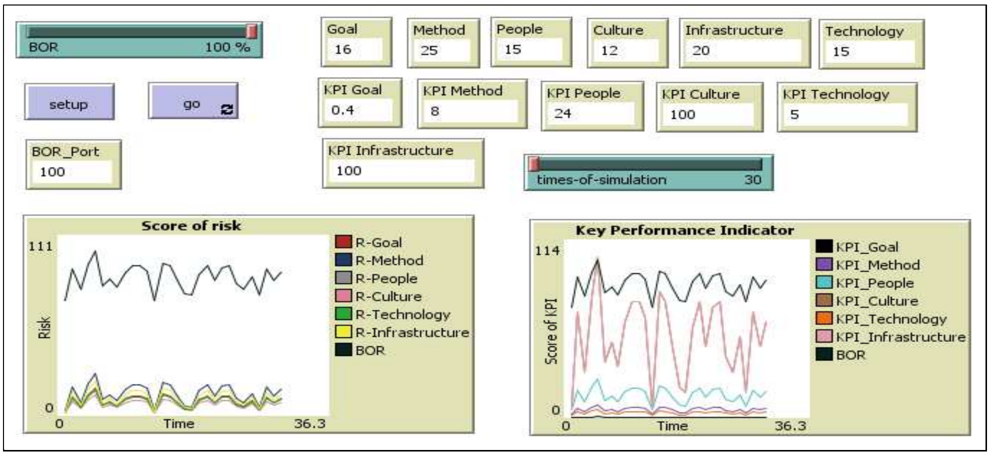

Figure 4 The interface of simulation modelling

Table 3 and Table 4 show examples of simulation model output in three times. The tables show that the difference value of BOR obtained different values of key performance indicators and risk.

Table 3 Output of simulation model: the level of risk assessment

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

Table 4 Output of simulation model: the level of key performance indicators

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

This research applied face validity [20] and a subjective approach [24] to verify and validate the conceptual model. As the objective of the verification and validation process is to ensure that the model fulfils decision maker requirements, formal design of model review [19] has been applied. Results of verification and validation model found that participants agreed with the result of the data analysed and they considered applying the socio-technical system in the risk assessment and mitigation activity and report.

Analysis of resilience assessment on the fertilizer industry supply networks can be determined based on KPIs that are obtained from the output of the simulation results. For example, if the BOR is 90%, the interoperability dimensions: the number of customers to complain is 0.27% and inaccurate data entry is 68%. This shows the level of collaboration within the system supply networks is still low. Next on the dimensions of Safety: loss of working hours are 18 hours and break down loading or unloading machinery is 4 times per month. In addition, the dimension of reliability: tardiness in the process of loading and unloading is 6 hours. This indicates that the level of resilience of the fertilizer industry in continuity of the process is still too low. Fourth dimension, Availability: the availability of open storage for storing excess stocks of fertilizer also reached 68% which means there was still plenty of fertilizer stock that had not been distributed due to the level of the port utility still being low.

7. Conclusion

This research introduces a new conceptual framework to assess resilience in supply networks elements by considering risk assessment and infrastructure availability changes. A case study in the Indonesian fertilizer industry has been presented as an example of the conceptual framework implementation. The results of the case study analysis found that the port is an important infrastructure in the supply networks flow and had significant effect on risk and resilience. A simulation model has been built to represent conceptual modelling in computer language. The advantages of simulation modelling are it helps researchers and decision makers to predict and measure resilience level in the supply networks and investigate correlation between the berth occupancy ratio in a port, risk assessment level and key performance indicators by using historical data from the industry. In addition, the decision makers can explore the influence of port availability on their supply networks flow without changing the real system. Moreover, results of simulation modelling can help decision makers to predict risk assessment results and use them as valuable information to establish a mitigation plan and control the value of key performance indicators to achieve targets.

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