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Cost-effective Strategy to Mitigate Transportation Disruption in Supply Chain

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COST-EFFECTIVE STRATEGY TO MITIGATE TRANSPORTATION DISRUPTION IN SUPPLY CHAIN

This thesis is composed with the expectation of getting the approval from Industrial Engineering Department Graduate Program, Supervisor and examiners member of this research to fulfill the requirements for the Degree of Master in Engineering

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Declare that my thesis entitled:

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Is a complete independent work of mine, completed without using any illegal information, nor the work of others that I recognize as my own work.

All cited and references are listed in the bibliography.

If it turns out that this statement is not true, I am willing to accept the consequences in accordance with the regulations.

Surabaya, July 19th 2017
Sincerely,

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ABSTRACT

Phenomena of disruption events in supply chain have gained many attractions by scholars. Even though transportation plays a central role in supply chain, studies in transportation disruption has received little attention. This research simulates a model of order delivery process from a focal company (FC) to a single distributor, where a transportation disruption stochastically occurs. Considering the possibility of sales loss during the disruption duration, we proposed a redundant stock, flexible route, and combined flexibility-redundancy (ReFlex) as mitigation strategies and a base case as a risk acceptance strategy. The objective is to find out the best strategy that promote cost-effectiveness against transportation disruption. In the base case, delivery process was halt during the disruption duration and resumed as soon as the road has been fixed. In the redundant stock situation, FC placed an extra stock in distributor's warehouse that act as a buffer against stockouts. In flexible route, FC use an alternative route for the delivery process only when disruption occurred. In ReFlex, when disruption occurs, not only that alternative route was taken, but also an extra stock in distributor's warehouse was placed to protect against stockouts. We ran the simulation model using these strategies for 5 brands. We found that the proposed mitigation strategies were having the capability to negate the impact of transportation disruption, each with its own cost and effectiveness, while accepting the risk caused the greatest loss. We found that redundant stock gave the best effectiveness against disruption for all brands, ReFlex as the second best, while flexible route gave the least effectiveness. We also found through sensitivity analysis that ReFlex has the potential to become the best option with buffer stock quantity improvement. Finally, through cost-effectiveness analysis (CEA) we gave recommendations of which strategy should be applied based on the decision maker willingness to pay.

Keywords: Transportation disruption, mitigation strategy, redundant stock, flexible route, simulation modeling, cost-effectiveness analysis

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EFEKTIVITAS BIAYA PADA STRATEGI PENANGGULANGAN DISRUPSI TRANSPORTASI PADA RANTAI PASOK

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ABSTRAK

Fenomena disrupsi dalam rantai pasok telah banyak diminati para peneliti. Meskipun transportasi memainkan peran sentral dalam rantai pasok, studi tentang disrupsi transportasi hanya mendapat sedikit perhatian. Penelitian ini mensimulasikan proses pengiriman pesanan dari perusahaan yg di amati (focal company - FC) ke distributor tunggal, dimana terjadi disrupsi transportasi secara stokastik. Mengingat adanya kemungkinan kehilangan penjualan selama disrupsi terjadi, kami menawarkan *redundant stock*, *flexible route*, dan gabungan *redundancy-flexibility* (ReFlex) sebagai strategi mitigasi dan *base case* sebagai strategi penerimaan risiko. Tujuannya adalah untuk mengetahui strategi terbaik yg menunjukkan efektivitas biaya terhadap disrupsi transportasi. Pada *base case*, proses pengiriman dihentikan selama masa disrupsi dan dilanjutkan begitu jalan telah diperbaiki. Pada *redundant stock*, FC menempatkan persediaan tambahan di gudang distributor yang bertindak sebagai penyangga terhadap *stockouts*. Pada *flexible route*, FC menggunakan jalur alternatif untuk proses pengiriman hanya saat terjadi disrupsi. Pada ReFlex, ketika terjadi disrupsi, tidak hanya rute alternatif yang diambil, tapi persediaan tambahan di gudang distributor juga ditempatkan sebagai perlindungan terhadap *stockouts*. Kami menjalankan model simulasi dengan menggunakan strategi-strategi ini kepada 5 merek. Kami menemukan bahwa strategi mitigasi yang diusulkan memiliki kemampuan untuk mengurangi dampak disrupsi transportasi, masing-masing dengan biaya dan efektivitasnya sendiri, sementara penerimaan risiko pada base case menyebabkan kerugian terbesar. Kami menemukan bahwa *redundant stock* memberikan keefektifan terbaik dalam menanggulangi disrupsi pada semua merek, ReFlex sebagai yang terbaik kedua, sementara rute yang fleksibel memberi sedikit efektivitas. Kami juga menemukan melalui analisis sensitivitas bahwa ReFlex berpotensi menjadi pilihan terbaik dengan melalui peningkatan jumlah persediaan penyangga. Akhirnya, melalui analisis efektivitas biaya (*cost-effectiveness analysis* - CEA) kami memberikan rekomendasi mengenai strategi mana yang harus diterapkan berdasarkan keinginan pembuat keputusan untuk membayar.

Keywords: Disrupsi transportasi, strategi mitigasi, *redundant stock*, *flexible route*, pemodelan simulasi, analisis efektivitas biaya

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CHAPTER 1

INTRODUCTION

1.1. Background

All supply chain are inherently risky because all supply chains will experience, sooner or later one or more unanticipated event that would disrupt normal flow of goods and material (Christopher et al., 2007). This increased risk of disruption has been further exacerbated by recent trend and practices in managing supply chain such increased complexity due to global sourcing, increased reliance on outsourcing and partnering, single sourcing strategies, and lean supply chain that focused on reducing inventory (Hendricks and Singhal, 2005). A disruption is defined as an event that interrupts the material flows in the supply chain, resulting in an abrupt cessation of the movement of goods (Wilson, 2007). In addition, Tang et al. (2008) mentioned that a disruption happens because there is a radical transformation of the supply chain system, through the non-availability of certain production, warehousing and distribution facilities, or transportation options because unexpected events caused by human or natural factors. There are many examples that demonstrate the unexpected event of supply chain disruption. On March 2000, Ericsson had a supply disruption of critical cellular phone component because their key supplier (Philips's plant in New Mexico) was caught on fire, the supply disruption at Philips caused Ericsson $200 million loss of sales (Latour, 2001). Thailand flood in 2011 forced Western Digital to closed two factories and led to paralysis of transportation facilities on a large scale (Liu et al., 2016). In 2002, union strike at a U.S. West Coast port disrupted transshipment and deliveries and it took 6 months to get back to normal operations and schedules (Cavinato, 2004). From these cases, disruption risk tend to have a chain effect on supply chain and also has a material impact both on cost and company value if underestimated or completely ignored (Chopra and Sodhi, 2004; Christopher et al., 2007; Schmidt and Raman, 2012).

Considering the severe impact, there were many research has been conducted in the area of supply chain disruption, most of them about supply disruption and/or facility disruption. Unfortunately, transportation disruption as one aspect of the risk management of supply chain disruption (Liu et al., 2016; Sheffi et al., 2003) has received less attention (Hishamuddin et al., 2013; Ho et al., 2015; Wilson, 2007). One example of transportation disruption that crippling a supply chain was the catastrophic event of Iceland's Eyjafjallajokull volcano eruption in 2010 that disrupting the air transportation from and going to Europe, it had forced Nissan and BMW to stop their production. Wilson (2007), Yang and Wu (2007), and Figliozzi and Zhang (2010) studied the impact of transportation disruption in supply chain and found that it may lead to drop in supply chain performance. We concluded that transportation disruption has a great negative impact on supply chain that threatening company's business continuity, hence transportation disruption is a worth research topic.

To the best of our knowledge, Wilson (2007) was the first research paper that investigated the phenomena of transportation disruption in supply chain. Beside Wilson (2007), until 2017 there exists several research paper investigating transportation disruption in supply chain: Yang and Wu (2007), Bai and Wang, (2008), Chen and Zhang (2009), Figliozzi and Zhang (2010), Husdal and Brathen (2010), Ishfaq (2012), Houshyar et al. (2013), Hishamuddin et al. (2013), Cui et al. (2016), Zhen et al. (2016), and Liu et al. (2016). From all of these mentioned research papers, we found out that none of them was trying to apply strategies (in a real situation) to protect the supply chain from the harmful effect of transportation disruption. We proposed 4 strategies to engage a disrupted transportation scenario: (1) "Do nothing" strategy; (2) Mitigation strategy through redundancy; (3) Mitigation strategy through flexibility; (4) Mitigation strategy through redundancy-flexibility (combination).

Talluri et al., (2013) mentioned that simply proposing mitigation strategies is not adequate, hence Talluri et al., (2013) urged the effectiveness of a strategy must be judged with respect to its cost and non-cost factors. This research was trying to fill the gap of research in transportation disruption by evaluating cost-effectiveness of the proposed strategies against transportation disruption. We chose simulation modeling as a tool to measure the cost and effectiveness of each strategy against transportation disruption because it has the capability to analyze complex model when the analytical techniques are difficult to implement (Law, 2007), especially if the system incorporates stochastic variables (Pujawan et al., 2015). Simulation modeling is also has been proven as a valuable tool to investigate the effectiveness of mitigation strategies against supply chain disruptions (Schmitt, 2011; Son and Orchard, 2013). Finally, a cost-effectiveness analysis (CEA) was chosen as a multi-criteria decision making tool for its proven capability in assessing and comparing the cost-effectiveness of alternate strategies, especially when the effectiveness measure is difficult to monetized (Boardman et al., 2010).

1.2. Research Question

This research was trying to address the research question: what is the best strategy that cost-effectively mitigate transportation disruption in supply chain?

1.3. Research Objectives

Given the reasons outlined in the introduction, this research tried to achieve the following objectives:

1. To prove the capability of the proposed mitigation strategies on negating the impact of transportation disruption;
2. To show the cost and effectiveness of each strategy when deployed against transportation disruption;
3. To give recommendation of the best strategy that cost-effectively mitigate transportation disruption.

1.4. Benefits

This research was targeting both academics and professional in supply chain (particularly in finished goods distribution). Therefore, this research offered two potential benefits as follows:

1. For academics, this research will add a contribution to supply chain disruption body of knowledge, in particular transportation disruption. This research was

applying the existing mitigation strategies and evaluating its cost-effectiveness through real distribution activities. Hence, this research indirectly tried to confirm whether the said mitigation strategies as good or as effective as it was claimed to mitigate disruptions in supply chain.

2. For professional, by evaluating the cost-effectiveness, this research had a managerial implication on decision making process, that not only about whether or not the management should financially invest on mitigation strategy, but also (if they invest), which mitigation strategy should be applied according to the willingness of payment.

1.5. Research Limitation

When conducting this research, we applied some limitations into the scope of our research as follows:

1. The case study is limited into a single focal company.
2. The distribution is limited to a single distributor.
3. The transportation mode during the distribution is limited via land mode (using truck) of which has the farthest distance from the focal company's plant to distributor's warehouse.

1.6. Assumptions

This research was conducted under the following assumptions:

1. The risk of transportation disruption assumed to be the single source of uncertainty. Hence other type of risk doesn't exist;
2. The distributor's warehouse capacity is assumed to be unlimited, thus able to hold any redundant stock quantity.

Other assumptions in respect of the simulation were introduced gradually in simulation study in chapter 5.

1.7. Thesis Structure

The remainder of this thesis was structured as described below.

CHAPTER 2 **LITERATURE REVIEW**

This chapter shows the literatures that we used to build and strengthen our research, including methodologies and practices that widely adopted by scholars.

CHAPTER 3 **RESEARCH METHOD**

This chapter gives explanation about how we fulfill the objective of this research by our constructed research framework. This chapter also shows methods that we used in this research.

CHAPTER 4 **DATA COLLECTION**

This chapter describes about how we obtain the data for this research. This includes the reasons for selecting the focal company (consigner) and the distributor (consignee), consequent cost functions, delivery schedules, and natural disaster frequency, transportation activity, and proposed strategies.

CHAPTER 5 **SIMULATION STUDY & CEA**

This chapter shows how we conduct the simulation study and CEA by using applying the specified methods from chapter 3 and collected data from chapter 4.

CHAPTER 6 **ANALYSIS & FINDINGS**

This chapter shows how we conduct sensitivity analysis by changing specific factors for each brand and analyze changes in responses and recommendations. Then we presented the findings.

CHAPTER 7	**CONCLUSIONS & CONTRIBUTIONS** In this chapter we draw conclusions from our findings and presented contributions that this research has to offered.

CHAPTER 2

LITERATURE REVIEW

This chapter shows the literatures that we used to build and strengthen our research, including methodologies and practices that widely adopted by scholars.

2.1. Supply Chain

Supply chain defined by Pujawan and Mahendrawathi (2010, p. 5) as network of companies that working together to create and deliver a product to end customer. These companies not only the suppliers and manufacturer, but also distributors, retailers, transporters, and even the customers themselves. The word 'network' had been advised by Christopher (2011) and Chopra and Meindl (2015) as the representation of the word 'chain', since typically there will be multiple suppliers that supply our suppliers as well as multiple customers that become our customers' customer, of which should be included in the system. Figure 2.1 below illustrates the term network in the supply chain that both Pujawan and Mahendrawathi (2010) and Christopher (2011) were explaining about.

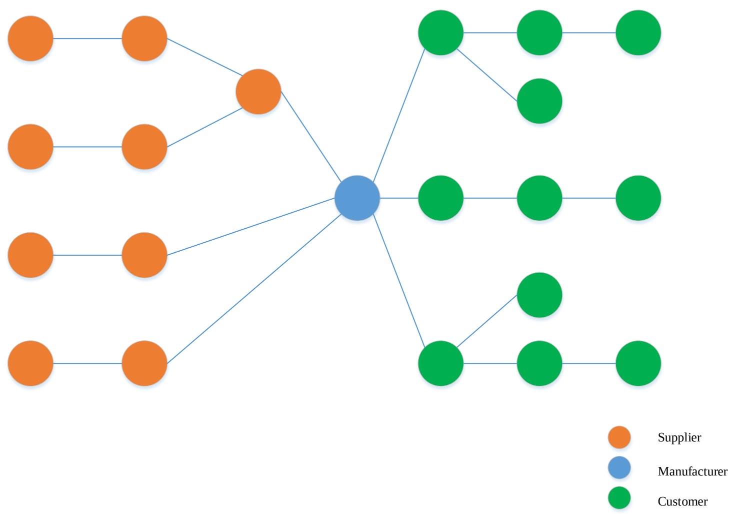


Figure 2.1 Supply chain as a network of companies

As shown by Figure 2.1 above that the blue circle represents the manufacturer that produce finished goods using materials from the suppliers (the orange circle). These suppliers also have suppliers, while on the right hand side of the manufacturer, there exists customers (green circle). There are customers that directly doing business with manufacturer and these customers also have customers. The network between supplier's suppliers to manufacturer and from manufacture to customer's customers creates stages in supply chain as mentioned by Chopra and Meindl (2015) that depicted in Figure 2.2 below.

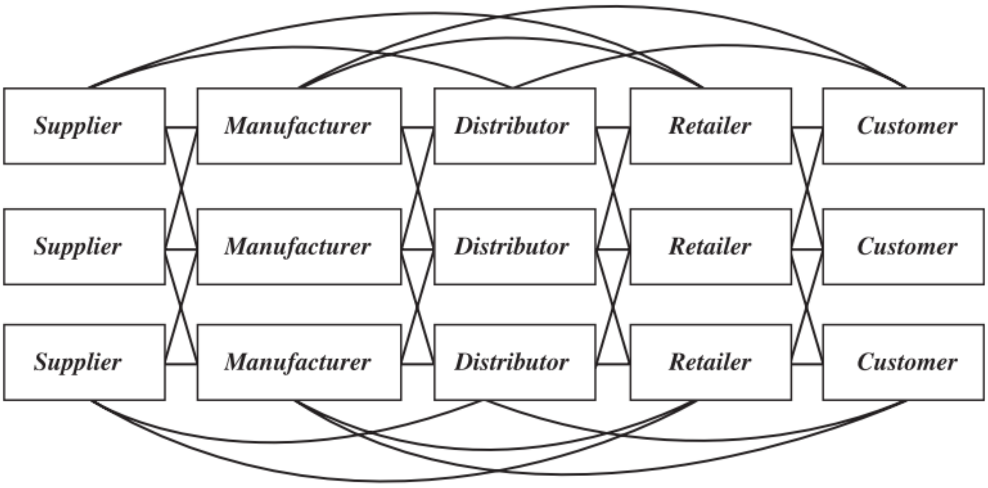


Figure 2.2 Network between companies creates stages in supply chain (Chopra and Meindl, 2015, p. 3)

Between one stage to another stage is connected through the flows of products, information, and funds (Chopra and Meindl, 2015; Pujawan and Mahendrawathi, 2010). The stages in supply chain depicted in Figure 2.2 certainly different in reality, since each design of the supply chain is unique, the design depends on both the customer's needs and the roles played by the stages involved (Chopra and Meindl, 2015).

2.1.1. Competitive Advantage

While supply chain is the physical network between companies, then supply chain management (SCM) is the method, tools, or approach to manage the flows inside the network (Pujawan and Mahendrawathi, 2010, p. 7). Since today's competition no longer between companies but between supply chain, therefore many manufacturing companies have introduced supply chain management to optimize their supply chain performance (Takata and Yamanaka, 2013). Christopher (2011) said that through an effective management of supply chain and logistics, a company can offer a better quality and performance of delivering its product to the customers, hence more preferred by the customers than that of the competitors. But in order to gain such competitive advantage, Porter (1985) said that company need to overlook into the value chain activities and make these activities perform better than the competitors'. The value chain activities depicted in Figure 2.3 below.

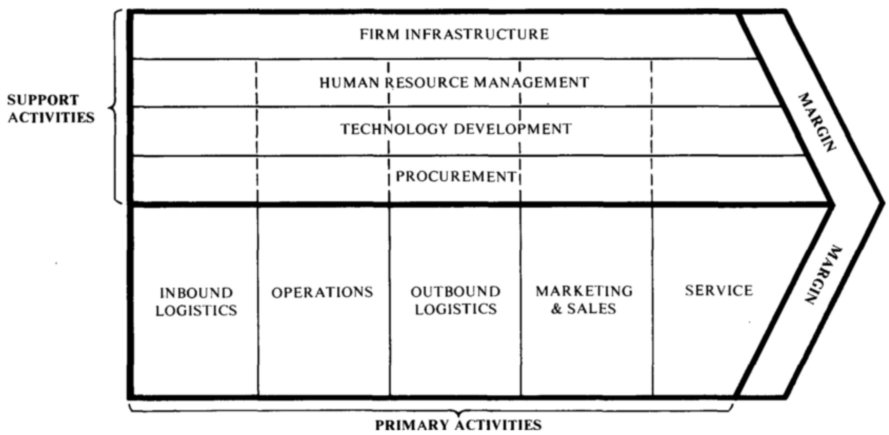


Figure 2.3 The value chain activities (Porter 1985, p.37)

When overlook these value chain activities, company should evaluate whether they have a real competitive advantage in that particular activity or not. When they do not, company should consider the option of outsource this activity to a partner that can provide value or cost advantage (Christopher, 2011). From Figure 2.3 above, outbound logistics is one of the primary activity of value chain and according to Porter (1985), outbound logistic is associated with collecting, storing, and physically distributing product to customers including delivery vehicle operation. In reality most companies do not have the luxury of having their own fleet of vehicles and the drivers to perform physical distribution of the finished products to the customer (or they could have but it would cost the company a lot of funding). Hence, most of the companies outsource the finished goods delivery to the trucking companies that would enable the value and cost advantage for the company.

2.1.2. Supply Chain Vulnerability

The risk of disruption has been further exacerbated by recent trend and practices in managing supply chain such increased complexity due to global sourcing, increased reliance on outsourcing and partnering, single sourcing strategies, and lean supply chain that focused on reducing inventory (Hendricks and Singhal, 2005). Waters (2007) said that vulnerability reflects the likeliness of a supply chain being disrupted. Furthermore, Jüttner (2005) found that managers believed these trends/practices increased supply chain vulnerability: globalization (52 percent of managers), reduction of inventory (51 percent), centralized distribution (38%), supplier reduction (36 percent), outsourcing (30 percent), and centralized production (29%).

2.1.3. The Role of Transportation in Supply Chain

Transportation refers to the movement of product from one location to another as it makes its way from the beginning of a supply chain to the customer (Chopra and Meindl, 2015). Transportation services play a central role in seamless supply chain operations, moving inbound materials from supply sites to manufacturing facilities, repositioning inventory among different plants and distribution centers, and delivering finished products to customers (Stank and Goldsby, 2000). Road transport has dominated the distribution of finished products at the lower levels of the supply chain, particularly in the delivery of retail supplies (McKinnon, 2006). By the recent adopted trends such lean supply chain, buffer stocks have been severely reduced and with the customer's demand of shorter order lead times, making the finished goods distribution becomes highly sensitive to even short delays in the transport system. Therefore, a low probability event such disruption that temporarily halt the road freight system would have caused a severe impact on the customer’s inventory level.

2.2. Supply Chain Disruption

Disruptions in supply chain defined by Wilson (2007) as unanticipated event that interrupts the material flows in the supply chain, resulting in abrupt cessation of the movement of the goods. Sources or drivers of these disruptions stated by Chopra and Sodhi (2004) are natural disasters, labor dispute, supplier bankruptcy, war and terrorism, and single source dependency. The nature of the drivers described by Taleb (2007) as a black swan or Simchi-levi et al. (2008) as unknown-unknown risk, an event that very unlikely to occurred but has massive impact. The massive-negative impact was shown through a study conducted by Hendricks and Singhal (2003), found that supply chain disruptions has caused 107% decrease in operating income, 7% lower sales growth, 11% higher costs, and 33 – 40 % lower stock returns after three years period of the disruption.

2.2.1. Transportation Disruption

Transportation disruption defined by Sheffi et al. (2003) as delay or unavailability of the transportation infrastructure, leading to the impossibility to move goods, either inbound and outbound. The uniqueness of transportation disruption that differentiate it from supply disruption lies in the availability of the both parties, consigner and consignee. Let us take a simple supply chain, consists of one supplier one distributor. In the case of supply disruption, supplier is the one that having disruption event, causing inability to supply material/products to the unharmed distributor. In the case of transportation disruption, both supplier (consigner) and distributor (consignee) are intact/unharmed because disruption only occurred in the transportation infrastructure. An example of transportation disruption occurred in real supply chain operations was the event of volcanic eruption of mount Eyjafjallajökull in Iceland 2010. The eruption crippled the air transportation within the area and cause negative impact on economy. Some of the notable impacts were: (1) causing a grounded cargo shipment from Africa, made Kenya's farmers to dump tones of vegetables and flowers destined for the UK causing financial loss of $1.3m a day (Wadhams, 2010); (2) causing interruptions in the supply of parts that forced BMW to suspends production at three of its plants in Germany which affecting 7000 vehicles and forced Nissan to stop productions in two factories in Japan which affecting 2000 vehicles (Wearden, 2010).

Published research that studying phenomena of transportation disruption in supply chain are as follows: Wilson (2007), Yang and Wu (2007), Bai and Wang, (2008), and Houshyar et al. (2013) found that transportation disruption may lead to drop in supply chain performance. In addition, Wilson (2007) found that transportation disruption type-2 (occurred between supplier and distributor) is the most severe type of transportation disruption. Chen and Zhang (2009) proposed a dispatching vehicle policy that optimize vehicle capacity and dispatching time along a route should a transportation disruption occurred. Figliozzi and Zhang, (2010) found that disruption costs include lost sales, expediting costs, intangibles such as loss of reputation, and financial impacts on companies' cash flows are very difficult to quantify even with full access to a company's proprietary operational, financial, and sales data. Husdal and Brathen (2010) found that industry and business are the immediate sector that experience the severe impact of transportation disruption since the first day after disruption occurred. Ishfaq (2012) found that flexibility in transportation can provide opportunity to build resilience concept into the supply chain. Hishamuddin et al. (2013) found that optimal recovery schedule is highly dependent on the relationship between the backorder cost and the lost sales cost parameters. Cui et al. (2016) found that their proposed model can yield a supply chain system design that minimizes the impacts from probabilistic disruptions and also leverages expedited shipments and inventory management to balance tradeoffs between transportation and inventory costs. Zhen et al. (2016) found that the backup transportation is very efficient to reduce the profit loss, causing a less insurance coverage to be purchased in advance of disruption; Liu et al. (2016) found that the improved model of grey neural networks is a feasible prediction method for transportation disruption. From the literatures mentioned above, we summarized 5 facts of transportation disruption as the following:

1. By the case of BMW and Nissan (Wearden, 2010), transportation disruption leads to supply disruption;
2. Based on the type of the goods flow, transportation disruption has the most negative impact when occurred between manufacturer and distributor (type-2) (Wilson, 2007);
3. In addition, during transportation disruption occurrence, distributor's (consignee) inventory level is exhaust or in a stockouts period, but when the disruption finished, the inventory level extremely increased (Wilson, 2007);
4. By the case of BMW, Nissan, and Kenya's flower industry, we concluded that based on the product characteristics, transportation disruption has a great negative impact on product with un-perishable (high value – low volume) characteristics and perishable (low value – high volume) characteristics.
5. The more the transportation lead time, the greater the impact of transportation disruption.

2.3. Responses Against Disruption

The drivers of supply chain disruption Chopra and Sodhi (2004), are something that beyond a manager control and taking care of this problem will always adding extra costs, disturbing the cost efficiency of the supply chain (Chopra and Sodhi, 2014). Hence, dealing with disruption in supply chain left the manager with three options, which are risk acceptance (do nothing), risk shifting (insurance), and tailor mitigation strategies.

2.3.1. Risk Acceptance

The first option roots from the fact that most managers know the inherently risky supply chain is, but chose to do nothing either to avoid the incurred extra costs and/or don't know how to proactively or reactively deal with the risk. Simchi-Levi et al. (2015) found that managers choose to do nothing against the risk of disruptions, not only because they are afraid to misallocate financial resources (i.e. tailoring mitigation strategies) that might end up in a poor financial performance report but also investing in such mitigation strategies would not giving them spotlight whether or not an actual disruption occurred. Therefore, this option is commonly adopted by the manager, but Chopra and Sodhi (2014) mentioned that doing nothing will likely gave the most severe impact.

2.3.2. Risk Shifting

The second option arose because managers saw disruptions as something that has extremely low probability of occurrence, hence insurance assumed to be the best measurement to deal with it. Gurnani and Mehrotra (2012) noted that a disruption event in one link could quickly ripple to another link in the chain. Using the same logic, it is believed that a potential transportation disruption has ripple effects both downstream and upstream (Wilson, 2007), therefore could ‘‘quickly cripple the entire supply chain” (Giunipero and Eltantawy, 2004, p. 703). From this fact, we argued that insurance policy is ineffective to cover the whole economic impact caused by transportation disruption. This argument was strengthened by several literatures. Stauffer (2003) in his report noted that trying to cover the risks through insurance is no longer as feasible as it once was. Paulsson (2007) stated that compensation from a third party (i.e. insurance company) for the negative effects of a disruption rarely covers fully the negative effects seen from a supply chain perspective. Gurnani and Mehrotra (2012) noted that if insurance is available, it can only mitigate the direct impact (i.e. the loss of revenue), but it cannot replace customers who impatiently turn to the competitors during a disruption, nor can it restore a loss of reputation. Renesas (2011, p.16) in their report showed that insurance only cover approximately 24% of the total 65.5-billion-yen economic loss caused by the Great East Japan Earthquake in 2011. In global perspective, Munich Re (2016, p.56) showed that in the event of disaster/catastrophic, insurance policy only cover relatively small proportion compared to the overall economic loss. Hence, Olson and Swenseth (2014) suggested that rather than relying on simple insurance, it is better to rely on the broader view of risk management that offers risks prevention or impact reduction, through loss-prevention and control systems. In addition, we believed that relying on insurance to deal with transportation disruptions in supply chain was also irrelevant, since disruption occurred because of the unavailability of transportation infrastructures which fall in local or central government responsibility which of course, outside the coverage of insurance policy.

2.3.3. Risk Mitigation

There exist several strategies to deal with supply chain disruptions or particularly, transportation disruption. Chopra and Sodhi (2004) proposed several strategies to mitigate various risk in supply chain, from these strategies, we identified that adding capacity, adding inventory, having redundant suppliers, increasing responsiveness, increasing flexibility, and increasing capability were strategies that suitable to mitigate disruption risk. Tang (2006) noted that postponement, strategic stock, flexible supply base, make-and-buy, economic incentives, flexible transportation, revenue management, dynamic assortment planning, and silent product rollover were the robust strategies to mitigate supply chain disruptions. Wilson (2007) proposed alternative routes, alternative modes of transportation, alternative suppliers, transshipment strategic between warehouse, VMI, carrying additional inventory, having redundant supplier, postponement, and mass customization to protect against transportation disruption risk in supply chain. Stecke and Kumar (2009) proposed several coping actions to mitigate the effect of transportation disruption risk in supply chain that mainly in a form of flexibility and redundancy, which were: maintain multiple manufacturing facilities with flexible and/or redundant resources, carry extra inventory, secure alternate suppliers, choose flexible transportation options, standardize and simplify process, component commonality, postponement, influence customer choice, and insurance. Chen and Ji (2009) proposed adopting less risky transportation mode and alternative transportation modes to avoid transportation disruption risk, also outsource to 3PL as effective way to reduce transportation disruption risk. Ishfaq (2012) was building resilience into supply chain via transportation flexibility (routes and modes) in response of transportation disruption events. Fan et al. (2016) build flexibility into supply chain via postponement strategy to create slack time against supply chain disruptions; this slack time existed as a result of diversified speed of transportation modes.

This third option is aimed to build a resilient supply chain that able to maintain its desired performance level even tough disruption occurred. As mentioned by Sheffi et al. (2003) , creating a resilient supply chain commonly through two approaches: building flexibility and redundancy. Furthermore, Sheffi et al. (2003) stated that redundancy is easy to build and less expensive in short term, while building flexibility is difficult and costly but appears to be more cost-effective compared to building redundancy in long term. In addition, according to Pujawan (2004), one should not pursuing high degree of flexibility unless the market indicates the need for it. Furthermore, Rice and Caniato (2003) was also suggested that it is possible for the company to adopt a combination of flexibility and redundancy.

1. Redundancy

   Redundancy requires the firm to maintain capacity to respond to disruptions in the supply chain, largely through investments in capital and capacity prior to the point of need (Rice and Caniato, 2003). Simchi-levi et al. (2008) proposed an investment in redundancy to manage the risk of disruptions in supply chain. A more detail application of redundancy as mitigation strategy against disruptions was conducted by Son and Orchard (2013). They applied redundant strategy to mitigate supply disruption by proposing Q-policy which add extra quantity to initial the initial order of the EOQ and R-policy which build an exclusive stock, preserved to protect the retailer/distributor from stockouts during disruption period. They found that R-policy dominantly advantageous than Q-policy.

2. Flexibility

   Flexibility requires the firm to create capabilities in the firm's organization to respond against disruptions in supply chain by using existing capacity that can be redirected or reallocated (Rice and Caniato, 2003). Ishfaq (2012) investigated whether the existing US transportation networks provide an opportunity to improve the resilience of a supply chain network through the proposed flexible logistics strategy. The exploratory study showed that companies can improve the resilience of their supply chains by maintaining flexible transportation operations.

3. Combination of Flexibility and Redundancy

   Rice and Caniato (2003) noted that firm will likely choose a mixture of flexibility and redundancy by taking into consideration the different cost and service characteristics offered by flexibility and redundancy. Schmitt (2011) showed that a combined policy between inventory reserves and back-up capabilities could give the best protection against supply chain disruption.

2.4. Simulation Modeling

Blanchard and Fabrycky (2006) defined system as a set of interconnected components working together toward a common objective. A system could have so many components that interconnected with unique behavior to each other, thus increasing the system complexity. In order to provides performance measurement of this complex system, an act of modeling is needed. Such a simplified representation of an actual and complex system is called a model, hence, simulation modeling is an attempt to analyze complex systems by a simplified representation of a system under study (Altiok and Melamed, 2010). A main reason behind conducting a simulation modeling is that it has the capability of modeling the system and its complex interrelationships and at the same time enabling low cost investigation to make conclusions about how the actual system might behave (Rossetti, 2015). There exist several types of simulation model:

1. Static vs. Dynamic: it considered static if the system under investigation doesn't change significantly with respect of time, but if it changes with respect of time, then it considered as dynamic.
2. Discrete vs. Continuous: If a simulation model dynamically changes at discrete points in time then it considered as discrete simulation model. If the model

dynamically changes at continuously in time that it considered as continuous simulation model.

3. Deterministic vs. Stochastic: a simulation model considered as deterministic if the model doesn't have random input. But if there is a least some input being random then it considered as stochastic.

Besides the aforementioned types of simulation model, when running a simulation model in a simulation software, the simulator should aware that there are two types of time frame of simulation, named steady-state simulation and terminating simulation. A steady-state simulation recognized by its nature that has no clear point of time of which would terminate the simulation running, sometimes the time frame itself theoretically infinite. In practice, a steady-state simulation will be run in a very long time and terminated only if it reaches a steady-state condition. In opposite, a terminating simulation recognized by a limited time frame which dictated by the model itself. The beginning and the termination of the simulation are clearly defined and reflect the natural behavior of how the system under study works. Although Discrete-Event Simulation (DES) and Monte Carlo simulation shows similarities in its practicality on discrete system behavior, we chose DES instead of Monte Carlo simulation as the approach to simulate system under study because in opposite with Monte Carlo, which is basically sampling experiments and time independent (Olson and Evans, 2002), the system under study involve the time path and an explicit representation of the sequence in which events occur. In comparison with the previous research, particularly by Wilson (2007) and Yang and Wu (2007), this research decided to choose DES instead of system dynamic (SD) because in opposite with SD, which objective is more on the strategic level in order to gain insight into the interrelations between the different parts of a complex system (Brailsford and Hilton, 2001), the objective of this research was to compare and evaluate alternate strategies in tactical /operational decision making level, of which strongly lead this research towards the characteristics of DES as described by Brailsford and Hilton (2001) and Tako and Robinson (2009).

2.4.1. Application of Simulation in Risk Management

Simulation has been widely used as a tool in risk management, particularly within supply chain disruptions. Schmitt and Singh (2009) used Monte Carlo simulation to assess the vulnerability of supply chain against disruption risk and quantity the impact on customer service. Son and Orchard (2013) Measured the effectiveness of two mitigation strategy: reserved stock (R-policy) and larger order quantity (Q-policy) using simulation. They found that R-policy had better performance that Q-policy. In transportation disruption, simulation also had been proven as a valuable tool. Wilson (2007) used simulation to measure the impact of transportation disruption in supply chain performance. Yang and Wu (2007) also used simulation to investigate the impact of transportation disruption on performance of e-collaboration supply chain. Bai and Wang (2008) applied discrete-continuous combined simulation to simulate supply chain under transportation disruption using VMI and traditional structure. Pujawan et al. (2015) demonstrated that, by using simulation modelling, the impracticality and difficulty of analytical methods especially when the system exhibits uncertainties and incorporates stochastic variables can be overcome.

2.4.2. Conducting Simulation Study

There exist several literatures that proposed a good guidance to conduct a simulation study, such Banks (1998), Law (2007) , Sadowski (2007), and Rossetti (2015) . We chose to use guidance from Banks (1998), since his methodology was used as the main reference by Law (2007) , Sadowski (2007), and Rossetti (2015). Banks (1998) proposed 12 steps in simulation which depicted in Figure 2.4. Each step in Figure 2.4 was also presented in simulation methodologies that proposed by the other literatures either in the same terms or different. The sequence of undergoing each step was also similar. Below are brief explanations of each step:

1. Problem formulation. This should be the first step taken by the analyst since this will determine the direction of simulation study. Therefore, problem formulation need to be set and stated clearly, either by the analyst itself or by

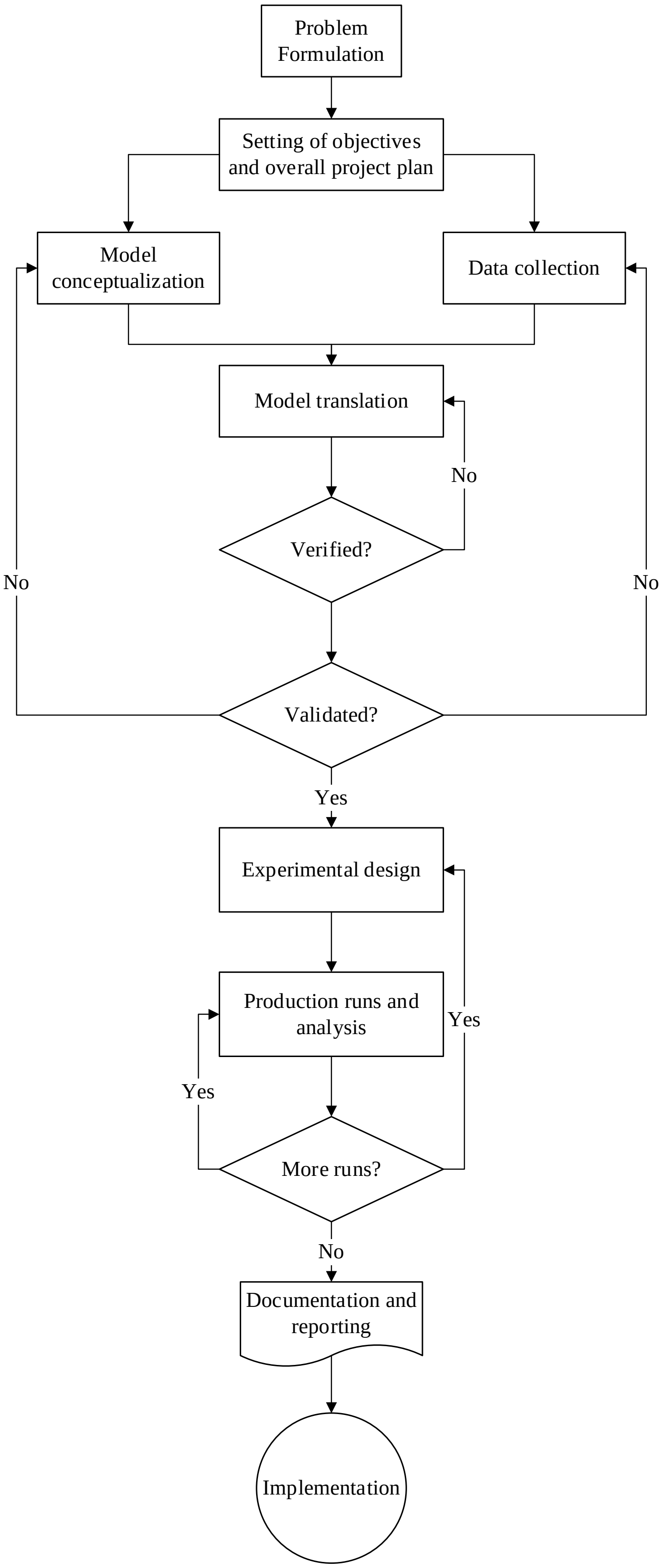


Figure 2.4 12 Steps in simulation study (Banks, 1998, p. 16)

the client (decision maker). Along the progression of the simulation study, sometimes this step need to be revisited or harnessed.

2. Setting of objectives. This step should set a detailed description of the objective of the study which often includes general goals such comparison, optimization, prediction, and investigation (Rossetti, 2015). The objectives indicate the questions to be answered by simulation study based on the problem formulation (Banks, 1998).
3. Model conceptualization. In this step, the analyst tried to abstracting the real-world system under study by building mathematical and logical relationship concerning the structure of the system (Banks, 1998). The purpose of conceptual modeling tools is to convey a more detailed system description so that the model may be translated into a computer representation (Rossetti, 2015).
4. Data collection usually takes a large portion of time required to perform simulation study, therefore it is wise to begin this step as early as possible, simultaneously with model conceptualization (Banks et al., 2010). This also indicates that the analyst can readily construct the model while the data collection is progressing (Banks, 1998)
5. Model translation can begin immediately after the model conceptualization and data collection completed. Model translation is coding the conceptual model into a computerized model (Banks, 1998). After computerized model complete, it is ready to be operationalized by deploying the data collected into the computerized model. This first operationalization called pilot run with only 1 replication.
6. Verification concerns with the issue of whether the computerized model is working as it should. Verification is making sure that the computerized model doesn’t deviate from its conceptual model. The accuracy of transforming a problem formulation into a conceptual model or the accuracy of converting a conceptual model into an executable computerized model is evaluated in model verification (Balci, 2002).
7. Validation concerns with the issue of whether the conceptual simulation model is an accuracy rate representation of the real system / system under study

(Banks, 1998; Kleijnen, 1995a). If there is an existing real system, then it is advisable to compare the simulation output with the existing system to perform a model validation. But, there are cases that the system under study is not exist, for example when the purpose of the simulation study is to propose a new design of a system. Approaches or techniques to perform model verification and validation (V&V) were mentioned and explained in the literature by Balci (1994, p.154), Kleijnen (1995b), Banks (1998, p.23), Law (2007, p.253), Sargent (2013, p.16).

8. When the computerized model which operationalized in the pilot run passed the V&V process, then this step decides to determine which factors have the greatest effect on a response which is often called factor screening or sensitivity analysis (Law, 2007)
9. In this step, the initial run (which was only 1 replication) then advanced to the production run with more than 1 replication. The outputs from production run then analyzed to measure the performance for the system being simulated. This analysis process was referred by Sadowski (2007, p.273) and Law (2015) as statistical analysis of simulation output to determine the accuracy of the output.
10. When the accuracy is below the predetermined desirable level, adjustments are needed. The analyst determines whether additional runs are needed or if additional scenarios need to be simulated (Banks, 1998).
11. Documentation and reporting serve numerous reasons such giving the opportunity for the same or different analyst to understand how the simulation model operates, stimulate confidence of the simulation model by the client, and enable the client to easily review the final recommendation from the analyst (Banks, 1998).
12. The successful of implementation depends on how well the previous 11 steps have been performed (Banks et al., 2010).

In summary, these 12 steps of simulation study can represent in 4 major phases. The first phase consists of step 1 and 2 is called the clarifications and recalibrations phase. Because this phase entails the analyst or the client to clarify the problems and objectives that the simulation model tries to address. Also because sometimes analyst and client need to recalibrate these problems and objectives as the simulation progressing. The second phase consists of step 3, 4, 5, 6, and 7, which is the actual model building and data collection. Therefore, in the progress sometimes a continuing interplay among steps is required (Banks et al., 2010). The third phase consists of phase 8, 9, and 10, that concerns with running and experimenting the simulation model to produce the early specified of desirable output. The output variables then analyzed to estimate a contained random error by using proper statistical analysis (Banks et al., 2010). The fourth phase called implementation, contains step 11 and 12. The success of implementation depends on how well the previous 11 steps have been performed (Banks et al., 2010).

2.5. Cost-Effectiveness Analysis (CEA)

As stated by Karlsson and Johannesson (1996), CEA is based on the maximization of the health effects for a given amount of resources. Therefore, CEA as decision making tool is used commonly in the field of medicine and health care, for example: measuring the cost per effectiveness of various prescribed drugs or the cost per quality gained of various given treatments. Incorporating the concept of CEA into the second objective of this research, made us basing the CEA on the minimization of negative effects of transportation disruption for a certain amount of consequential costs. There are always 2 inputs in CEA, where the costs are measured in monetary units and the effects are measured in non-monetary units (Karlsson and Johannesson, 1996). CEA is preferred over cost-benefit analysis (CBA) when monetizing all the benefit of the proposed alternative of strategies is difficult (Boardman et al., 2010). Gift and Marrazzo (2007) showed that CEA strengths lie on its ability to express cost per unit outcome and allows for comparison of different interventions that achieving the same outcome; while weak because unable to compare different interventions that producing different outcomes. They also showed that CBA strengths lie in its ability to express all costs and outcomes in monetary terms and allow for different interventions; while having weakness because dictating expression of welfare effects in monetary terms, which can be difficult and may not be widely accepted. In addition, we summarized decision rules of CEA as follows:

1. A proper CEA is always comparative in nature (Petitti, 1999). When using CEA, one should know that there is more than one strategy to be evaluated and each strategy is competing with each other;
2. All of the evaluated strategies should assumed to be mutually exclusive (Karlsson and Johannesson, 1996). Therefore, decision maker can only execute/implement one strategy while neglecting the other (one can choose A or B, but not both);
3. Since its competing and mutually exclusive nature, it is impossible to conclude anything (what strategy to be implemented) about the cost effectiveness of the different strategies based on average cost-effectiveness ratios, instead, one is dictated to conduct CEA using incremental cost-effectiveness ratio (ICER) (Karlsson and Johannesson, 1996);
4. Because of its mutually exclusive nature, cost-effectiveness ratio cannot be interpreted as a rank list (Johannesson and Weinstein, 1993);
5. Comparing between cost-effectiveness ratio of each strategy can only be made between strategy that producing the same outcome (Johannesson and Weinstein, 1993).

Talluri et al. (2013) highlighted the importance of testing and comparing alternative mitigation strategies in a comprehensive manner against a particular type of risk. The fundamental nature of CEA that centered on the comparative and mutually exclusive behavior; the advantage of CEA over CBA, of which doesn’t entail any monetization of performance given by each mitigation strategy; and the non-financial performance measurement that we used as our effectiveness input, were 3 particulars that provided us with a plausible argument to choose CEA for testing and comparing our proposed mitigation strategies against transportation disruption.

2.5.1. Incremental Cost-Effectiveness Ratio (ICER)

While an average cost-effectiveness ratio (ACER) is estimated by dividing the consequential cost of a strategy by a measure of effectiveness without any concern to its alternatives, an incremental or marginal cost-effectiveness ratio (ICER) is an estimate of the cost per unit of effectiveness of switching from one strategy to another, or the cost of using one strategy in preference to another (Petitti, 1999). ICER mathematically expressed in Equation 2.1 below.

$$ICER_{(i)} = \frac{Cost_{(i)} - Cost_{(i-1)}}{Effectiveness_{(i)} - Effectiveness_{(i-1)}} \tag{2.1}$$

where:

$ICER_{(i)}$ = the cost-effectiveness ratio when switching strategy $(i-1)$ with i

subscript i = strategy i ; i = 2, 3, …, I

I = number of proposed strategies

Since this research concerns with evaluating 4 strategies that compete each other in response to transportation disruption, where decision maker has limited amount of fund (therefore can only implement one strategy), it is clear that ICER is an obvious choice. According to Petitti (1999), before the cost is valued, contributors of the cost should be defined first. One of the cost contributors that Petitti (1999) introduced that relevant with this research is direct costs, which we interpreted as monetary value consumed due to implementing a strategy. Effectiveness in the other hand not measured in monetary value. In correlation with transportation disruption, we used the same measurement of Wilson (2007) which is unfilled customer orders as our degree of effectiveness.

An effective algorithm to correctly calculate ICER has been introduced by Johannesson and Weinstein (1993) and conducted via a hypothetical case by (Karlsson and Johannesson (1996). We summarized this efficient algorithm as follows:

1. Define cost and effectiveness terms are referring to;

2. Measure/calculate the cost and effectiveness for each strategy;
3. List strategies in ascending order of either effectiveness or costs;
4. Identify and eliminate strongly dominated strategy (have increased costs and reduced effectiveness compared with the immediate alternative) **and/or**;
5. Identify and eliminate weakly dominated strategy (have equal cost with reduced effectiveness or increased costs with same effectiveness compared with the immediate alternative);
6. Calculate ICER using Equation 2.1.
7. If $ICER_i > ICER_{i+1}$ (ICER changed in descending order) then strategy i considered to be extended dominated by strategy $i+1$, thus should be eliminated.
8. Repeat step 6 and 7 if necessary
9. Produce recommendation of acceptable strategy based on the ICERs

When i = 1, this strategy is called the base case which refers to the current or typical deployed strategy. Consistently with Equation 2.1, base case is automatically skipped in step 6. Strongly dominated in step 4 means that strategy i is less cost-effective than strategy $i+1$, since strategy i+1 gives lesser cost with better effectiveness. Weakly dominated in step 5 means that strategy i is less cost-effective than strategy $i+1$ since strategy $i+1$ either gives same cost with better effectiveness or lesser cost with same effectiveness. Extended dominated in step 7 means that strategy i is less effective than strategy $i+1$, since switching directly from strategy $i-1$ to strategy $i+1$ gives better effectiveness with lesser cost than switching from strategy i to strategy $i+1$ which gives lesser effectiveness with greater cost.

2.5.2. Application of Cost-Effectiveness in Risk Management

In risk management, cost-effectiveness was used by Schmit and Roth (1990) to evaluate the effectiveness of various risk management practices. Sherwin et al. (2016) also evaluated cost-effectiveness of mitigation strategies with a low volume high value supply chain against delay risk due to unreliable production process.

2.6. Research Gap

Table 2.1 below shows previous research of transportation disruption and position of this research relative to those previous research. To the best of our knowledge, a research by Wilson (2007) was the initial focused research in transportation disruption. Furthermore, it was mentioned by Ho et al. (2015), that transportation disruption in contrast to supply disruption, has received little attention by academic. The first gap we'd like to address in this research is the lack of contribution on the transportation disruption knowledge.

From Table 2.1 below, we could also realize that there are 6 papers that fused strategies and investigates SC performance under transportation disruption event. But from this 6 papers, only the paper by Ishfaq (2012) that used case study as data source for the investigation, the other 5 papers used numerical example. The second gap we'd like to address in this research is the lack of case study as data source on investigation of SC performance under transportation disruption event.

Table 2.1 Previous research in transportation disruption

Authors	Year	Solution method	Alternate strategy	Data source	Research objective
Wilson	2007	System dynamic simulation	1, 2	Numerical example	Investigating transportation disruption impacts on SC performance under the proposed strategies
Yang & Wu	2007	System dynamic simulation	1, 2, 3	Numerical example	Investigating transportation disruption impacts on SC performance under the proposed strategies
Bai & Wang	2008	discrete-continuous simulation	1, 2	Numerical example	Investigating transportation disruption impacts on SC performance under the proposed strategies
Chen & Zhang	2009	Stochastic optimal control	n/a	n/a	Developing mathematical model of optimal vehicle dispatching policy for transportation disruption
Figliozzi & Zhang	2010	Discrete choice modeling	n/a	case study	Estimating and understanding the costs and causes of transportation related supply chain disruptions
Husdal & Brathen	2010	Survey	n/a	case study	Investigating how businesses and freight carriers are affected by and relate to transportation disruption
Ishfaq	2012	Mixed integer linear programming	4, 5	case study	Evaluating flexible transportation strategy against transportation disruption
Houshyar et al.	2013	Simulation modeling	1, 2	Numerical example	Investigating transportation disruption impacts on SC performance under the proposed strategies
Hishamuddin et al.	2013	Heuristic	n/a	Numerical example	Developing real-time rescheduling mechanism as recovery plan in case of transportation disruption
Cui et al.	2016	Nonlinear integer programming	n/a	Numerical example	Integrating transportation disruptions of regular shipments in the integrated supply chain system design framework
Zhen et al.	2016	Mixed integer linear programming	1, 6, 7, 8	Numerical example	Investigating transportation disruption risk-hedging strategy of distribution centers
Liu et al.	2016	Grey neural network	n/a	case study	Helping enterprises better predict market demand after transportation disruption
Albertzeth & Pujawan	2017	Simulation modeling + CEA	1, 5, 9, 10	case study	To provide decision maker with best strategy that promote cost-effectiveness against transportation disruption

Note:

1) Basic (do nothing)
2) VMI
3) Collaborative Forecasting
4) Multi-Mode
5) Flexible route
6) Business interuption (BI) insurance
7) Backup transportation (BT)
8) BI + BT
9) Redundant stock
10) Redundant stock + Flexible route

CHAPTER 3

RESEARCH METHODS

This chapter gives explanation about how we fulfill the objective of this research by our constructed research framework. This chapter also shows methods that we used in this research.

3.1. Research Framework

In Chapter 1 we specified a research questions (RQ) that we need to answer in order to fulfill the objective of this research. This RQ laid a foundation of two major constructs that builds our research framework, shown in Figure 3.1 below.

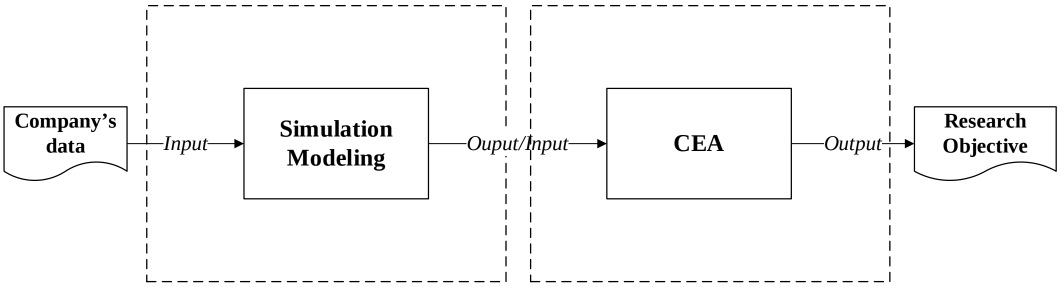


Figure 3.1 Research Framework

As shown by Figure 3.1 above, by using simulation modeling as a tool we conducting a simulation study that would be able to obtain the cost and effectiveness for each of the proposed strategy and by using CEA as our decision analysis tool we would be able to measure their cost-effectiveness. This process was executed sequentially since to conduct CEA, first we need to conduct simulation study and use its outputs as our inputs to be fed into CEA. Feeding these inputs into CEA will consequently assess the cost-effectiveness of which the output will be the objective of this research.

3.2. Methods on Simulation Modeling

The first construct of the research framework is shown in Figure 3.2 below. This first construct shows that we used company's data as an input to our constructed model of system under study. Our model then simulate this input to produce outputs that shall be used as an input of the second construct. While simulation modeling is a tool, an act of conducting the simulation is called simulation study.

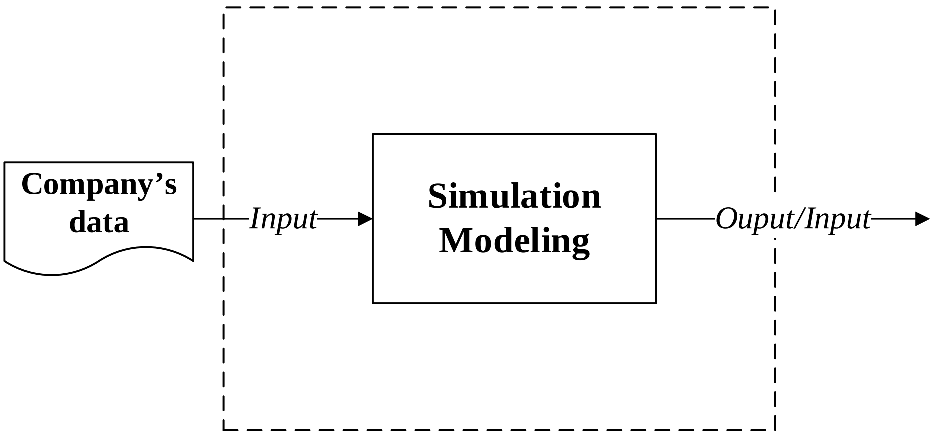


Figure 3.2 First construct of the research framework

In Chapter 2, we had introduced a 12-steps of conducting simulation study (depicting in Figure 2.4) by Banks (1998) also the arguments of why this steps are adopted into this research. In the following sections we present the methods that we used for these steps. But take notice that not every step needs specific method to be able to be executed. For example, problem formulation (step 1) is quite easily deduced and executed without needing any specific or scientific method. Therefore, here we present the methods for data collection (step 4), model translation (step 5), verification (step 6) and validation (step 7), experimental design (step 8), production run and analysis (step 9), and more runs (step 10).

3.2.1. Data collection

Relating the methods for simulation input from Banks (1998) and (Law, 2007), we present 4 methods to convert the collected data from focal company into a simulation input as follows:

1. Use directly the data values obtained as an input in the simulation. Hence, when a simulation study use this method it's called trace-driven simulation (Law, 2007, p. 279);
2. Fit a probability distribution to the data values. If there are sufficient data values, say 50 or more it may be appropriate to fit a probability distribution to the data (Banks, 1998, p. 20) using standard technique of statistical inference and perform hypothesis test to determine the goodness of fit (Law, 2007, p. 279).
3. When it is not possible to fit the data into a probability distribution or the suggested probability distributions found to be inconclusive (Banks, 1998, p. 21), the data values themselves are used to define an empirical distribution function (Law, 2007, p. 279).
4. In a rare case when there are no data values are available, analyst may obtain a subjective estimate or called guesstimate concerning the system under study (Banks, 1998, p. 21).

3.2.2. Model translation

Model translation is coding the conceptual model into a computerized model (Banks, 1998), but not ready to operationalized until the data collected deployed into the computerized model. In order to coding the conceptual model into computerized model, Law (2007, p. 188) presented 2 methods as the following:

1. Via programming languages: C, C++, or Java
2. Via simulation packages, which is divided into general purpose (i.e. Rockwell Arena® and Extend ®) and application oriented (i.e. Flexim®, ProModel®, and Quest®)

We decided to use Rockwell Arena® as our software package due to its familiarity and simplicity that the software offered.

3.2.3. Verification and Validation (V&V)

Verification concerns with the issue of whether the computerized model is working as it should while validation concerns with the issue of whether the conceptual simulation model is an accuracy rate representation of the real system / system under study (Banks, 1998; Kleijnen, 1995a). Approaches or techniques to perform model V&V were mentioned and explained in the literature by Balci (1994, p.154), Kleijnen (1995b), Banks (1998, p.23), Law (2007, p.253), Sargent (2013, p.16). Here we listed methods of conducting verification from Law (2007) and Banks (1998, p.23) as the following:

1. Law (2007): (1) program debug; (2) structured walk-through; (3) sensitivity analysis; (4) compare with hand calculations (trace); (5) comparing the simulation and analytic results from the simple case; (6) observe animation; (7) compare mean and sample variance between simulation results and system under study (historical data).
2. Banks (1998, p.23): (1) follow the principles of structured programming; (2) make the operation model as self-documenting as possible; (3) have the computer code checked by more than one person; (4) check to see that the values of the input data are being used appropriately; (5) for a variety of input-data values, ensure that the outputs are reasonable; (6) use the debugger feature; (7) animation.

Here we listed methods of conducting validation from Law (2007) and Sargent (2013, p.16) as the following:

1. Law (2007): (1) comparison with an existing system; (2) comparison with another model; (3) comparison with expert opinion (face validity); (4) observe animation; (5) inspection approach; (6) sensitivity analysis.
2. Sargent (2013, p.16): (1) face validity; (2) parameter variability–sensitivity analysis; (3) extreme condition tests; (4) Turing test; (5) historical data validation; (6) comparison to other model; (7) animation.

3.2.4. Experimental Design

In experimental design terminology, the input parameters and structural assumptions composing a model are called factors, and output performance measures are called responses. The major goal of experimental design in simulation is to determine which factors have the greatest effect on a response which is often called factor screening or sensitivity analysis (Law, 2007). Factors can be either quantitative or qualitative and being controllable or uncontrollable. In experimental design we usually focus on the quantitative factors which controllable. In conducting experimental design instead of using one-factor-at-a time (OFAT), Law (2007) advised to use factorial designs as our method since factorial designs is more efficient and show us interactions. Factorial designs either be 2^k Factorial Designs or 2^{k-p} Fractional Factorial Designs, depends on the number of factor k. Factors are selected by analyst no more than 15, through intuition, prior knowledge, and the like (Banks, 1998, p. 177).

3.2.5. Production Runs and Analysis

Production runs is simply change the number of replication which was only 1 in pilot run to be multiple run. In this research production run is done in 10 replications. After production runs is finished, Sadowski (2007, p.273) and Law (2015) suggested that the output will be analyzed to measure its accuracy using a method called the statistical analysis of simulation output. The statistical analysis of simulation output was based on 3 classic statistical equations specified by Law (2015, p. 1812). These 3 classic statistical equations are included in simulation software package. For example, in Arena® these equations are already calculated in the report under the term of half-width which represents the accuracy of the reported simulation output.

3.2.6. More Runs

When the accuracy is below the predetermined desirable level, analyst required to increase the accuracy, one suggested way by running more replications.

To determine how many replications are needed to correct the accuracy, Sadowski (2007) proposed a method as expressed in Equation 3.1 below:

$$n \cong n_0 \frac{h_0^2}{h^2} \tag{3.1}$$

where:

n = the new number of replications

n_0 = the number of initial replications

h_0^2 = the initial value of half-width

h^2 = the desired value of half-width

Calculating Equation 3.1 will result in an approximation of the number of new replications that needed to be re-run into the simulation software. In summary, combined all the methods mentioned above, we modified steps of simulation study by (Banks, 1998) and presented the methods used to conduct simulation study as depicted in Figure 3.3 below.

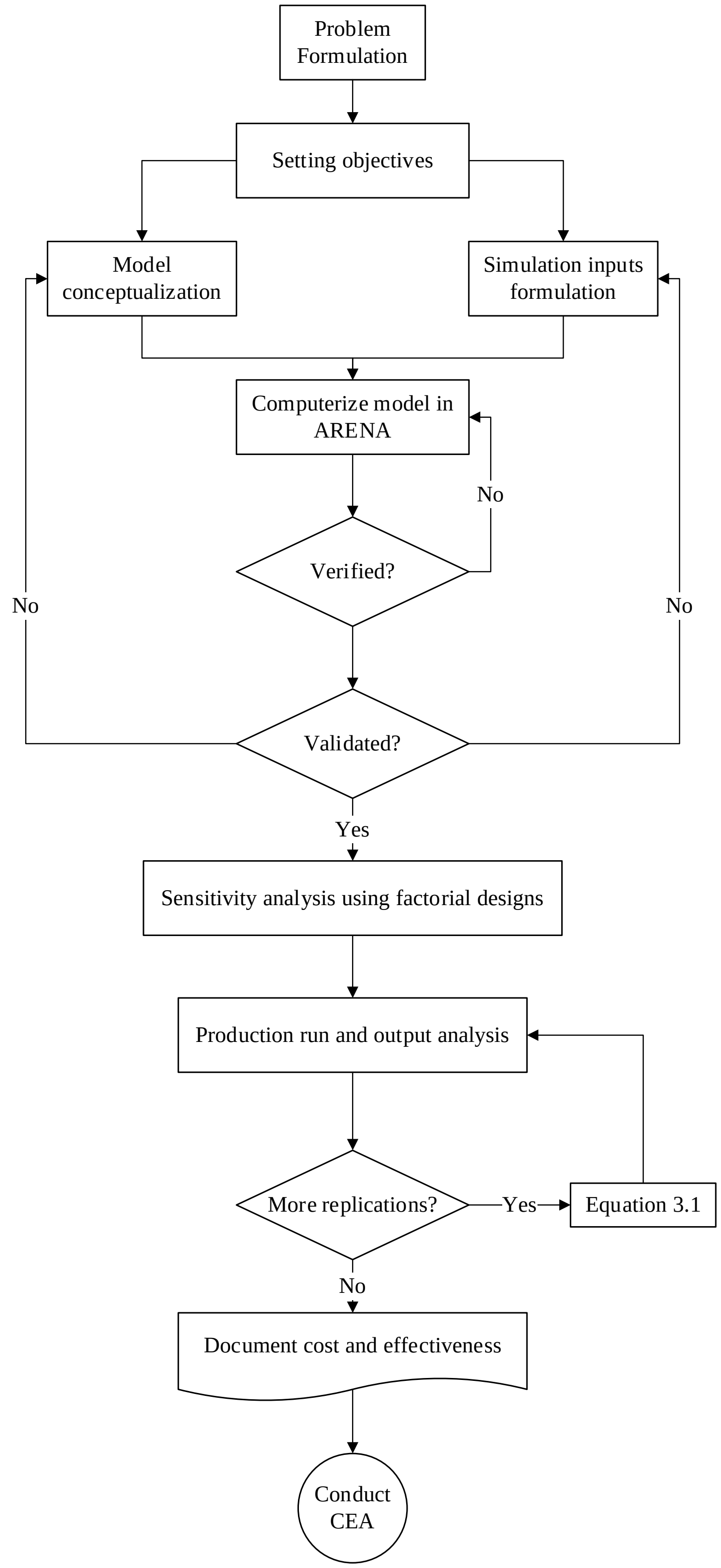


Figure 3.3 Methods to conduct simulation study for this research (adapted from Banks (1998))

3.3. Methods on CEA

The second construct of the research framework was trying to assess the cost-effectiveness of each strategy. This second construct as depicted in Figure 3.3 below can only be executed if the previous construct already gives outputs that will be used as inputs to conduct CEA.

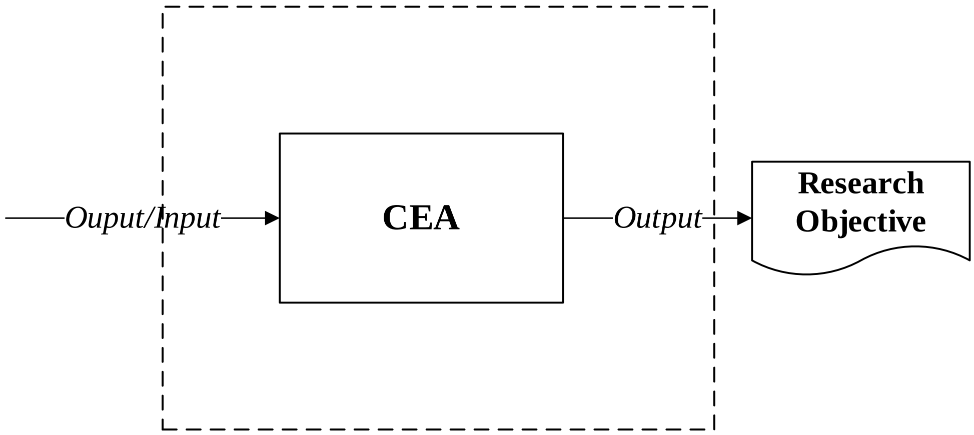


Figure 3.4 Second construct of the research framework

As shown in Figure 3.4 above, after conducting the CEA we can assess the cost-effectiveness of each strategy and the output of this construct is a full operation the research framework which fulfilled the objective of this research. As explained in Chapter 2.5, due to its competitive and mutually exclusive nature of CEA, then the essential of CEA lays on the calculation of ICER. We expressed the effective algorithm of calculating ICER as the following:

1. Define cost and effectiveness terms are referring to;
2. Measure/calculate the cost and effectiveness for each strategy;
3. List strategies in ascending order of either effectiveness or costs;
4. Identify and eliminate strongly dominated strategy (have increased costs and reduced effectiveness compared with the immediate alternative) **and/or**;

5. Identify and eliminate weakly dominated strategy (have equal cost with reduced effectiveness or increased costs with same effectiveness compared with the immediate alternative);
6. Calculate ICER using Equation 2.1.
7. If $ICER_i$ > $ICER_{i+1}$ (ICER changed in descending order) then strategy i considered to be extended dominated by strategy $i + 1$, thus should be eliminated.
8. Repeat step 6 and 7 if necessary
9. Produce recommendation of acceptable strategy based on the ICERs

Step 1 & 2 of the algorithm can be obtained from the output of simulation study and that's the reason why we could not conduct CEA before the simulation study. We also added sensitivity analysis into the algorithm. Sensitivity analysis in CEA served a quite similar purposes sensitivity analysis are mentioned as follows:

1. To find out how sensitive our cost-effectiveness ratios if factors changes;
2. To find out the robustness of the cost-effectiveness ratios if factor changes.

This CEA sensitivity analysis (CEA-SA) corresponded with the factors changes in simulation study sensitivity analysis (SS-SA). In summary, we present translate the effective algorithm of ICER in flowchart and use it as our method of conducting CEA in Figure 3.5 below.

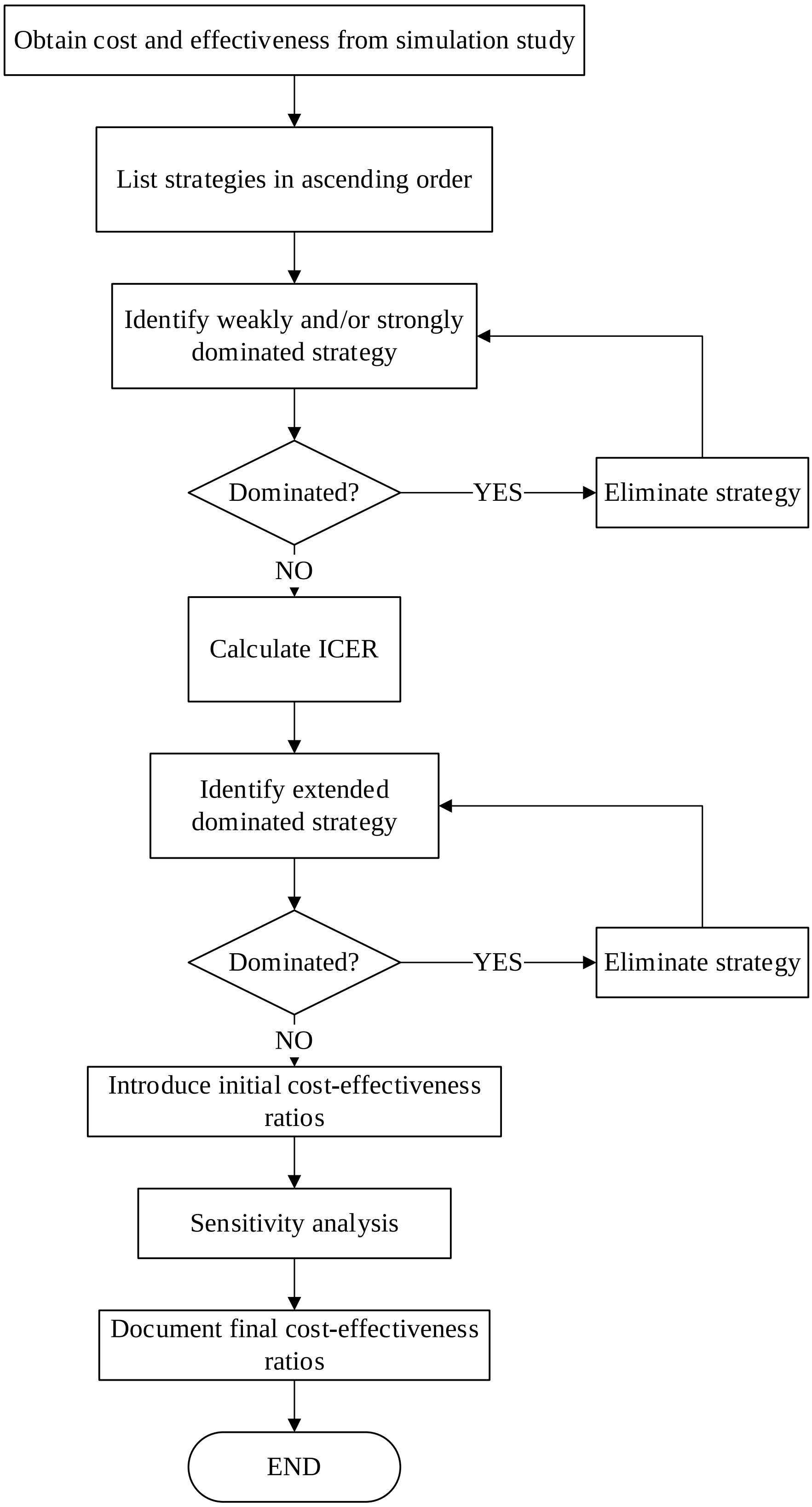


Figure 3.5 ICER effective algorithm as method to conduct CEA

CHAPTER 4

DATA COLLECTION

This chapter describes about how we obtain the data for this research. This includes the reasons for selecting the focal company (consigner) and the distributor (consignee), consequent cost functions, delivery schedules, and natural disaster frequency, transportation activity, and proposed strategies.

4.1 Relationship Between Focal Company and Distributor

Focal company (FC) located in Makassar City, South Sulawesi. FC's main product is wheat flour with more than 10 products with various brands in various size (weight). FC's market area divided into 3 regions, named local, east, and west. Local area means that FC served only customers located in Makassar City. East area means that FC served customers located outside Makassar City (Sulawesi Island), East Java, Kalimantan, and Indonesia's east region. West area covers the rest. In distributing its finished products, FC used 2 transportation modes of water (vessel) and land (truck). FC outsource this transportation activity to the 3rd party. For the local area, all transportation handled by using trucks and for the west area, transportation handled using vessel to the port and trucks from port to warehouses. For the east area some customers (medium distance) were still served using trucks (i.e. Tana Toraja, Poso, and Luwuk) and some customers (longer distance) were served by vessel (i.e. Kendari, Gorontalo, and Papua). We chose this FC because the perishability of the finished products (which highly rejected by customers if more than 2 weeks old stored and the commitment of FC to maintain an excellent service level to its customers with lowest costs (as noted in the FC's vision and mission).

We then chose a sole distributor in Poso City, Central Sulawesi. There is no other distributor that partnering with FC in Poso. We chose this distributor because it has the longest lead time (here assumed equal to distance) from FC's location and its delivery is still served by trucks. The delivery activity between FC and distributor represents Transportation Disruption Type-2 (TD-2) which according to Wilson (2007) has the greatest negative impact should transportation disruptions occurred. The supply chain of FC is depicted in Figure 4.1 below.

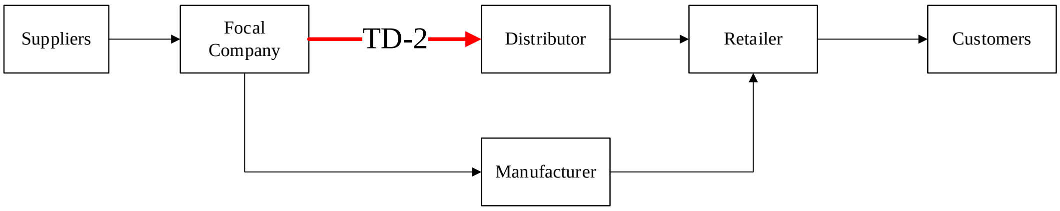


Figure 4.1 The Supply Chain of Focal Company

As shown by Figure 4.1 above, FC sells its products to the distributor where distributor re-sell the products to retailers. Distributor act as a reseller who fills a known end retailer's demand from its inventory, which in turn is replenished by the FC. We assume that natural-catastrophic events may occur at any point in time causing unavailability of road infrastructure (main route) that connecting FC's site with distributor site with a frequency per year. Once a transportation disruption occurs, the ability of FC to replenish distributor's inventory stops temporarily (for the duration of the disruption); however, retailer's demand can continue to be met from inventory until it is depleted. Depending on the duration of the disruption and on-hand inventory at the time of the beginning of a disruption, distributor could very likely experience stockouts. Here we assume that any unmet demand considered as loss of sales (no backorder). The recovery process (fixing the road) will be executed as soon as a disruption begins. Hence, the disruption duration is equal to the recovery process. Replenishment (here on we call it delivery) process from the FC resumes as soon as recovery process is finished.

4.2 Collected Data on FGSC Department

Data was collected from Department of Finished Good Supply Chain (FGSC) and Department of Procurement. A file of delivery schedule was obtained directly from FGSC manager via e-mail. The relevant details contained in the delivery schedule was summarized as follows:

1. Delivery history: January 2016 - December 2016

   This was the first obstacle during data collection process. FC was adopting and using Microsoft Dynamics AX as their ERP software since 2012. Even tough distributor has established business with FC more than 20 years, the historical data recorded digitally was started from 2012 record. In addition, when the Manager of FGSC department tried to 'pull' the records, the oldest historical data stored in the server was from the year of 2016 above. We tried to check another customer served by truck (i.e. Palopo, Luwuk, Tana Toraja) but the result stayed the same. We concluded that since the delivery data records of trucking-served customers are vast, then the IT department must be set the system to remove data that more than 2 years old. That is why the oldest data in the server starts from 2016. This fact has consequence to determine simulation input in ARENA.

2. Delivery Date:

   This is the actual date of delivery from FC in Makassar to distributor's site in Poso. Actual delivery date shows the exact date of trucks leaving FC's site for delivering products to distributor.

3. Customer's Order (CO) date:

   This is a recorded date of distributor asking (placing order) FC to deliver certain product brand in certain quantity to its site.

4. Brands, Quantity, and Volume:

   Data of brands and its quantity that delivered to distributor's site. Brands, quantity, and volume determined by the customer's order. Volume is measured in metric ton (MT). There were 15 brands delivered during year of 2016. These 15 brands were delivered in different quantity and each brand has certain SKU. For the sake of simplicity, we would choose brands that represent 80% of total volume delivered and we found that brand A, B, C, D, and E were representing. These 5 selected brands together with the other 10 were presented in Table 4.1 below.

Table 4.1 Delivered brands during the year of 2016

Brand	SKU (Kg)	Qty	Total Volume (Kg)
A	25	9695	242375
B	10	14856	148560
C	25	5430	135750
D	25	4506	112650
E	25	3754	93850
F	25	900	22500
G	20	1102	22040
H	25	500	12500
I	9	1100	9900
J	10	900	9000
K	10	900	9000
L	20	300	6000
M	10	250	2500
N	1.8	498	896.4
	Total		827521.4

Continuing data in Table 4.1, we also show the delivery details for brand A, B, C, D, and E consecutively in Table 4.2, Table 4.3, Table 4.4, Table 4.5, and Table 4.6.

Table 4.2 Delivery details for brand A

Date of Delivery	Days in Year	Qty (Zak)	MT
1/26/2016	25	780.00	19.5
2/22/2016	52	100.00	2.5
2/23/2016	53	400.00	10
3/12/2016	71	300.00	7.5
3/31/2016	90	300.00	7.5
4/11/2016	101	1000.00	25
4/19/2016	109	600.00	15
4/30/2016	120	800.00	20
5/12/2016	132	1000.00	25
5/21/2016	141	600.00	15
5/25/2016	145	600.00	15
5/26/2016	146	1000.00	25
5/27/2016	147	800.00	20
6/3/2016	154	400.00	10
6/14/2016	165	200.00	5
6/27/2016	178	300.00	7.5
7/26/2016	207	515.00	12.875

Table. 4.3 Delivery details for brand B

Date of Delivery	Days in Year	Qty (Box)	MT
1/26/2016	25	300.00	3
2/22/2016	52	200.00	2
3/12/2016	71	750.00	7.5
3/31/2016	90	500.00	5
4/11/2016	101	2000.00	20
4/19/2016	109	1000.00	10
5/27/2016	147	1000.00	10
6/3/2016	154	1000.00	10
6/14/2016	165	1000.00	10
6/27/2016	178	1000.00	10
7/26/2016	207	800.00	8
9/26/2016	269	2100.00	21
9/27/2016	270	1000.00	10
10/22/2016	295	750.00	7.5
10/24/2016	297	750.00	7.5
11/9/2016	313	400.00	4
12/30/2016	364	306.00	3.06

Table. 4.4 Delivery details for brand C

Date of Delivery	Days in Year	Qty (Zak)	MT
1/26/2016	25	500.00	12.5
2/22/2016	52	1,000.00	25
4/30/2016	120	200.00	5
5/21/2016	141	300.00	7.5
5/25/2016	145	200.00	5
5/27/2016	147	500	12.5
6/20/2016	171	1000	25
6/23/2016	174	1000	25
6/27/2016	178	200	5
7/26/2016	207	530	13.25

Table. 4.5 Delivery details for brand D

Date of Delivery	Days in Year	Qty (Zak)	MT
1/26/2016	25	100.00	2.5
2/22/2016	52	100.00	2.5
3/11/2016	70	600.00	15
5/21/2016	141	100.00	2.5
5/25/2016	145	100.00	2.5
6/3/2016	154	200	5
6/14/2016	165	300	7.5
7/26/2016	207	400	10
8/9/2016	221	500	12.5
9/26/2016	269	300	7.5
9/27/2016	270	300	7.5
10/22/2016	295	300	7.5
10/24/2016	297	300	7.5
11/9/2016	313	300	7.5
11/25/2016	329	300	7.5
12/30/2016	364	306	7.65

Table. 4.6 Delivery details for brand E

Date of Delivery	Days in Year	Qty (Zak)	MT
1/26/2016	25	100	2.5
2/23/2016	53	200	5
3/11/2016	70	400	10
3/12/2016	71	200	5
3/31/2016	90	350	8.75
4/11/2016	101	200	5
5/25/2016	145	100	2.5
5/27/2016	147	100	2.5
6/14/2016	165	100	2.5
6/27/2016	178	100	2.5
7/26/2016	207	200	5
8/9/2016	221	300	7.5
9/26/2016	269	200	5
9/27/2016	270	200	5
10/22/2016	295	200	5
10/24/2016	297	200	5
11/9/2016	313	200	5
11/25/2016	329	200	5
12/30/2016	364	204	5.10

5. Time lapse between order and estimated retailer's demand

   Since we know the CO dates, we then could calculate time how many days passed between order. Consequently, we could also calculate demand rate for each period. Here we present the time lapse between order and estimated retailer's demand rate for each 5 brands in Table 4.7, Table 4.8, Table 4.9, Table 4.10, and Table 4.11.

Table 4.7 Days between order and estimated demand for brand A

Period	Qty	CO Date	Next CO Date	# Day	Estimated Demand
1/26/2016 - 2/21/2016	780.00	1/23/2016	2/22/2016	30	26.00
2/22/2016 - 3/10/2016	500.00	2/22/2016	3/11/2016	18	27.78
3/11/2016 - 4/7/2016	600.00	3/11/2016	4/8/2016	28	21.43
4/8/2016 - 5/8/2016	2400.00	4/8/2016	5/9/2016	31	77.42
5/9/2016 - 6/1/2016	4000.00	5/9/2016	6/2/2016	24	166.67
6/2/2016 - 7/24/2016	900.00	6/2/2016	7/25/2016	53	16.98
7/25/2016 - N/A	515.00	7/25/2016	N/A	N/A	0.00
Average				30.67	56.05

Table 4.8 Days between order and estimated demand for brand B

Period	Qty	CO Date	Next CO Date	# Day	Estimated Demand
1/26/2016 - 2/21/2016	300.00	1/23/2016	2/22/2016	30	10.00
2/22/2016 - 3/10/2016	200.00	2/22/2016	3/11/2016	18	11.11
3/11/2016 - 4/7/2016	1250.00	3/11/2016	4/8/2016	28	44.64
4/8/2016 - 5/24/2016	3000.00	4/8/2016	5/25/2016	47	63.83
5/25/2016 - 6/1/2016	1000.00	5/25/2016	6/2/2016	8	125.00
6/2/2016 - 7/21/2016	2000.00	6/2/2016	7/22/2016	50	40.00
7/22/2016 - 9/15/2016	800.00	7/22/2016	9/16/2016	56	14.29
9/16/2016 - 10/4/2016	3100.00	9/16/2016	10/5/2016	19	163.16
10/5/2016 - 11/8/2016	1500.00	10/5/2016	11/9/2016	35	42.86
11/9/2016 - 12/28/2016	400.00	11/9/2016	12/29/2016	50	8.00
12/29/2016 - N/A	364.00	12/29/2016	N/A	N/A	0.00
Average				34.1	52.29

Table 4.9 Days between order and estimated demand for brand C

Period	Qty	CO Date	Next CO Date	# Day	Estimated Demand
1/26/2016 - 2/21/2016	500.00	1/26/2016	2/22/2016	27	18.52
2/22/2016 - 4/25/2016	1000.00	2/22/2016	4/26/2016	64	15.63
4/26/2016 - 5/18/2016	200.00	4/26/2016	5/19/2016	23	8.70
5/19/2016 - 6/19/2016	1000.00	5/19/2016	6/20/2016	32	31.25
6/20/2016 - 7/21/2016	2200.00	6/20/2016	7/22/2016	32	68.75
7/22/2016 - N/A	530.00	7/22/2016	N/A	N/A	0.00
Average				35.6	28.57

Table 4.10 Days between order and estimated demand for brand D

Period	Qty	CO Date	Next CO Date	# Day	Estimated Demand
1/26/2016 - 2/22/2016	100.00	1/26/2016	2/22/2016	27	3.70
2/23/2016 - 3/10/2016	100.00	2/22/2016	3/11/2016	18	5.56
3/11/2016 - 5/18/2016	600.00	3/11/2016	5/19/2016	69	8.70
5/19/2016 - 6/1/2016	200.00	5/19/2016	6/2/2016	14	14.29
6/2/2016 - 7/21/2016	500.00	6/2/2016	7/22/2016	50	10.00
7/22/2016 - 8/4/2016	400.00	7/22/2016	8/5/2016	14	28.57
8/5/2016 - 9/15/2016	500.00	8/5/2016	9/16/2016	42	11.90
9/16/2016 - 10/16/2016	600.00	9/16/2016	10/17/2016	31	19.35
10/17/2016 - 11/8/2016	600.00	10/17/2016	11/9/2016	23	26.09
11/9/2016 - 12/29/2016	600.00	11/9/2016	12/29/2016	50	12.00
12/30/2016 - 1/9/2017	306	12/29/2016	-		0.00
Average				33.8	14.02

Table 4.11 Days between order and estimated demand for brand E

Period	Qty	CO Date	Next CO Date	# Day	Estimated Demand
1/26/2016 - 2/21/2016	100	1/23/2016	2/22/2016	30	3.33
2/22/2016 - 3/10/2016	200	2/22/2016	3/11/2016	18	11.11
3/11/2016 - 4/7/2016	950	3/11/2016	4/8/2016	28	33.93
4/8/2016 - 5/18/2016	200	4/8/2016	5/19/2016	41	4.88
5/19/2016 - 6/13/2016	200	5/19/2016	6/14/2016	26	7.69
6/14/2016 - 7/21/2016	200	6/14/2016	7/22/2016	38	5.26
7/22/2016 - 8/4/2016	200	7/22/2016	8/5/2016	14	14.29
8/5/2016 - 9/15/2016	300	8/5/2016	9/16/2016	42	7.14
9/16/2016 - 10/16/2016	400	9/16/2016	10/17/2016	31	12.90
10/17/2016 - 11/8/2016	400	10/17/2016	11/9/2016	23	17.39
11/9/2016 - 12/28/2016	400	11/9/2016	12/29/2016	50	8.00
12/29/2016 - N/A	204	12/29/2016	N/A	N/A	0.00
Average				31	11.45

A small fragment of delivery schedule as the major source that contained all the above data is shown in Figure 4.2 below.

Cust. Regior	CO Date	Actual Delivery	City	State	Item name	SO C	mT
East 2	1/26/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Dua Pedang @25kg	500.00	12.50
East 2	1/23/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Gatotkaca@25kg plastik	780.00	19.50
East 2	1/23/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Gatotkaca@25kg plastik	780.00	19.50
East 2	1/26/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Kompas@25kg plastik	500.00	12.50
East 2	1/26/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Gerbang@25kg	100.00	2.50
East 2	1/26/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Gunung@25kg	100.00	2.50
East 2	1/26/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Kompas@25kg plastik	500.00	12.50
East 2	1/23/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Kompas@10kg/box (B)	300.00	3.00
East 2	1/26/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Gatotkaca@25kg plastik	780.00	19.50
East 2	1/26/2016	1/26/2016	KABUPATEN POSO	Sulawesi Tengah	Terigu Dua Pedang @25kg	500.00	12.50

Figure 4.2 Delivery schedule obtained from FC

4.3 Data Collected on Procurement Department

Besides the delivery schedule, we also collected data via interview with procurement officers about travel time and distance, alternative route, and penalty cost in case delivery was late. We summarized the data collected as follows:

1. Regular or primary route of delivery from Makassar to Poso was using Trans-Sulawesi road as depicted in Figure 4.3 below.

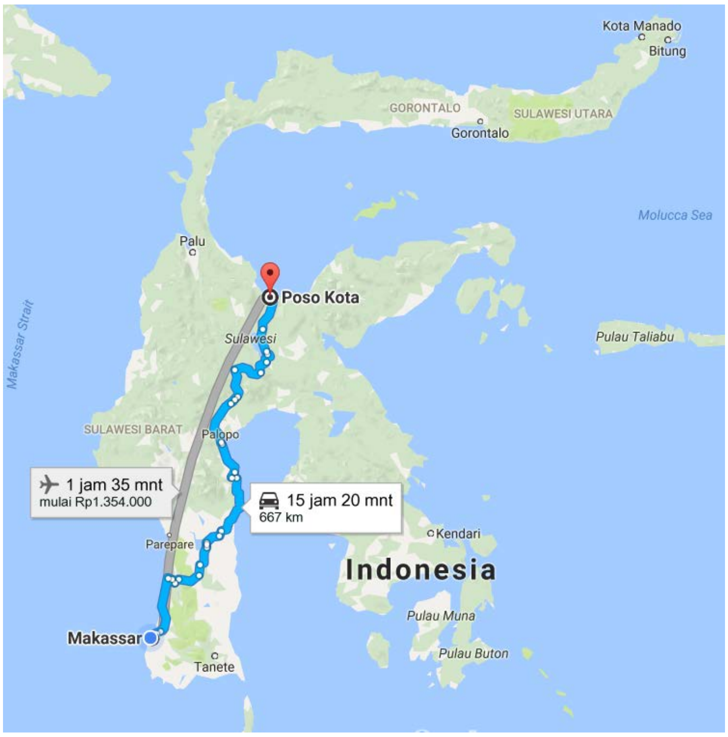


Figure 4.3 Primary route Makassar- Poso (source: maps.google.com)

   According to the Figure 4.3 above, the travel time was 15 hours 20 minutes, in reality truck drivers need to take breaks and stops a couple of times for the local tax. Hence the actual travel time was 2 days. The distance also needs revision because via interview, the actual regular distance was 689.4 Km.

2. Alternative route that typically used by truck drivers when the primary route disrupted was via west coast, Makassar – Mamuju (West Sulawesi) – Poso. The alternative route was depicted in Figure 4.4 and Figure 4.5 below.

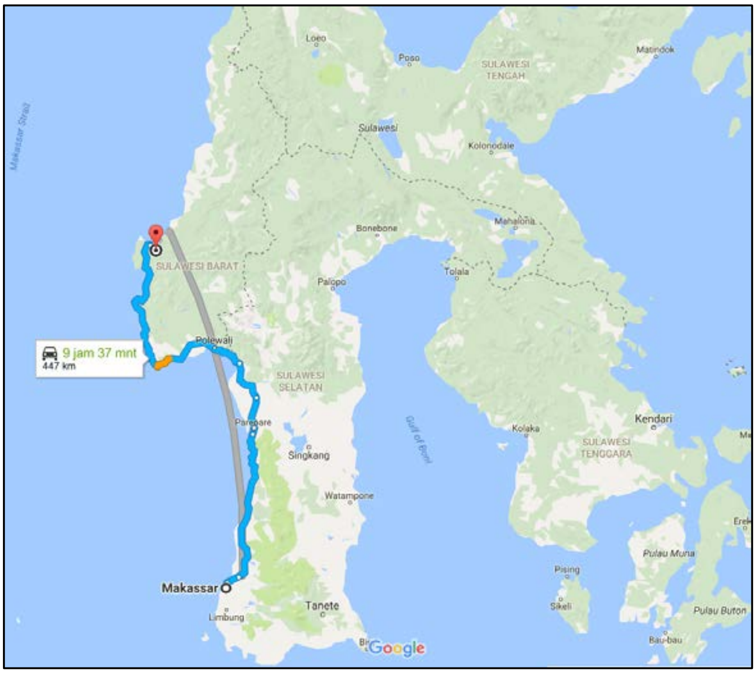


Figure 4.4 Travel route from Makassar to Mamuju

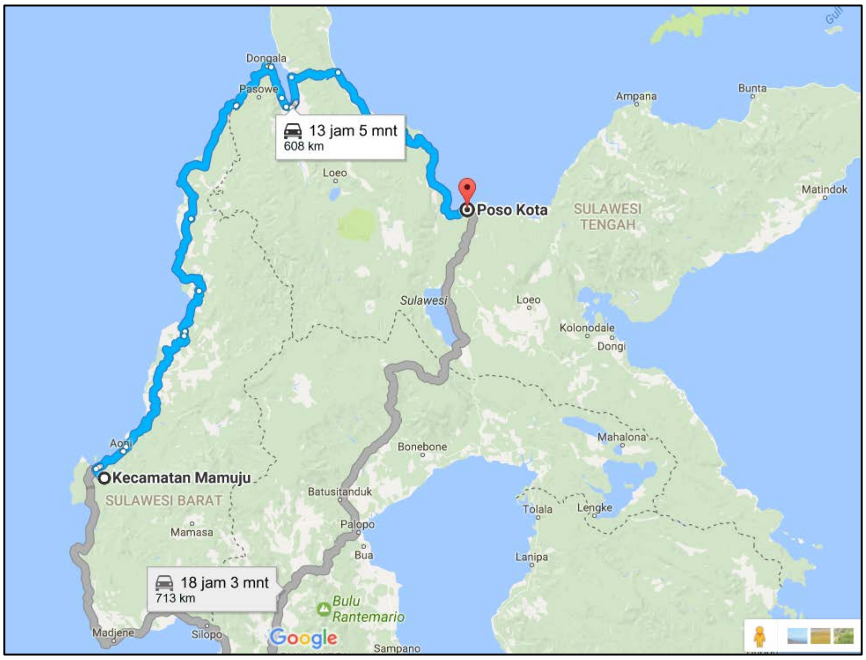


Figure 4.5 Travel route from Mamuju to Poso

The actual accumulated travel time from Makassar – Mamuju – Poso was 4 days with 1040 Km accumulated distance.

3. Penalty costs due to lateness of delivery is usually charged by the customers to the suppliers. In this case, there was no penalty costs charged by distributor to FC when delivery was late. The only consequence due lateness was the risk of having a bad reputation and the risk of loss of distributor's willingness to purchase (i.e. lowering the quantity of purchase order).
4. Freight Rate

   Freight rate is a cost of hiring a truck with certain capacity on a specific destination. A freight rate for a truck with 25 MT capacity destined to Poso was Rp. 14.850.000. The rate per MT per Km was Rp 14.850.000 / (689.4*25) = Rp 861.62.

4.4 Data collected on Sales Department

We also collected data in respect of the selling price that FC charged for each unit SKU that distributor order. The list of the selling price (ppn included) for 5 brands we selected was presented in Table 4.12 below.

Table 4.12 Brand's selling price

Brand	Selling Price (per unit)	
A	Rp	133,100.00
B	Rp	80,000.00
C	Rp	152,000.00
D	Rp	155,000.00
E	Rp	162,800.00

4.5 Data Collected on BNPB

In order to cause a transportation disruption into the delivery process, we collected data of natural disaster event from Badan Nasional Penanggulangan Bencana (BNPB) via their website http://dibi.bnpb.go.id/data-bencana/crosstab. Firstly, we determine the natural disaster affected area for South Sulawesi, since traveling from Makassar to Poso is spending 80% of the distance through South Sulawesi region. Secondly, we determine landslide, flood, and landslide-flood as our focused natural disaster source, since this types are the major source of road infrastructure failures in South Sulawesi. Thirdly, we determine 2001 to 2016 as the years of observation. Lastly, we presented the frequency of natural disaster for each year observed. The frequency of natural disaster is shown in Table 4.13 below.

Table 4.13 Frequency of natural disaster by year

Year	Frequency	Year	Frequency
2001	2	2009	21
2002	3	2010	78
2003	5	2011	20
2004	12	2012	22
2005	5	2013	30
2006	25	2014	21
2007	32	2015	28
2008	34	2016	40

4.6 Proposed Strategies and Impact Costs

Impact cost defined as the consequent cost incurred due to applying a strategy. We proposed 4 strategies to mitigate negative impact of transportation disruption, named: (1) Base Case; (2) Redundant Stock; (3) Flexible Route; and (4) Redundant-Flexibility (ReFlex). For every strategy applied, the element of transportation cost (TC) will always exist which expressed in Equation 4.1 below.

$$TC = Rate * Regular\ Distance * Delivery\ qty/40 \quad (4.1)$$

4.6.1 Base Case

FC would wait until the road is fixed, then started delivery, so it incurred an extra holding cost (EHC) that depends on the holding costs (per unit per day), disruption duration (DD), and delivery quantity being hold. Where the holding costs equals to 30% of selling the brand's selling price (BSP). Hence the impact costs of this strategy was TC + EHC.

$$EHC = \frac{BSP * annual\ values}{period} * DD * Delivery\ qty \quad (4.2)$$

where:

EHC	= extra holding costs (Rp)
BSP	= selling price of the brand from FC to distributor (Rp)
DD	= the duration of disruption (day)
$Period$	= 365 days in a year
$Annual\ values$	= set to be 30% or 0.3

4.6.2 Redundant Stock

Similar with base case, except in the very beginning of delivery period, FC placed an extra inventory we called redundant stock in distributor's warehouse. Since redundant stock are kept in distributor's warehouse, it is impractical if it exclusively reserved in the case of disruption. In contrary, it can also use to satisfy daily demand or to protect against lateness that caused by other factor than disruption. Also to persuade distributor to kept the redundant stock in its warehouse, the redundant holding cost (RHC) was paid 50% by FC. Therefore, the total consequent costs of applying this strategy was the TC + EHC +RHC + redundant transportation cost (RTC).

$$RHC = R * BSP * annual\ values * 0.5 \quad (4.3)$$

$$RTC = (R/40) * rate * regular\ distance \quad (4.4)$$

where:

R = redundant stock quantity

4.6.3 Flexible Route

In this strategy, FC doesn't have to wait until the road is fixed. FC persuade the trucking company to use alternative route for the delivery process when the transportation disruption occurred. When transportation disruption doesn't occur the truck used the regular route. As compensation, FC will pay additional cost named extra distance costs (EDC) to the trucking company. In summary, the total impact costs for this strategy was TC + EDC.

$$EDC = Rate * Alternative\ distance * (Delivery\ qty/40) \quad (4.5)$$

4.6.4 ReFlex

This strategy combined the redundant stock with flexible route. When transportation disruption occurs truck will use the alternative route causing lateness which is 4 days of trip. To cover this 4 days of lateness, in the very beginning of period, FC placed a redundant stock equals to 4 days of demand (retailer's). Hence, the total impact costs of this strategy was TC + RHC + RTC + EDC.

CHAPTER 5

SIMULATION MODEL & CEA

This chapter shows how we conduct the simulation study and CEA by using applying the specified methods from chapter 3 and collected data from chapter 4

5.1. Simulation Study

We conduct a simulation study according to the method we introduced in Chapter 3.

5.1.1. Problem Formulation

We translate the Research Question (RQ) as the problem formulation for this simulation study: “We don’t know the cost and effectiveness of each proposed strategy against transportation disruption”

5.1.2. Setting Objectives

Based in the problem formulation, we defined the objective of this simulation study as: “To find out the value of cost and effectiveness of each proposed strategy”

5.1.3. Model Conceptualization

FC sells its products to the distributor where distributor re-sell the products to retailers. Distributor act as a reseller who fills a known end retailer’s demand from its inventory, which in turn is replenished by the FC. We assume that natural-catastrophic events may occur at any point in time causing unavailability of road infrastructure (main route) that connecting FC’s site with distributor site with a frequency per year. Once a transportation disruption occurs, the ability of FC to replenish distributor’s inventory stops temporarily (for the duration of the disruption); however, retailer’s demand can continue to be met from inventory until it is depleted. Depending on the duration of the disruption and on-hand inventory at the time of the beginning of a disruption, distributor could very likely experience stockouts. Here we assume that any unmet demand considered as loss of sales (no backorder). The recovery process (fixing the road) will be executed as soon as a disruption begins. Hence, the disruption duration is equal to the recovery process. Replenishment (here on we call it delivery) process from the FC resumes as soon as recovery process is finished. The proposed strategies conceptualized as follows:

1. 1st strategy: Base Case

   FC would wait until the road is fixed, then started delivery, so it incurred an extra holding cost (EHC) that depends on the holding costs (per unit per day), disruption duration (DD), and delivery quantity being hold. Where the holding costs equals to 30% of selling the brand's selling price (BSP). Hence the impact costs of this strategy was TC + EHC.

2. 2nd strategy: Redundant Stock

   Similar with base case, except in the very beginning of delivery period, FC placed an extra inventory we called redundant stock in distributor's warehouse. Since redundant stock are kept in distributor's warehouse, it is impractical if it is exclusively reserved in the case of disruption. Therefore, it can also be used to satisfy daily demand or to protect against lateness that caused by other factor than disruption. Also to persuade distributor to kept the redundant stock in its warehouse, the redundant holding cost (RHC) was paid 50% by FC. Therefore, the total consequent costs of applying this strategy was the TC + EHC +RHC + redundant transportation cost (RTC).

3. 3rd strategy: Flexible Route

   In this strategy, FC doesn't have to wait until the road is fixed. FC persuade the trucking company to use alternative route for the delivery process when the transportation disruption occurred. When transportation disruption doesn't occur the truck used the regular route. As compensation, FC will pay additional cost named extra distance costs (EDC) to the trucking company. In summary, the total impact costs for this strategy was TC + EDC.

4. 4th strategy: ReFlex

   This strategy combined the redundant stock with flexible route. When transportation disruption occurs truck will use the alternative route causing lateness which is 4 days of trip. To cover this 4 days of lateness, in the very beginning of period, FC placed a redundant stock equals to 4 days of demand (retailer's). Hence, the total impact costs of this strategy was TC + RHC + RTC + EDC.

We introduced 3 simulation logics to accommodate the coding process of the proposed strategies. Each strategy consists of these simulation logic:

1. Delivery logic

   This logic explains the delivery process from FC to distributor. Date of delivery and quantity of each delivery are triggered by the delivery schedule. For the 1st and 2nd strategy, the delivery is using regular route, either or not disruption occur. For the 3rd and 4th strategy, when disruption not occur, use regular route. But when disruption occur, use alternative route. When the delivered products arrived at distributor's site, the inventory instantly updated and the incurred cost will be calculated.

2. Demand logic

   This logic explains the process of how demands reducing the inventory level. Demand assumed to be arrived every day with the rate for each period is different from one another. Every time a demand arrived, inventory is used to satisfy that demand. When demand cannot be satisfied, there will be a stockouts under the assumption of no backorder. During the execution, this logic will record the total number of unsatisfied demand.

3. Disruption logic

   This logic generates occurrence of natural disaster that may or may not disturb the delivery process. When a natural disaster happened at the same time with a schedule delivery, then the delivery logic will be disrupted. For 1st and 2nd strategy the delivery will not resume until the road is fixed. For 3rd and 4th the delivery will use alternative route without waiting for the road to be fixed.

In summary, demand and disruption logic are the same on every strategy. But for delivery logic, the construction will be different for each strategy. When simulating every brand, the simulation input should have adjusted according to the correspond brand.

5.1.4. Simulation Inputs Formulation

Using the method in Chapter 3, we could translate the data we have collected to become simulation inputs. The formulation is presented in Table 5.1 below.

Table 5.1 Input for simulation study

Collected Data	Method to translate into simulation inputs	Input value
Delivery date	Use directly the data values	See Appendix
Quantity delivered	Use directly the data values	See Appendix
Regular route travel time	Guesstimate	Constant: 2 days
Alternative route travel time	Guesstimate	Constant: 4 days
Demand date	Use directly the data values	See Appendix
Demand quantity	Use directly the data values	See Appendix
Natural disaster occurrence	Empirical distribution function	See Table 5.2
Disruption duration	Fit a probability distribution to the data values	0.14+LogN(3.19,8.64) days
Redundant stock quantity	Use directly the data values	See Table 5.3

Natural disaster occurrence was obtained by calculate the cumulative distribution function (CDF) from data in Table 4.13 frequency of natural disaster by year). The value of probability then used as the input in ARENA using expression "DISC (upper limit, probability)". The input value is presented in Table 5.2 below. As a remainder, there are 2 strategy using redundant stock which are 2nd strategy (redundant stock) and 4th strategy (ReFlex). The quantity for each brand is different according to the average days per period and average demand rate per year. For example, quantity for brand A can be calculated using data from Table 4.7; for the 2nd strategy we'd like to protect the inventory for 1 period, thus equal to $30.67 * 56.05 = 1719.05 \approx 1720$ unit; for the 4th strategy we'd like to protect the inventory for 4 days of transport time using alternative route, thus equal to $4 * 56.05 = 224.2 \approx 225$ unit. The same principal applied to other brand. Table 5.3 below shows the quantity of buffer stock for 5 brands in each strategy.

Table 5.2 Simulation input for natural disaster occurrence

Lower limit	Upper limit	Probability
0	5	0.25
5	10	0.25
10	15	0.31
15	20	0.38
20	25	0.63
25	30	0.75
30	35	0.88
35	40	0.94
40	45	0.94
45	50	0.94
50	55	0.94
55	60	0.94
60	65	0.94
65	70	0.94
70	75	0.94
75	80	1.00

Table 5.3 Redundant stock quantity for 2nd and 4th strategy

Brand	Redundant stock value	
	For 2nd strategy	For 4th strategy
A	1720	225
B	1784	210
C	1018	115
D	474	57
E	355	46

5.1.5. Computerized Model in ARENA

We translated the conceptual model into computerized model using simulation software package ARENA ®. We build the computerized model using brand E since this brand has the least volume of delivery and the existence of delivery for every month, thus the chance of having disruption is highly probable. We start building the computerized model by translate the 3 logic we explained before into the ARENA ®. We started from the 1st strategy way up to 4th strategy. The computerized model of base case, redundant stock, flexible route, and ReFlex are depicted consecutively in Figure 5.1, Figure 5.2, Figure 5.3, and Figure 5.4 below. We then conducted a pilot run of brand E for every strategy in a single replication. The time unit for the simulation is in days with replication length for 368 days. To match the historic nature of the system under study, we start the simulation from January 1st 2016.

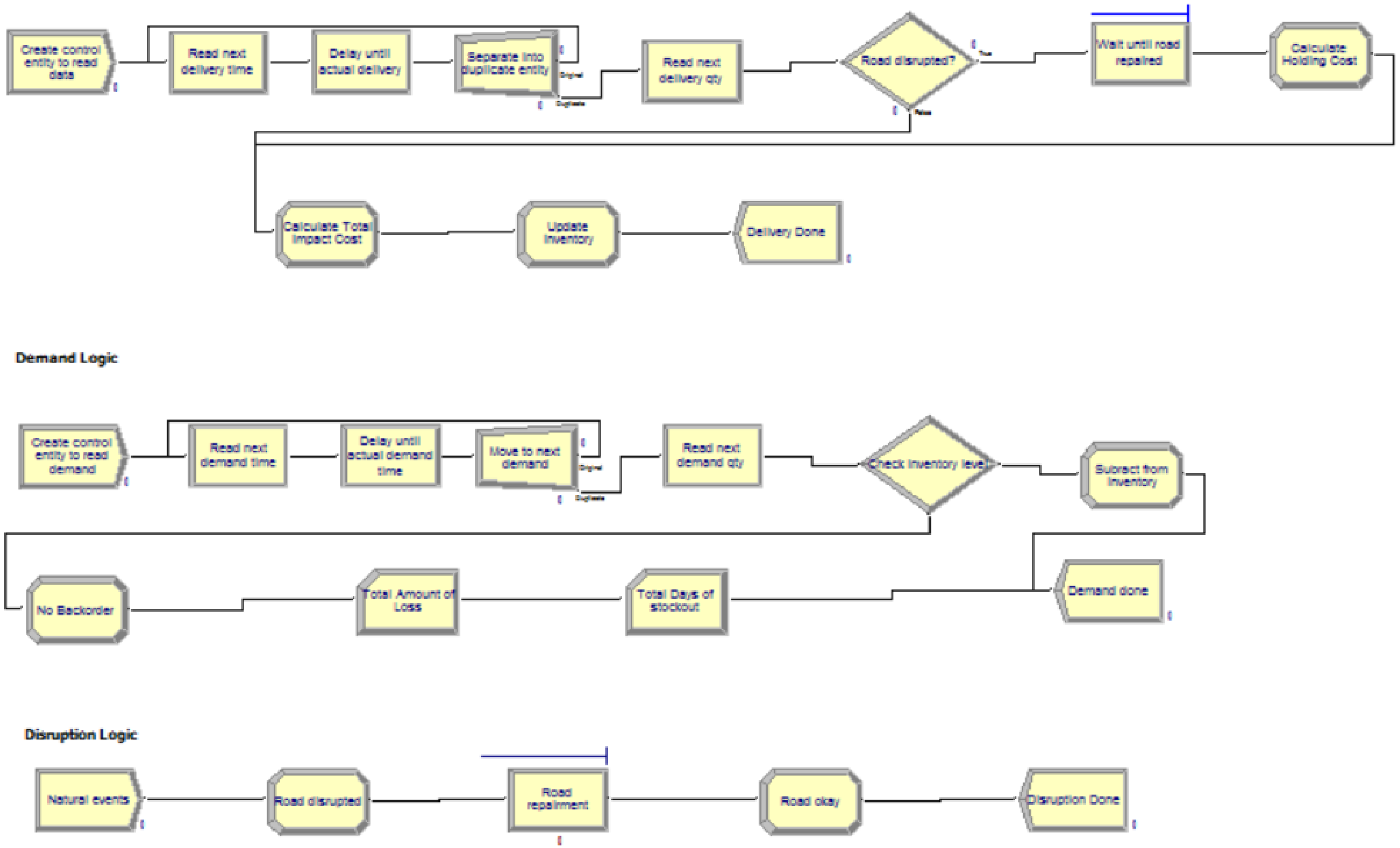


Figure 5.1 Computerized model for base case strategy

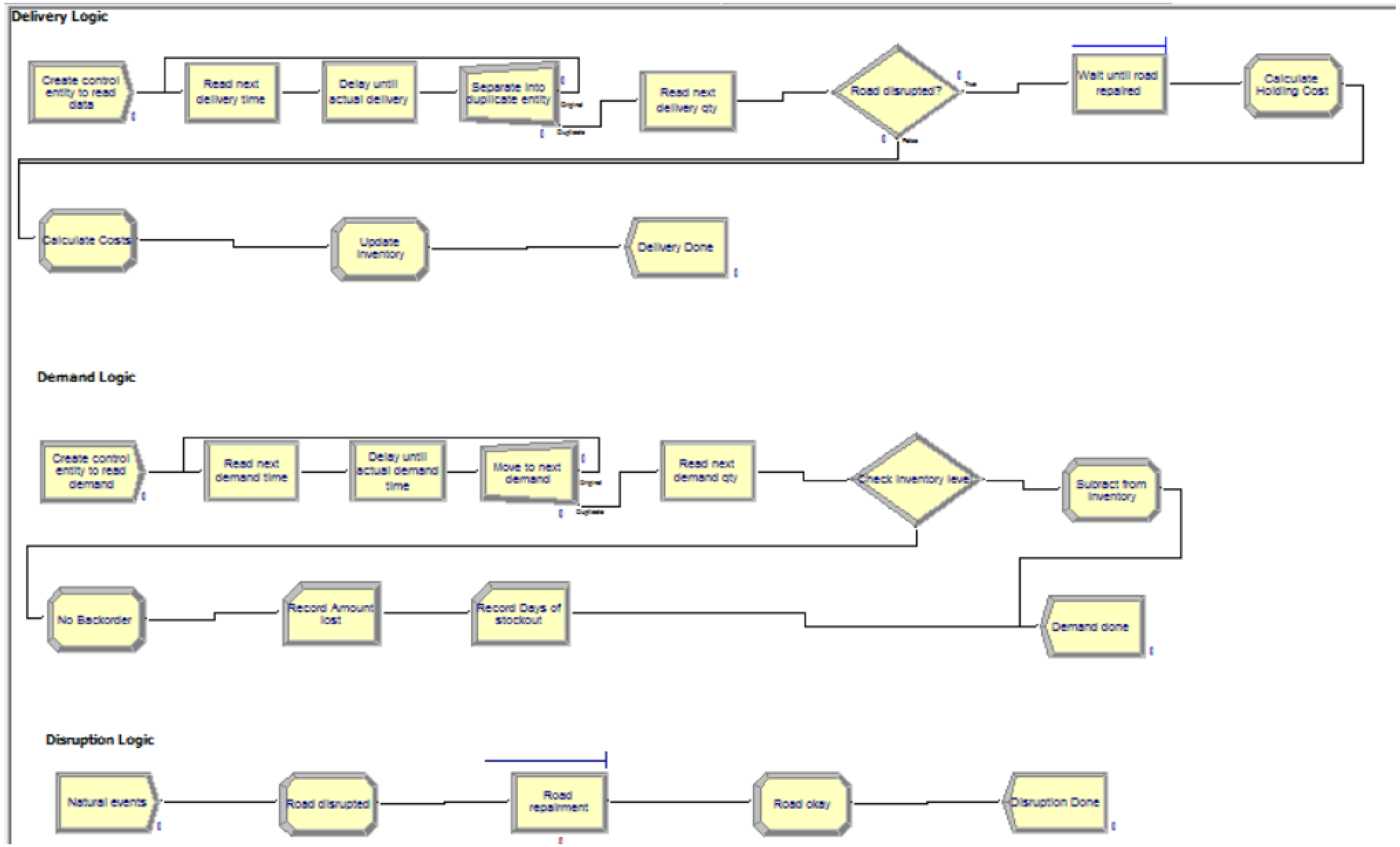


Figure 5.2 Computerized model for redundant stock strategy

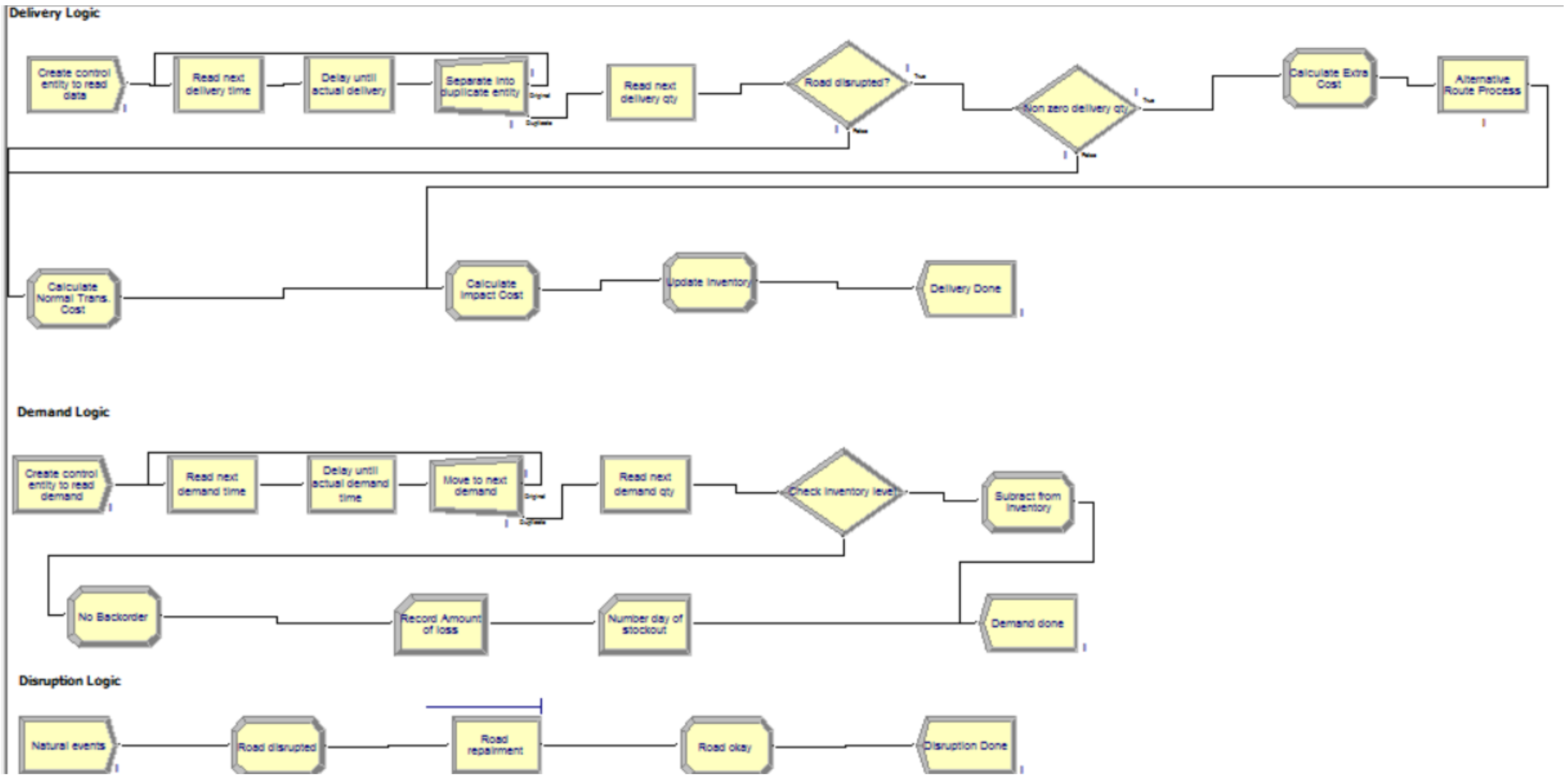


Figure 5.3 Computerized model for flexible route strategy

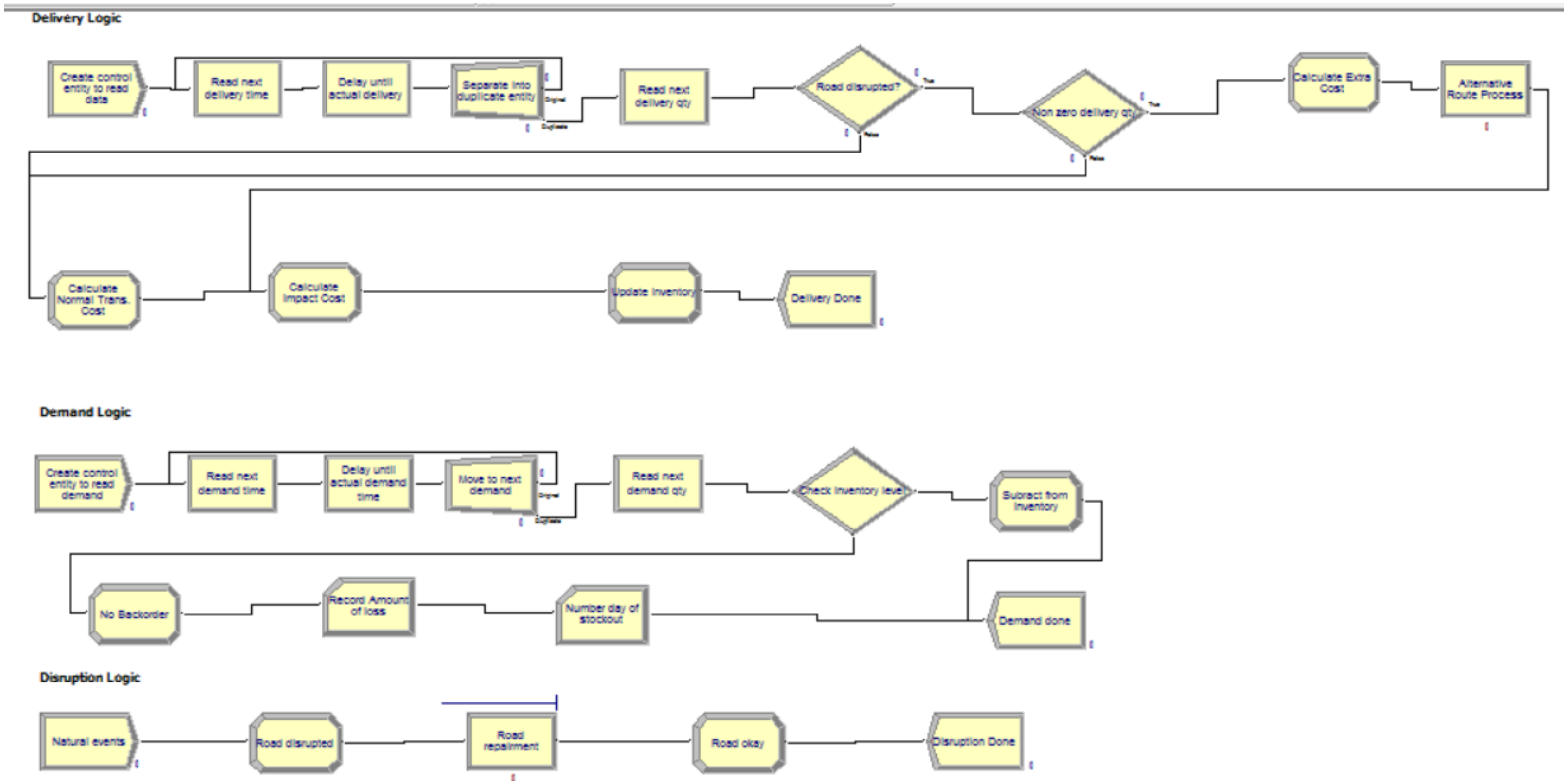


Figure 5.4 Computerized model for ReFlex strategy

5.1.6. Verification

We conduct a verification test by comparing the graphical output of simulation with graphical output of hand calculations. We found that our computerized model gave the same output as our hand calculations. The graphical comparison between base case strategy was depicted in Figure 5.5; redundant strategy in Figure 5.6; flexible route in Figure 5.7; and ReFlex in Figure 5.8.

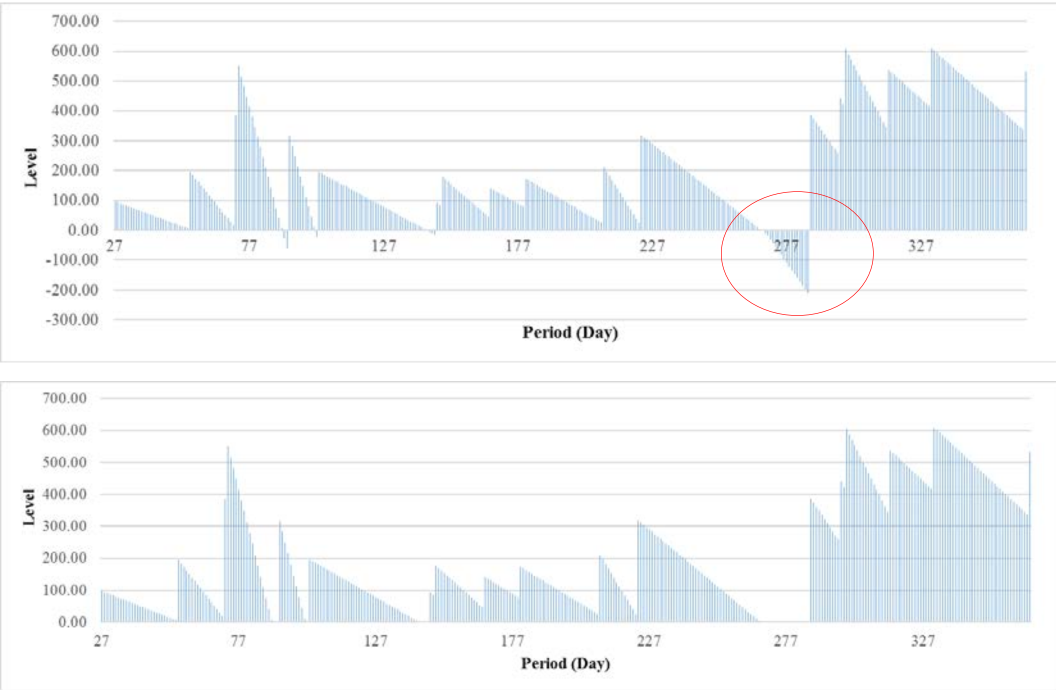


Figure 5.5 Output comparison of hand calculations (top) with computerized model (bottom) on base case

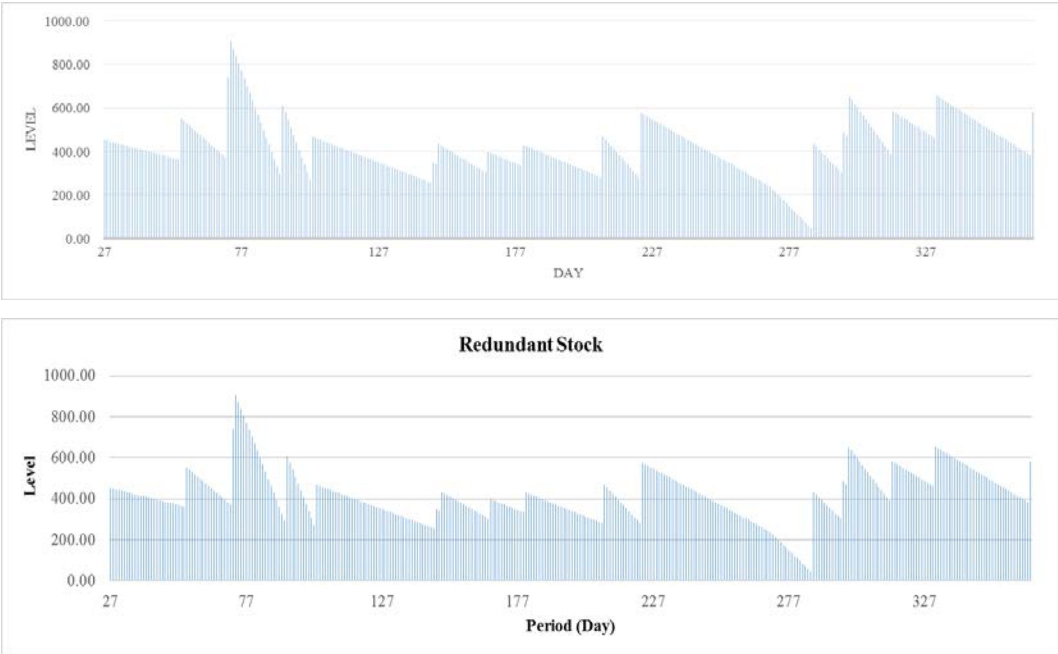


Figure 5.6 Output comparison of hand calculations (top) with computerized model (bottom) on redundant stock strategy

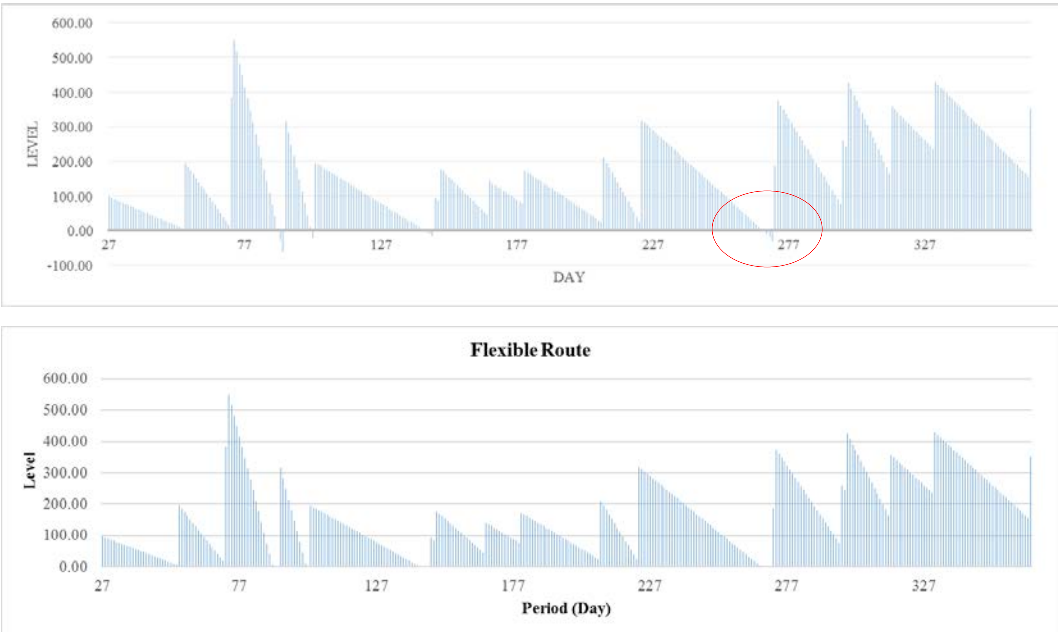
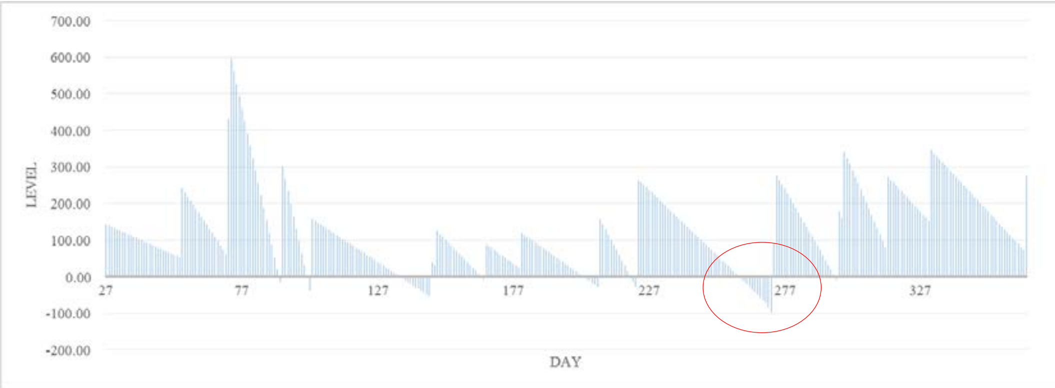


Figure 5.7 Output comparison of hand calculations (top) with computerized model (bottom) on flexible strategy



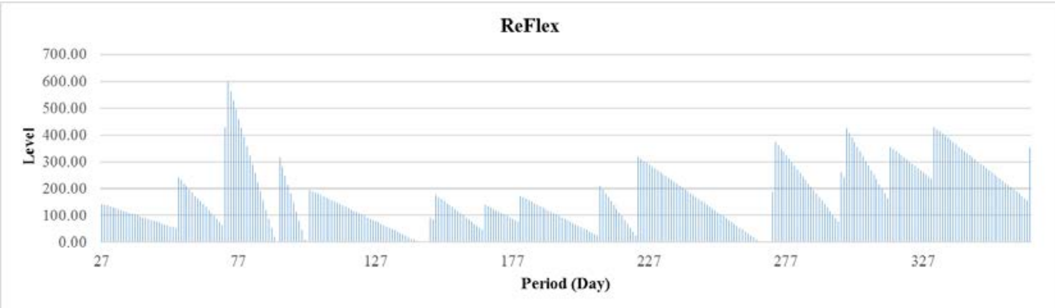


Figure 5.7 Output comparison of hand calculations (top) with computerized model (bottom) on ReFlex strategy

There is a minor different between hand calculations graphic with computerized model graphic which is the minus inventory level (red circled) in hand calculations. We did this on purpose in order to show that the stockout period in computerized model equals to unsatisfied demand.

5.1.7. Validation

A real system in this research is referring to a delivery activity that interrupted by transportation disruption event. Unfortunately comparing the output of simulation model with output of the real system is improbable because the real system itself doesn't exist, not yet exist, or exists but undocumented by FC. Therefore, we conduct validation test by comparing the result of our simulation model with result from another similar model which already valid. We compare our model with the model belong to Wilson (2007), since her model based on transportation disruption. In Wilson (2007) model, the inventory level of distributor during disruption is flat or experience a stockout, but after the disruption over and FC resume its delivery, inventory level of distributor raised significantly high. The same phenomenon happened in our base case strategy.

5.1.8. Sensitivity Analysis

We decided to conduct sensitivity analysis of simulation study at the same time with sensitivity analysis of CEA. This decision is under the following considerations:

1. If we conduct sensitivity analysis at this stage, we will find our analysis to be lack of behavioral accuracy since at this stage the simulation run only in 1 replication.
2. Conducting sensitivity analysis means we changes the value of relevant factors to see how sensitive the responses are. In other words, changing factors will likely change responses (cost & effectiveness) thus affecting the CEA. So, for the sake of efficiency, we can conduct both sensitivity analysis simultaneously while serve the same purpose.

5.1.9. Production Run & Output Analysis

When V&V testing has been passed, we can change from pilot run to production run. In production run, we increase the replication from 1 to 10 replications and the run length is still the same (368 days). We conduct production run for 4 strategies in 5 brands, so in total there are 20 results simulation responses (impact cost and amount of loss). Therefore, we took a sample of simulation output of brand E, depicted in Table 5.4 below.

Table 5.4 Simulation output for brand E with 10 replications

Strategy	10 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	57228533.00	3553575.46	6.21	284.25	285.41	100.41
Redundant Stock	70866450.00	3685124.03	5.20	117.33	220.17	187.65
Flexible Route	60355923.00	3119399.65	5.17	63.48	41.16	64.84
ReFlex	62162344.00	3119399.65	5.02	33.08	30.84	93.23

From Figure 5.8 above, the half-width represents the simulation behavioral accuracy under 95% confidence interval. For example, for base case strategy, with 95% C.I, the Mean for impact cost was Rp 70,866,450.00 with half-width Rp 3,685,124.03. It means that with 95% C.I we believe that the True Mean will fall between the interval of Rp 70,866,450.00 ± Rp 3,685,124.03 or [Rp 74,551,574.03, Rp 67,181,352.97]. While the amount of loss was 117.33 ± 220.17 or [337.5, -102.84]. This interval for impact cost is quite wide, while the amount of loss shows much wider interval which look unrealistic. The similar results were also found in the other brand. It means that the bigger the half-width means the smaller the accuracy of our simulation study. Therefore, we want to make this half-width value smaller to get greater/better accuracy. One method that would approximately solve this problem is by using Equation 3.1 to find n number of replications larger than 10.

5.1.10. Replications

To find the number replications that give better accuracy, first we must set target of how small the half-width we want. This target is subjectively set by analyst and therefore, the new half-width value will just be an approximation value around the target. In this research, we wanted to press the half-width value into 20 times smaller. By Equation 3.1 it means that $n \cong 10\,(20)^2$,which n equals to 4000 replications. Then we run the simulation again by changing 10 replications to 4000 replications.

5.1.11. Document Cost and Effectiveness

The results of simulation run for brand A, B, C, D, and E with 4000 replications compared with 10 replications was presented consecutively in Table 5.5, Table 5.6, Table 5.7, Table 5.8, and Table 5.9.

Table 5.5 Comparison of simulation output based on the number of replications for brand A

Strategy	10 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	147289350.00	8656739.92	5.88	1663.76	1421.19	85.42
Redundant Stock	207171186.00	8656739.92	4.18	711.90	1113.40	156.40
Flexible Route	159790585.00	14301637.46	8.95	388.10	138.80	35.76
ReFlex	167623964.00	14301637.46	8.53	180.56	121.58	67.33

Strategy	4000 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	143393372.00	179539.94	0.13	947.27	25.04	2.64
Redundant Stock	203275208.00	179539.94	0.09	114.89	16.29	14.18
Flexible Route	150869721.00	306782.72	0.20	716.52	10.69	1.49
ReFlex	158703100.00	306782.72	0.19	497.87	10.36	2.08

Table 5.6 Comparison of simulation output based on the number of replications for brand B

Strategy	10 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	92087625.00	5721433.92	6.21	2045.77	1346.91	65.84
Redundant Stock	124092600.00	5721433.92	4.61	876.74	1047.88	119.52
Flexible Route	97897645.00	6308088.86	6.44	782.29	339.25	43.37
ReFlex	101665046.00	6308088.86	6.20	572.29	339.25	59.28

Strategy	4000 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	88425475.00	156824.59	0.18	2571.22	51.94	2.02
Redundant Stock	120430450.00	156824.59	0.13	1228.32	39.54	3.22
Flexible Route	92704651.00	160794.17	0.17	2478.70	50.23	2.03
ReFlex	96472053.00	160794.17	0.17	2291.99	49.17	2.15

Table 5.7 Comparison of simulation output based on the number of replications for brand C

Strategy	10 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	80059701.00	2739330.96	3.42	701.95	333.09	47.45
Redundant Stock	118387422.00	2739330.96	2.31	82.16	137.10	166.87
Flexible Route	85663678.00	4990628.49	5.83	548.59	230.43	42.00
ReFlex	89993430.00	4990628.49	5.55	433.59	230.43	53.14

Strategy	4000 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	80380674.00	121683.01	0.15	1489.82	30.04	2.02
Redundant Stock	118708395.00	121683.01	0.10	696.35	24.86	3.57
Flexible Route	84475836.00	200454.25	0.24	1442.23	29.32	2.03
ReFlex	88805589.00	200454.25	0.23	1329.63	29.21	2.20

Table 5.8 Comparison of simulation output based on the number of replications for brand D

Strategy	10 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	67362589.00	2991451.09	4.44	273.37	212.37	77.69
Redundant Stock	85421999.00	2991451.09	3.50	59.56	77.11	129.46
Flexible Route	72808077.00	3832785.05	5.26	63.68	33.65	52.84
ReFlex	74979778.00	3832785.05	5.11	23.18	21.46	92.56

Strategy	4000 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	66868842.00	96444.19	0.14	312.63	7.64	2.44
Redundant Stock	84928252.00	96444.19	0.11	40.61	5.08	12.51
Flexible Route	70292619.00	114412.20	0.16	258.85	4.69	1.81
ReFlex	72464320.00	114412.20	0.16	203.29	4.63	2.28

Table 5.9 Comparison of simulation output based on the number of replications for brand E

Strategy	10 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	57228533.00	3553575.46	6.21	284.25	285.41	100.41
Redundant Stock	70866450.00	3685124.03	5.20	117.33	220.17	187.65
Flexible Route	60355923.00	3119399.65	5.17	63.48	41.16	64.84
ReFlex	62162344.00	3119399.65	5.02	33.08	30.84	93.23

Strategy	4000 Replications of 95 Confidence Interval					
	Impact Cost			Amount of Loss		
	Mean (Rp)	Half-Width (Rp)	% Half-Width	Mean	Half-Width	% Half-Width
Base Case	55886922.06	76530.06	0.14	480.21	9.79	2.04
Redundant Stock	69670332.00	79850.45	0.11	215.20	7.66	3.56
Flexible Route	58545037.00	91154.85	0.16	452.21	8.94	1.98
ReFlex	60351458.00	91154.85	0.15	407.79	8.87	2.18

From these Table above, changing replications from 10 to 4000 replications, gave significant improvement on the half-width value which for the impact cost the percentage of half-width value was less than 1 % and for the amount of loss the percentage of half-width value was less than 5%.

5.2. Cost-Effectiveness Analysis

Since running the simulation with 4000 replications gave better behavioral accuracy of the simulation responses, in CEA we will use these values. For a detail example of conducting CEA, will use simulation output from Table 5.9 of brand E as input.

5.2.1. Obtain cost and effectiveness from simulation study

We extract information from Table 5.9 so that we can focus on the cost and effectiveness of each strategy for brand E.

Table 5.10 Impact cost (cost) and loss of sales (effectiveness) for brand E

Strategy	Impact Cost	Loss of Sales (%)
Base Case	Rp 55,886,922.06	12.79
Redundant Stock	Rp 69,670,332.00	5.24
Flexible Route	Rp 58,545,037.00	12.05
ReFlex	Rp 60,351,458.00	10.73

5.2.2. List Strategies in Ascending Order

Then listed the strategies in ascending order either the for the impact cost or for the % loss of sales. In this research, we list the strategies based on the % loss of sales value, presented in Table 5.11 below.

Table 5.11 Strategies listed in ascending order

Strategy	Impact Cost	Loss of Sales (%)
Base Case	Rp 55,886,922.06	12.79
Flexible Route	Rp 58,545,037.00	12.05
ReFlex	Rp 60,351,458.00	10.73
Redundant Stock	Rp 69,670,332.00	5.24

Carefully note that the lesser the loss of sales percentage, the bigger effectiveness we gained, thus a small loss of sales percentage equals to big effectiveness. The ascending order means that we set an order from the least effective to the greatest effective.

5.2.3. Identify Weakly and/or Strongly Dominated Strategy

From Table 5.11 above, we need to identify the weakly and/or strongly dominated strategy. One easy way to identify is to hold on to a logic that with the increasing cost comes increasing effectiveness. Firstly, move from base case to flexible route, impact cost increase and the effectiveness also increase (lesser loss of sales percentage); move from flexible route to ReFlex the cost also increases so does the effectiveness; lastly move from ReFlex to redundant stock the cost also increases and so does the effectiveness. Since the movement from one strategy to another in an increasing order, this proves that there is no weakly or dominated strategy.

5.2.4. Calculate ICER

Now we could calculate effectiveness ratios for each strategy using Equation 2.1. The base case becomes the status-quo strategy; hence we didn't calculate its effectiveness ratio. Using Equation 2.1 the effectiveness for each strategy is presented in Table 5.12 below.

Table 5.12 Cost-effectiveness ratio for each strategy

Strategy	Impact Cost	Loss of Sales (%)	ICER
Base Case	Rp 55,886,922.06	12.79	
Flexible Route	Rp 58,545,037.00	12.05	Rp (3,592,047.21)
ReFlex	Rp 60,351,458.00	10.73	Rp (1,368,500.76)
Redundant Stock	Rp 69,670,332.00	5.24	Rp (1,697,426.96)

5.2.5. Identify Extended Dominated Strategy

From Table 5.12 above, the cost-effectiveness was presented as a negative value which is unusual, but it is not wrong (we can safely ignore the negative sign). The meaning of cost-effectiveness ratio is as follows: when we switch base case with flexible route, then for every 1% decrement of loss of sales costs Rp 3,592,047.21; switching flexible route with ReFlex, then for every 1% decrement of loss of sales costs Rp 1,368,500.76; switching ReFlex with redundant stock, then for every 1% decrement of loss of sales costs Rp 1,697,426.96. As explained in Chapter 2.5.1, an identification of extended dominated strategy will lead us towards flexible route. The same logic in previous section could also applied to identify extended dominated strategy, but this time we use the cost-effectiveness ratio. The movement from one cost-effectiveness ratio to another should be in an increasing manner (hence named incremental). Switching base case with flexible route doesn't show any problem, but when switching flexible route with ReFlex the movement is not incremental. It means that switching base case with flexible route is not as cost-effective as switching base case directly to ReFlex. Furthermore, switching base case with ReFlex gives more effectiveness with lower cost that switching base case with flexible route which gives lower effectiveness with more cost. Thus, we can eliminate flexible route from Table 5.12 and recalculate the cost-effectiveness ratio, as depicted in Table 5.13 below.

Table 5.13 Cost-effectiveness ratio after eliminate flexible route

Strategy	Impact Cost	Loss of Sales (%)	ICER
Base Case	Rp 55,886,922.06	12.79	
ReFlex	Rp 60,351,458.00	10.73	Rp (2,167,250.46)
Redundant Stock	Rp 69,670,332.00	5.24	Rp (1,697,426.96)

When we take a look at cost-effectiveness ratio of ReFlex in Table 5.13, we can clearly recognize that switching base case with ReFlex indeed gives greater effectiveness with small cost increment. Once again we identify if any strategy is extended dominated. By using the same principal when we screened out flexible route, it is clear that ReFlex should be eliminated since this strategy extended dominated by redundant stock. After eliminate ReFlex, then we can recalculate a new cost-effectiveness ratio, which depicted in Table 5.14 below.

Table. 5.14 Cost-effectiveness ratio after eliminated ReFlex

Strategy	Impact Cost		Loss of Sales (%)	ICER	
Base Case	Rp	55,886,922.06	12.79		
Redundant Stock	Rp	69,670,332.00	5.24	Rp	(1,825,617.21)

Since there the cost-effectiveness ratio is on the right incremental order. We can move to the next step by making an initial recommendation.

5.2.6. Introduce Initial Recommendation

A kind reminder, that cost-effectiveness ratio is not a rank and only one strategy can be applied/adopted. Therefore, instead of an instruction, an initial recommendation was given to the decision maker so that they can decide which strategy they should applied or perhaps choose to do nothing (base case). Decision will be made based on the willingness-to-pay (WTP) which reflects the financial capacity that the decision maker has. WTP will use cost-effectiveness ratio as its measurement. WTP for each strategy is presented in Table 5.15 below.

Table 5.15 Initial recommended strategy for brand E

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp1,825,617.21	Base Case
Rp1,825,617.21	≥	WTP	Redundant Stock

We can interpret this initial recommendation in Table 5.15 as the following:

1. If decision maker is only willing to pay less than Rp. 1,825,617.21 for every 1% decrement of loss of sales than it is suggested to applied base case strategy.

2. But if decision maker is willing to pay at least 1,825,617.21 and more for every 1% decrement of loss of sales than it is suggested to applied redundant stock as mitigation strategy.

By using the same method for conducting CEA, we present the initial recommendation for brand A, B, C, and D consecutively in Table 5.16, Table 5.17, Table 5.18, and Table 5.19.

Table 5.16 Initial recommended strategy for brand A

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 3,141,323.11	Base Case
Rp 3,141,323.11	to	Rp 3,305,222.21	Flexible Route
Rp 3,305,223.21	to	Rp11,115,237.90	ReFlex
Rp11,115,238.90	≥	WTP	Redundant Stock

Table 5.17 Initial recommended strategy for brand B

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp3,223,058.91	Base Case
Rp3,223,058.91	≥	WTP	Redundant Stock

Table 5.18 Initial recommended strategy for brand C

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp2,178,277.66	Base Case
Rp 2,178,277.66	to	Rp2,319,278.07	Flexible Route
Rp 2,319,279.07	≥	WTP	Redundant Stock

Table 5.19 Initial recommended strategy for brand D

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp2,256,241.13	Base Case
Rp2,256,241.13	to	Rp3,424,156.14	ReFlex
Rp3,424,156.14	≥	WTP	Redundant Stock

CHAPTER 6

ANALYSIS & FINDINGS

This chapter shows how we conduct sensitivity analysis by changing specific factors for each brand and analyze changes in responses and recommendations. Then we presented the findings.

6.1. Sensitivity Analysis

We conduct a sensitivity analysis by changing relevant factor of each strategy. Sensitivity analysis will serve 2 purposes as the following:

1. Simulation study: Finding out how sensitive a response change when the factors are changing
2. CEA: Finding out how sensitive the initial recommendation when the responses are changing.

These purposes are interrelated to each other because factors are affecting responses and responses are affecting the recommendation. We changed certain factors that relevant/important for certain strategy, except for base case. This important factors will change the responses of the corresponds strategy. The responses are impact cost and loss of sales percentage. For redundant stock strategy the important factor is the stock that kept as a buffer in distributor's warehouse. We will reduce the initial stock value by 50% as the new stock value. For flexible route strategy, the important factor is the alternative route travel time. Here we assumed that truck company is able to reduce the transport time via alternative route in such a way (i.e. cutting breaks) that the transport time is 3 days from formerly 4 days. For ReFlex strategy, the important factors are the stock and the alternative route travel time. The alternative route travel time will be reduced to 3 days and the stock will be increased by 400%. The reason we increased stock in ReFlex but decrease 50% in redundant stock is to serve the second purpose we mentioned earlier. Since ReFlex has 2 important factors then, the value combination between stock and travel time would use 2^k Factorial Designs, with $k = 2$. We divided the work of sensitivity analysis based on brand. We also made notations of BC (base case), RS (redundant stock), FR (flexible route), and RF (ReFlex). Every notation will be accompanied by a number, where 0 (zero) refers to the initial value in the correspond strategy, any number other than 0 is the new developed strategy with different assigned value for the purpose of this analysis. For example, RS-0 means that this is redundant strategy with initial assigned value, where RS-1 is the development strategy of RS-0 with different adjusted value. Every new strategy (i.e. RS-1) will be simulated with the same run parameters of the original strategy.

6.2. Findings on Brand A

We developed new strategies by changing the value of the factors for each strategy, run the new strategies, and document responses in the following Table 6.1.

Table 6.1 Factors variation on brand A

Notation	Factors		Responses		Total Qty	% Loss
	Trans. Time	Stock	Total Impact Cost	Loss of sales		
BC	N/A	N/A	Rp 143,393,372.00	947.27	9695	9.77
FR-1	3	N/A	Rp 150,869,721.00	694.54	9695	7.16
FR-0	4	N/A	Rp 150,869,721.00	716.52	9695	7.39
RS-0	N/A	1720	Rp 203,275,208.00	114.89	11415	1.01
RS-1	N/A	860	Rp 191,342,687.00	204.72	10555	1.94
RF-1	3	225	Rp 158,703,100.00	477.01	9920	4.81
RF-2	3	900	Rp 182,203,239.00	65.62	10595	0.62
RF-0	4	225	Rp 158,703,100.00	497.87	9920	5.02
RF-3	4	900	Rp 182,203,239.00	72.40	10595	0.68

6.2.1. Factors and Responses Relationship

From Table 6.1 above, we then analyze each strategy to draw conclusion about the relationship between factors and responses:

1. Redundant stock: Decreasing stock from 1720 to 860 unit was decreasing cost by Rp 11,932,521 but increasing loss by 0.93 %.

Notation	Stock	Total Impact Cost	% Loss
RS-0	1720	Rp 203,275,208.00	1.01
RS-1	860	Rp 191,342,687.00	1.94
	860	Rp 11,932,521.00	-0.93

2. Flexible Route: Speeding up trans time from 4 to 3 days doesn't have any effect on cost but decrease loss by 0.23 %.

Notation	Trans.Time	Total Impact Cost	% Loss
FR-0	4	Rp 150,869,721.00	7.39
FR-1	3	Rp 150,869,721.00	7.16
	1	0.00	0.23

3. ReFlex: Speeding up trans time from 4 days to 3 days doesn't have any effect on cost but decrease % loss by 0.137; Adding up stock from 210 to 840 unit increase the cost by Rp 23,500,139 but decrease % loss by 4.26.

Notation	Trans.time	Stock	Cost	% Loss
RF-0	4	225	Rp 158,703,100.00	5.02
RF-1	3	225	Rp 158,703,100.00	4.81
RF-3	4	900	Rp 182,203,239.00	0.68
RF-2	3	900	Rp 182,203,239.00	0.62

6.2.2. Final Recommendation

We used responses from Table 6.1 of all notations to perform sensitivity analysis on CEA (SA-CEA) as presented in Table 6.2 and Table 6.3 while a generated final recommendation presented in Table 6.4.

Table 6.2 Ascending order of SA-CEA for brand A

Notation	Total Impact Cost	% Loss
BC	Rp 143,393,372.00	9.77
FR-0	Rp 150,869,721.00	7.39
FR-1	Rp 150,869,721.00	7.16
RF-0	Rp 158,703,100.00	5.02
RF-1	Rp 158,703,100.00	4.81
RS-1	Rp 191,342,687.00	1.94
RS-0	Rp 203,275,208.00	1.01
RF-3	Rp 182,203,239.00	0.68
RF-2	Rp 182,203,239.00	0.62

Table 6.3 Elimination of dominated strategies of SA-CEA for brand A

Notation	Total Impact Cost	% Loss	ICER
BC	Rp 143,393,372.00	9.77	Status-quo
~~FR-0~~	~~Rp 150,869,721.00~~	7.39	Weakly dominated
FR-1	Rp 150,869,721.00	7.16	Rp (2,868,009.48)
~~RF-0~~	~~Rp 158,703,100.00~~	5.02	Weakly dominated
RF-1	Rp 158,703,100.00	4.81	Rp (3,325,809.03)
~~RS-1~~	~~Rp 191,342,687.00~~	1.94	Strongly dominated
~~RS-0~~	~~Rp 203,275,208.00~~	1.01	Strongly dominated
~~RF-3~~	~~Rp 182,203,239.00~~	0.68	Weakly dominated
RF-2	Rp 182,203,239.00	0.62	Rp (5,609,662.03)

Table 6.4 Final recommendation for brand A

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 2,868,009.48	BC
Rp2,868,009.48	to	Rp 3,325,808.03	FR-1
Rp3,325,809.03	to	Rp 5,609,661.03	RF-1
Rp5,609,662.03	≥	WTP	RF-2

By changing factors in simulation study and generate new strategies, it would or would not generate a new recommendation. A comparison of the initial recommendation in Table 5.16 and the final recommendation in Table 6.4 gave us several findings as follows:

1. We changed the factors hence generated 5 new strategies, but there it didn't change the number of recommended strategy from initial to final.
2. Speeding up the alternative route travel time not only replacing RF-0 with RF-1 but also replacing FR-0 with FR-1;
3. Speeding up the alternative route travel time from 4 to 3 days and adds up stock by 400% make RF-2 less costly and more effective, hence replacing RS-0;
4. The WTP interval for all recommended strategy is decrease.

6.3. Findings on Brand B

We developed new strategies by changing the value of the factors for each strategy, run the new strategies, and document responses in the following Table 6.5.

Table 6.5 Factors variation on brand B

Notation	Factors		Responses			% Loss
	Trans. Time	Stock	Total Impact Cost	Loss of sales	Total Qty	
BC	N/A	N/A	Rp 88,425,475.00	2571.22	14856	17.31
FR-1	3	N/A	Rp 92,704,651.00	2474.29	14856	16.66
FR-0	4	N/A	Rp 92,704,651.00	2478.70	14856	16.68
RS-0	N/A	1784	Rp 120,430,450.00	1228.32	16640	7.38
RS-1	N/A	892	Rp 104,427,962.00	1922.68	15748	12.21
RF-1	3	210	Rp 96,472,053.00	2287.85	15066	15.19
RF-2	3	840	Rp 107,774,258.00	1782.90	15696	11.36
RF-0	4	210	Rp 96,472,053.00	2291.99	15066	15.21
RF-3	4	840	Rp 107,774,258.00	1786.82	15696	11.38

6.3.1. Factors and Responses Relationship

From Table 6.5 above, we then analyze each strategy to draw conclusion about the relationship between factors and responses:

4. Redundant stock: Decreasing stock from 1784 to 892 unit decreasing cost by Rp 16,002,488 but increase % loss by 4.83.

Notation	Stock	Total Impact Cost	% Loss
RS-0	1784	Rp 120,430,450.00	7.38
RS-1	892	Rp 104,427,962.00	12.21
	892	Rp 16,002,488.00	-4.83

5. Flexible Route: Speeding up trans time from 4 to 3 days doesn't have any effect of cost but decrease loss by 0.03 %

Notation	Trans.Time	Total Impact Cost	% Loss
FR-0	4	Rp 92,704,651.00	16.68
FR-1	3	Rp 92,704,651.00	16.66
	1	0.00	0.03

6. ReFlex: Speeding up trans time from 4 days to 3 days doesn't have any effect on cost but decrease % loss by 0.026; Adding up stock from 210 to 840 unit increase the cost by Rp 11,302,205 but decrease % loss by 3.83.

Notation	Trans.time	Stock	Cost	% Loss
RF-0	4	210	Rp 96,472,053.00	15.21
RF-1	3	210	Rp 96,472,053.00	15.19
RF-3	4	840	Rp 107,774,258.00	11.38
RF-2	3	840	Rp 107,774,258.00	11.36

6.3.2. Final Recommendation

We used responses from Table 6.5 of all notations to perform sensitivity analysis on CEA (SA-CEA) as presented in Table 6.6 and Table 6.7 while a generated final recommendation presented in Table 6.8.

Table 6.6 Ascending order of SA-CEA for brand B

Notation	Total Impact Cost	% Loss
BC	Rp 88,425,475.00	17.31
FR-0	Rp 92,704,651.00	16.68
FR-1	Rp 92,704,651.00	16.66
RF-0	Rp 96,472,053.00	15.21
RF-1	Rp 96,472,053.00	15.19
RS-1	Rp 104,427,962.00	12.21
RF-3	Rp 107,774,258.00	11.38
RF-2	Rp 107,774,258.00	11.36
RS-0	Rp 120,430,450.00	7.38

Table 6.7 Elimination of dominated strategies of SA-CEA for brand B

Notation	Total Impact Cost	% Loss	ICER
BC	Rp 88,425,475.00	17.31	-
~~FR-0~~	~~Rp 92,704,651.00~~	16.68	Weakly dominated
~~FR-1~~	~~Rp 92,704,651.00~~	16.66	Extended dominated
~~RF-0~~	~~Rp 96,472,053.00~~	15.21	Weakly dominated
~~RF-1~~	~~Rp 96,472,053.00~~	15.19	Extended dominated
RS-1	Rp 104,427,962.00	12.21	Rp (3,138,618.04)
~~RF-3~~	~~Rp 107,774,258.00~~	11.38	Weakly dominated
~~RF-2~~	~~Rp 107,774,258.00~~	11.36	Extended dominated
RS-0	Rp 120,430,450.00	7.38	Rp (3,314,989.62)

Table 6.8 Final recommendation for brand B

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 3,138,618.04	BC
Rp 3,138,618.04	to	Rp 3,314,988.62	RS-1
Rp 3,314,989.62	≥	WTP	RS-0

By changing factors in simulation study and generate new strategies, it would or would not generate a new recommendation. A comparison of the initial recommendation in Table 5.17 and the final recommendation in Table 6.8 gave us several findings as follows:

1. We changed factors hence generated 5 new strategies. But only RS-1 that add a new alternative strategy into the final recommendation;
2. Even though ReFlex factors had a faster alternative route travel time and larger stock by 400%, it still couldn't replace RS-0 which gives the most effectiveness;
3. WTP interval for all recommended strategy is decrease.
4. WTP value that will enable the adoption of RS-0 decrease from Rp 3,223,058.91 to Rp 2,013,298.23;

6.4. Findings on Brand C

We developed new strategies by changing the value of the factors for each strategy, run the new strategies, and document responses in the following Table 6.9.

Table 6.9 Factors variation on brand C

Notation	Factors		Responses			
	Trans. Time	Stock	Total Impact Cost	Loss of sales	Total Qty	% Loss
BC	N/A	N/A	Rp 80,380,674.00	1489.82	5430	27.44
FR-1	3	N/A	Rp 84,475,836.00	1438.92	5430	26.50
FR-0	4	N/A	Rp 84,475,836.00	1442.23	5430	26.56
RS-0	N/A	1018	Rp 118,708,395.00	696.35	6448	10.80
RS-1	N/A	509	Rp 99,544,535.00	1070.27	5939	18.02
RF-1	3	115	Rp 88,805,589.00	1326.40	5545	23.92
RF-2	3	460	Rp 101,794,846.00	1018.26	5890	17.29
RF-0	4	115	Rp 88,805,589.00	1329.63	5545	23.98
RF-3	4	460	Rp 101,794,846.00	1021.17	5890	17.34

6.4.1. Factors and Responses Relationship

From Table 6.9 above, we then analyze each strategy to draw conclusion about the relationship between factors and responses:

1. Redundant stock: Decreasing stock from 1018 to 509 unit decreasing cost by Rp 19,163,860 but increase % loss by 7.22.

Notation	Stock	Total Impact Cost	% Loss
RS-0	1018	Rp 118,708,395.00	10.80
RS-1	509	Rp 99,544,535.00	18.02
	509	Rp 19,163,860.00	-7.22

2. Flexible Route: Speeding up trans time from 4 to 3 days doesn't have any effect of cost but decrease loss by 0.06

Notation	Trans.Time	Total Impact Cost	% Loss
FR-0	4	Rp 84,475,836.00	26.56
FR-1	3	Rp 84,475,836.00	26.50
	1	0.00	0.06

3. ReFlex: Speeding up trans time from 4 days to 3 days doesn't have any effect on cost but decrease % loss by 0.054; Adding up stock from 115 to 460 unit increase the cost by Rp 12,989,257 but decrease % loss by 6.64.

Notation	Trans.time	Stock	Cost	% Loss
RF-0	4	115	Rp 88,805,589.00	23.98
RF-1	3	115	Rp 88,805,589.00	23.92
RF-3	4	460	Rp 101,794,846.00	17.34
RF-2	3	460	Rp 101,794,846.00	17.29

6.4.2. Final Recommendation

We used responses from Table 6.9 of all notations to perform sensitivity analysis on CEA (SA-CEA) as presented in Table 6.10 and Table 6.11 while a generated final recommendation presented in Table 6.12.

Table 6.10 Ascending order of SA-CEA for brand C

Notation	Total Impact Cost	% Loss
BC	Rp 80,380,674.00	27.44
FR-0	Rp 84,475,836.00	26.56
FR-1	Rp 84,475,836.00	26.50
RF-0	Rp 88,805,589.00	23.98
RF-1	Rp 88,805,589.00	23.92
RS-1	Rp 99,544,535.00	18.02
RF-3	Rp 101,794,846.00	17.34
RF-2	Rp 101,794,846.00	17.29
RS-0	Rp 118,708,395.00	10.80

Table 6.11 Elimination of dominated strategies of SA-CEA for brand C

Notation	Total Impact Cost	% Loss	ICER
BC	Rp 80,380,674.00	27.44	-
~~FR-0~~	~~Rp 84,475,836.00~~	26.56	Weakly dominated
~~FR-1~~	~~Rp 84,475,836.00~~	26.50	Extended dominated
~~RF-0~~	~~Rp 88,805,589.00~~	23.98	Weakly dominated
~~RF-1~~	~~Rp 88,805,589.00~~	23.92	Extended dominated
RS-1	Rp 99,544,535.00	18.02	Rp (2,035,290.82)
~~RF-3~~	~~Rp 101,794,846.00~~	17.34	Weakly dominated
~~RF-2~~	~~Rp 101,794,846.00~~	17.29	Extended dominated
RS-0	Rp 118,708,395.00	10.80	Rp (2,653,695.49)

Table 6.12 Final recommendation for brand C

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 2,035,290.82	BC
Rp2,035,290.82	to	Rp 2,653,694.49	RS-1
Rp2,653,695.49	≥	WTP	RS-0

By changing factors in simulation study and generate new strategies, it would or would not generate a new recommendation. A comparison of the initial recommendation in Table 5.18 and the final recommendation in Table 6.12 gave us several findings as follows:

1. Even though we changed factors and generated 5 additional strategies, the number of recommended strategy didn't change from the initial to final.
2. Changing the important factors only replaced FR-0 from initial recommendation with RS-1 in the final recommendation;
3. Even though ReFlex factors had a faster alternative route travel time and larger stock by 400%, it still couldn't replace RS-0.
4. WTP value that will enable the application of RS-0 increased from Rp 2,319,279.07 to Rp 2,653,695.49

6.5. Findings on Brand D

We developed new strategies by changing the value of the factors for each strategy, run the new strategies, and document responses in the following Table 6.13.

Table 6.13 Factors variation on brand D

Notation	Factors		Responses		Total Qty	% Loss
	Trans. Time	Stock	Total Impact Cost	Loss of sales		
BC	N/A	N/A	Rp 66,868,842.00	312.63	4506	6.94
FR-1	3	N/A	Rp 70,292,619.00	256.82	4506	5.70
FR-0	4	N/A	Rp 70,292,619.00	258.85	4506	5.74
RS-0	N/A	474	Rp 84,928,252.00	40.61	4980	0.82
RS-1	N/A	237	Rp 75,898,547.00	124.94	4743	2.63
RF-1	3	57	Rp 72,464,320.00	201.34	4563	4.41
RF-2	3	228	Rp 78,979,424.00	74.89	4734	1.58
RF-0	4	57	Rp 72,464,320.00	203.29	4563	4.46
RF-3	4	228	Rp 78,979,424.00	75.92	4734	1.60

6.5.1. Factors and Responses Relationship

From Table 6.13 above, we then analyze each strategy to draw conclusion about the relationship between factors and responses:

1. Redundant stock: Decreasing stock from 474 to 237 unit decreasing cost by Rp 9,029,705 but increase % loss by 1.81.

Notation	Stock	Total Impact Cost	% Loss
RS-0	474	Rp 84,928,252.00	0.82
RS-1	237	Rp 75,898,547.00	2.63
	237	Rp 9,029,705.00	-1.81

2. Flexible Route: Speeding up trans time from 4 to 3 days doesn't have any effect of cost but decrease loss by 0.004.

Notation	Trans.Time	Total Impact Cost	% Loss
FR-0	4	Rp 70,292,619.00	5.74
FR-1	3	Rp 70,292,619.00	5.70
	1	0.00	0.04

ReFlex: Speeding up trans time from 4 days to 3 days doesn't have any effect on cost but decrease % loss by 0.035; Adding up stock from 57 to 284 unit increase the cost by Rp 6,515,104.00 but decrease % loss by 2.85.

Notation	Trans.time	Stock	Cost	% Loss
RF-0	4	57	Rp 72,464,320.00	4.46
RF-1	3	57	Rp 72,464,320.00	4.41
RF-3	4	228	Rp 78,979,424.00	1.60
RF-2	3	228	Rp 78,979,424.00	1.58

6.5.2. Final Recommendation

We used responses from Table 6.13 of all notations to perform sensitivity analysis on CEA (SA-CEA) as presented in Table 6.14 and Table 6.15 while a generated final recommendation presented in Table 6.16.

Table 6.14 Ascending order of SA-CEA for brand D

Notation	Total Impact Cost	% Loss
BC	Rp 66,868,842.00	6.94
FR-0	Rp 70,292,619.00	5.74
FR-1	Rp 70,292,619.00	5.70
RF-0	Rp 72,464,320.00	4.46
RF-1	Rp 72,464,320.00	4.41
RS-1	Rp 75,898,547.00	2.63
RF-3	Rp 78,979,424.00	1.60
RF-2	Rp 78,979,424.00	1.58
RS-0	Rp 84,928,252.00	0.82

Table 6.15 Elimination of dominated strategies of SA-CEA for brand D

Notation	Total Impact Cost	% Loss	ICER
BC	Rp 66,868,842.00	6.94	-
~~FR-0~~	~~Rp 70,292,619.00~~	5.74	Weakly dominated
~~FR-1~~	~~Rp 70,292,619.00~~	5.70	Extended dominated
~~RF-0~~	~~Rp 72,464,320.00~~	4.46	Weakly dominated
~~RF-1~~	~~Rp 72,464,320.00~~	4.41	Extended dominated
RS-1	Rp 75,898,547.00	2.63	Rp(2,098,035.95)
~~RF-3~~	~~Rp 78,979,424.00~~	1.60	Weakly dominated
RF-2	Rp 78,979,424.00	1.58	Rp(2,927,782.42)
RS-0	Rp 84,928,252.00	0.82	Rp(7,761,558.26)

Table 6.16 Final recommendation for brand D

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 2,098,035.95	BC
Rp2,098,035.95	to	Rp 2,927,781.42	RS-1
Rp2,927,782.42	to	Rp 7,761,558.26	RF-2
Rp7,761,558.26	≥	WTP	RS-0

By changing factors in simulation study and generate new strategies, it would or would not generate a new recommendation. A comparison of the initial recommendation in Table 5.19 and the final recommendation in Table 6.16 gave us several findings as follows:

1. There is new additional strategy into the final recommendation which is RS-1;
2. Changing the factors only replacing RF-0 from initial recommendation with RF-1 in final recommendation;
3. Even though ReFlex factors had a faster alternative route travel time and larger stock by 400%, it still couldn't replace RS-0 that gives the greatest effectiveness;
4. WTP value for RS-0 increased from Rp 3,424,156.14 to Rp 7,761,558.26.

6.6. Findings on Brand E

We developed new strategies by changing the value of the factors for each strategy, run the new strategies, and document responses in the following Table 6.17.

Table 6.17 Factors variation on brand E

Notation	Factors		Responses			% Loss
	Trans. Time	Stock	Total Impact Cost	Amount of Loss	Total Qty	
BC	N/A	N/A	Rp 55,886,922.06	312.63	3754	12.79
FR-1	3	N/A	Rp 58,545,037.00	451.09	3754	12.02
FR-0	4	N/A	Rp 58,545,037.00	452.21	3754	12.05
RS-0	N/A	355	Rp 69,670,332.00	215.20	4109	5.24
RS-1	N/A	178	Rp 62,719,538.00	341.68	3932	8.69
RF-1	3	46	Rp 60,351,458.00	406.72	3800	10.70
RF-2	3	184	Rp 65,770,721.00	290.74	3938	7.38
RF-0	4	46	Rp 60,351,458.00	407.79	3800	10.73
RF-3	4	184	Rp 65,770,721.00	291.61	3938	7.41

6.6.1. Factors and Responses Relationship

From Table 6.17 above, we then analyze each strategy to draw conclusion about the relationship between factors and responses:

1. Redundant stock: Decreasing up stock from 355 to 178 unit decreasing cost by Rp 6,950,794 but increase % loss by 3.45.

Notation	Stock	Total Impact Cost	% Loss
RS-0	355	Rp 69,670,332.00	5.24
RS-1	178	Rp 62,719,538.00	8.69
	177	Rp 6,950,794.00	-3.45

2. Flexible Route: Speeding up trans time from 4 to 3 days doesn't have any effect of cost but decrease loss by 0.003.

Notation	Trans.Time	Total Impact Cost	% Loss
FR-0	4	Rp 58,545,037.00	12.05
FR-1	3	Rp 58,545,037.00	12.02
	1	0.00	0.03

3. ReFlex: Speeding up trans time from 4 days to 3 days doesn't have any effect on cost but decrease % loss by 0.003; Adding up stock from 46 to 184 unit increase the cost by Rp 5,419,263.00 but decrease % loss by 3.32.

Notation	Trans.time	Stock	Cost	% Loss
RF-0	4	46	Rp 60,351,458.00	10.73
RF-1	3	46	Rp 60,351,458.00	10.70
RF-3	4	184	Rp 65,770,721.00	7.38
RF-2	3	184	Rp 65,770,721.00	7.41

6.6.2. Final Recommendation

We used responses from Table 6.17 of all notations to perform sensitivity analysis on CEA (SA-CEA) as presented in Table 6.18 and Table 6.19 while a generated final recommendation presented in Table 6.20.

Table 6.18 Ascending order of SA-CEA for brand E

Notation	Total Impact Cost	% Loss
BC	Rp 55,886,922.06	12.79
FR-0	Rp 58,545,037.00	12.05
FR-1	Rp 58,545,037.00	12.02
RF-0	Rp 60,351,458.00	10.73
RF-1	Rp 60,351,458.00	10.70
RS-1	Rp 62,719,538.00	8.69
RF-3	Rp 65,770,721.00	7.41
RF-2	Rp 65,770,721.00	7.38
RS-0	Rp 69,670,332.00	5.24

Table 6.19 Elimination of dominated strategies of SA-CEA for brand E

Notation	Total Impact Cost	% Loss	ICER
BC	Rp 55,886,922.06	12.79	-
~~FR-0~~	~~Rp 58,545,037.00~~	~~12.05~~	Weakly dominated
~~FR-1~~	~~Rp 58,545,037.00~~	~~12.02~~	Extended dominated
~~RF-0~~	~~Rp 60,351,458.00~~	~~10.73~~	Weakly dominated
~~RF-1~~	~~Rp 60,351,458.00~~	~~10.70~~	Extended dominated
RS-1	Rp 62,719,538.00	8.69	Rp (1,666,380.06)
~~RF-3~~	~~Rp 65,770,721.00~~	~~7.41~~	Weakly dominated
~~RF-2~~	~~Rp 65,770,721.00~~	~~7.38~~	Extended dominated
RS-0	Rp 69,670,332.00	5.24	Rp (2,013,298.23)

Table 6.20 Final recommendation for brand E

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp1,666,380.06	BC
Rp1,666,380.06	to	Rp2,013,297.23	RS-1
Rp2,013,298.23	≥	WTP	RS-0

By changing factors in simulation study and generate new strategies, it would or would not generate a new recommendation. A comparison of the initial recommendation in Table 5.15 and the final recommendation in Table 6.20 gave us several findings as follows:

1. There is new additional strategy into the final recommendation which is RS-1;
2. Even though ReFlex factors had a faster alternative route travel time and larger stock by 400%, it still couldn't replace RS-0 that gives the greatest effectiveness;
3. WTP value for RS-0 increased from Rp 1,825,617.21 to Rp 2,013,298.23.

6.7. Analysis on Findings

An analysis on findings conducted across all brands a behavior peculiarity has been founded. A comparison between the initial recommendation and final recommendation for brand A, B, C, D, and E, respectively shown in Figure 6.1, Figure 6.2, Figure 6.3, Figure 6.4, and Figure 6.5 as follows

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 3,141,323.11	Base Case
Rp 3,141,323.11	to	Rp 3,305,222.21	Flexible Route
Rp 3,305,223.21	to	Rp11,115,237.90	ReFlex
Rp11,115,238.90	≥	WTP	Redundant Stock

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 2,868,009.48	BC
Rp2,868,009.48	to	Rp 3,325,808.03	FR-1
Rp3,325,809.03	to	Rp 5,609,661.03	RF-1
Rp5,609,662.03	≥	WTP	RF-2

Figure 6.1 Comparison between initial recommendation (top) with final recommendation (below) for brand A

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp3,223,058.91	Base Case
Rp3,223,058.91	≥	WTP	Redundant Stock

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 3,138,618.04	BC
Rp 3,138,618.04	to	Rp 3,314,988.62	RS-1
Rp 3,314,989.62	≥	WTP	RS-0

Figure 6.2 Comparison between initial recommendation (top) with final recommendation (below) for brand B

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp2,178,277.66	Base Case
Rp 2,178,277.66	to	Rp2,319,278.07	Flexible Route
Rp 2,319,279.07	≥	WTP	Redundant Stock

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 2,035,290.82	BC
Rp2,035,290.82	to	Rp 2,653,694.49	RS-1
Rp2,653,695.49	≥	WTP	RS-0

Figure 6.3 Comparison between initial recommendation (top) with final recommendation (below) for brand C

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp2,256,241.13	Base Case
Rp2,256,241.13	to	Rp3,424,156.14	ReFlex
Rp3,424,156.14	≥	WTP	Redundant Stock

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp 2,098,035.95	BC
Rp2,098,035.95	to	Rp 2,927,781.42	RS-1
Rp2,927,782.42	to	Rp 7,761,558.26	RF-2
Rp7,761,558.26	≥	WTP	RS-0

Figure 6.4 Comparison between initial recommendation (top) with final recommendation (below) for brand D

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp1,825,617.21	Base Case
Rp1,825,617.21	≥	WTP	Redundant Stock

Willingness to Pay (WTP)			Recommended Strategy
WTP	<	Rp1,666,380.06	BC
Rp1,666,380.06	to	Rp2,013,297.23	RS-1
Rp2,013,298.23	≥	WTP	RS-0

Figure 6.5 Comparison between initial recommendation (top) with final recommendation (below) for brand E

Figures above show a behavior peculiarity between brand A with another brand. In brand A, the initial recommendation changes drastically after the sensitivity analysis conducted (which created improved version of flexible route and ReFlex), while for brand B, C, D, and E the changes are minor or don’t event change. To get a better visualization, Figure 6.6 below graphically show this peculiarity.

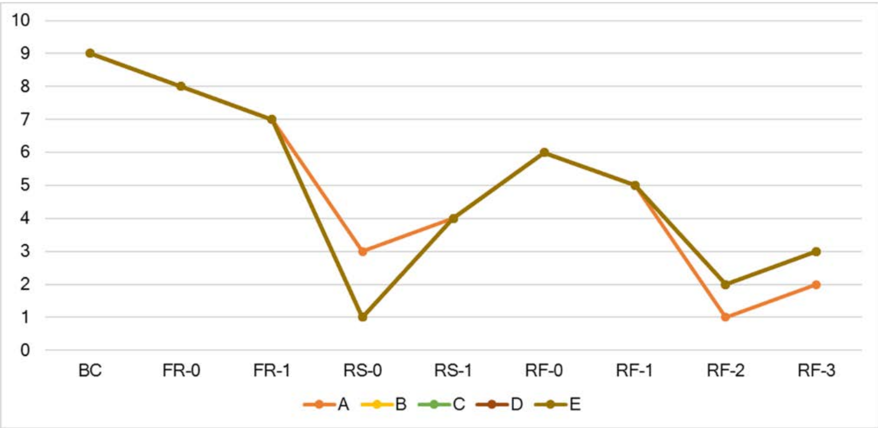


Figure 6.6 Graph of cost-effectiveness pattern between brands

Figure 6.6 above shows that brand A has a different pattern of cost-effectiveness ratio in comparison with brand B, C, D, and E (that has the same pattern). It means that factor changing in sensitivity analysis change the cost-effectiveness of ReFlex and Redundant stock strategy in respect to the brand. An analysis was conducted in order to find the underlying cause of this behavior and found that demand rate is also contribute to the cost-effectiveness of strategy against transportation disruption, as depicted in Figure 6.7 below.

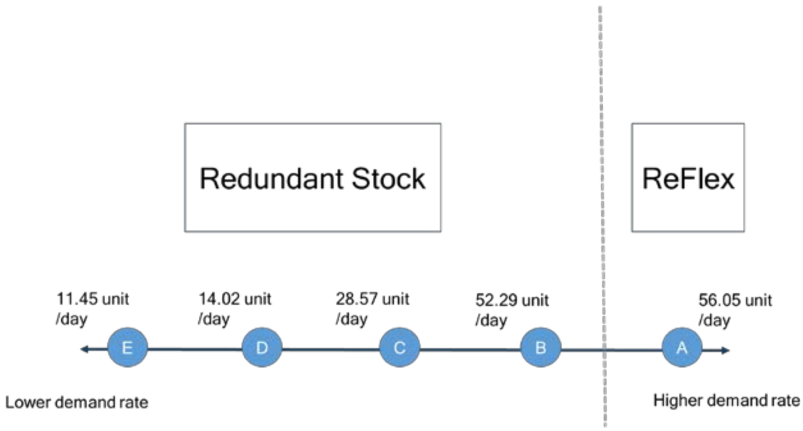


Figure 6.7 Cost-effectiveness of mitigation strategy relative to demand rate

Figure 6.7 above shows that the higher the demand rate the less cost-effective redundant stock to mitigate transportation disruption. This also indicates that in item/brand with higher demand rate, relying on a single mitigation strategy is no longer adequate. Therefore, with higher demand rate brand, an integrated mitigation strategy is necessary for a better protection against transportation disruption.

6.8. Comparisons of Findings with Previous Research

We summarized the findings and compared them with the previous research in supply chain disruption as the following:

1. From Table 6.1, Table 6.5, Table 6.9, Table 6.13, and Table 6.17 (respectively for brand A, B, C, D, and E) it is clear that when transportation disruption occurred, regardless of the strategy, the percentage of loss of sales will always exist. Therefore, we concurred with Wilson (2007) that transportation disruption has negative impact on SC;
2. Table 6.1, Table 6.5, Table 6.9, Table 6.13, and Table 6.17 show that the proposed mitigation strategies make the distribution process more resilient against the risk of transportation disruption. There, we concurred with Sheffi et al. (2003) that redundancy, flexibility, and combination between redundancy and flexibility create resiliency in supply chain;
3. Table 6.1, Table 6.5, Table 6.9, Table 6.13, and Table 6.17 show that base case strategy which accepting the risk without doing nothing give the greatest percentage of loss of sales compared with the deployment of mitigation strategy. Therefore, we confirmed a statement from Chopra & Sodhi (2014) that doing nothing (base case) will likely gave the most severe impact should disruptions occurred;
4. The findings in Table 6.1, Table 6.5, Table 6.9, Table 6.13, and Table 6.17 concurred with Simchi-levi et al. (2008), and Son & Orchard (2013 that redundancy (stock) could protect SC from disruption risk;
5. The findings in Table 6.1, Table 6.5, Table 6.9, Table 6.13, and Table 6.17 concurred with Ishfaq (2012) that flexibility (route) could protect SC from disruption risk;
6. The findings in Table 6.1, Table 6.5, Table 6.9, Table 6.13, and Table 6.17 concurred with Schmitt (2011) that a combination between redundancy and flexibility could protect SC from disruption risk.

CHAPTER 7

CONCLUSIONS & CONTRIBUTIONS

In this chapter we draw conclusions from our findings and presented contributions that this research has to offered.

7.1. Conclusions

From the findings that we showed in the previous chapter, we draw several conclusions for this research as the following:

1. The proposed mitigation strategies have been proven of having the capability to negate the impact of transportation disruption in supply chain with different costs and effectiveness;
2. On the evaluation with initial setting, for all brand, redundant stock strategy was the most expensive alternative but gave the best effectiveness while flexible route strategy was the least expensive but worst effectiveness. ReFlex strategy was sat in the middle with moderate cost with moderate effectiveness;
3. On the evaluation after sensitivity analysis, for brand B, C, D, and E, redundant stock strategy (RS-0 and RS-1) gives the highest cost with the best effectiveness; While flexible route (FR-0 and FR-1) gives the least cost with least effectiveness; ReFlex (RF-0, RF-1, RF-2, and RF-3) strategy gives a moderate cost with moderate effectiveness. In particular, for brand A, ReFlex shows a better effectiveness with lower cost than redundant stock.
4. When mitigating transportation disruption on item/brand with higher demand rate, ReFlex strategy is more cost-effective then redundant stock or flexible route strategy;

7.2. Contributions

After conducting this research, we made a list of contributions for academic and professional field, also the potential future research on transportation disruption.

7.2.1. Academic Field

The contributions for academic field was on addressing the mentioned research gaps. The contributions were listed as the following:

1. We filled the first research gap stated by Ho et al., (2015) for the lack of research in transportation disruptions literatures;
2. We filled the second research gap for the lack of case study as data source on investigation of SC performance under transportation disruption event.

7.2.2. Managerial Implication

From the final recommendation for brand A, B, C, D, and E depicted consecutively in Table 6.4, Table 6.8, Table 6.12, Table 6.16, and Table 6.20, we believed that this research had a managerial implication to focal company as follows:

1. Focal company get a clear description of the cost and effectiveness of each strategy, thus can decide whether or not the management should financially invest on mitigation strategy;
2. Focal company can decide which strategy should be applied according to the WTP.

7.2.3. Potential Future Research

We identified several drawbacks in this research, therefore we listed potential future research that hopefully could address the drawbacks, as follows:

1. In the final recommendation, the initial factors value was changed and created new strategies. These new strategies, specifically FR-1, RS-1, RF-1, RF-2, and RF-3 are not in an optimal state. Therefore, incorporating optimization before conducting CEA, is a potential future research to address the lack of optimum factors value in this research;
2. For allowing buffer stock quantity to be held by distributors, focal company in return offered to pay 50% of the buffer stock holding cost as compensation. In practical this compensation scheme is not always being agreed by the distributor. A potential future study could introduce a more agreeable compensation scheme. For example, through discounted price mechanism.

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Appendix A: Example of Verification for base case strategy on brand E

# Days	Inventory Level		# Days	Inventory Level	
	On-Hand Calculation	Simulation Result		On-Hand Calculation	Simulation Result
27	96.67	96.67	68	51.11	51.11
28	93.33	93.33	69	40.00	40.00
29	90.00	90.00	70	28.89	28.89
30	86.67	86.67	71	17.78	17.78
31	83.33	83.33	72	383.85	383.85
32	80.00	80.00	73	549.92	549.92
33	76.67	76.67	74	515.99	515.99
34	73.33	73.33	75	482.06	482.06
35	70.00	70.00	76	448.13	448.13
36	66.67	66.67	77	414.21	414.21
37	63.33	63.33	78	380.28	380.28
38	60.00	60.00	79	346.35	346.35
39	56.67	56.67	80	312.42	312.42
40	53.33	53.33	81	278.49	278.49
41	50.00	50.00	82	244.56	244.56
42	46.67	46.67	83	210.63	210.63
43	43.33	43.33	84	176.71	176.71
44	40.00	40.00	85	142.78	142.78
45	36.67	36.67	86	108.85	108.85
46	33.33	33.33	87	74.92	74.92
47	30.00	30.00	88	40.99	40.99
48	26.67	26.67	89	7.06	7.06
49	23.33	23.33	90	-26.87	0.00
50	20.00	20.00	91	-60.79	0.00
51	16.67	16.67	92	316.07	316.07
52	13.33	13.33	93	282.14	282.14
53	10.00	10.00	94	248.21	248.21
54	6.67	6.67	95	214.29	214.29
55	195.56	195.56	96	180.36	180.36
56	184.44	184.44	97	146.43	146.43
57	173.33	173.33	98	112.50	112.50
58	162.22	162.22	99	78.57	78.57
59	151.11	151.11	100	44.64	44.64
60	140.00	140.00	101	10.71	10.71
61	128.89	128.89	102	-23.21	0.00
62	117.78	117.78	103	195.12	195.12
63	106.67	106.67	104	190.24	190.24
64	95.56	95.56	105	185.37	185.37
65	84.44	84.44	106	180.49	180.49
66	73.33	73.33	107	175.61	175.61
67	62.22	62.22	108	170.73	170.73

# Days	Inventory Level		# Days	Inventory Level	
	On-Hand Calculation	Simulation Result		On-Hand Calculation	Simulation Result
109	165.85	165.85	152	153.85	153.85
110	160.98	160.98	153	146.15	146.15
111	156.10	156.10	154	138.46	138.46
112	151.22	151.22	155	130.77	130.77
113	146.34	146.34	156	123.08	123.08
114	141.46	141.46	157	115.38	115.38
115	136.59	136.59	158	107.69	107.69
116	131.71	131.71	159	100.00	100.00
117	126.83	126.83	160	92.31	92.31
118	121.95	121.95	161	84.62	84.62
119	117.07	117.07	162	76.92	76.92
120	112.20	112.20	163	69.23	69.23
121	107.32	107.32	164	61.54	61.54
122	102.44	102.44	165	53.85	53.85
123	97.56	97.56	166	46.15	46.15
124	92.68	92.68	167	140.89	140.89
125	87.80	87.80	168	135.63	135.63
126	82.93	82.93	169	130.36	130.36
127	78.05	78.05	170	125.10	125.10
128	73.17	73.17	171	119.84	119.84
129	68.29	68.29	172	114.57	114.57
130	63.41	63.41	173	109.31	109.31
131	58.54	58.54	174	104.05	104.05
132	53.66	53.66	175	98.79	98.79
133	48.78	48.78	176	93.52	93.52
134	43.90	43.90	177	88.26	88.26
135	39.02	39.02	178	83.00	83.00
136	34.15	34.15	179	77.73	77.73
137	29.27	29.27	180	172.47	172.47
138	24.39	24.39	181	167.21	167.21
139	19.51	19.51	182	161.94	161.94
140	14.63	14.63	183	156.68	156.68
141	9.76	9.76	184	151.42	151.42
142	4.88	4.88	185	146.15	146.15
143	0.00	0.00	186	140.89	140.89
144	-4.88	0.00	187	135.63	135.63
145	-9.76	0.00	188	130.36	130.36
146	-14.63	0.00	189	125.10	125.10
147	92.31	92.31	190	119.84	119.84
148	84.62	84.62	191	114.57	114.57
149	176.92	176.92	192	109.31	109.31
150	169.23	169.23	193	104.05	104.05
151	161.54	161.54	194	98.79	98.79

# Days	Inventory Level		# Days	Inventory Level	
	On-Hand Calculation	Simulation Result		On-Hand Calculation	Simulation Result
195	93.52	93.52	238	210.82	210.82
196	88.26	88.26	239	203.67	203.67
197	83.00	83.00	240	196.53	196.53
198	77.73	77.73	241	189.39	189.39
199	72.47	72.47	242	182.24	182.24
200	67.21	67.21	243	175.10	175.10
201	61.94	61.94	244	167.96	167.96
202	56.68	56.68	245	160.82	160.82
203	51.42	51.42	246	153.67	153.67
204	46.15	46.15	247	146.53	146.53
205	40.89	40.89	248	139.39	139.39
206	35.63	35.63	249	132.24	132.24
207	30.36	30.36	250	125.10	125.10
208	25.10	25.10	251	117.96	117.96
209	210.82	210.82	252	110.82	110.82
210	196.53	196.53	253	103.67	103.67
211	182.24	182.24	254	96.53	96.53
212	167.96	167.96	255	89.39	89.39
213	153.67	153.67	256	82.24	82.24
214	139.39	139.39	257	75.10	75.10
215	125.10	125.10	258	67.96	67.96
216	110.82	110.82	259	60.82	60.82
217	96.53	96.53	260	53.67	53.67
218	82.24	82.24	261	46.53	46.53
219	67.96	67.96	262	39.39	39.39
220	53.67	53.67	263	32.24	32.24
221	39.39	39.39	264	25.10	25.10
222	25.10	25.10	265	17.96	17.96
223	317.96	317.96	266	10.82	10.82
224	310.82	310.82	267	3.67	3.67
225	303.67	303.67	268	-3.47	0.00
226	296.53	296.53	269	-10.61	0.00
227	289.39	289.39	270	-17.76	0.00
228	282.24	282.24	271	-30.66	0.00
229	275.10	275.10	272	-43.56	0.00
230	267.96	267.96	273	-56.47	0.00
231	260.82	260.82	274	-69.37	0.00
232	253.67	253.67	275	-82.27	0.00
233	246.53	246.53	276	-95.18	0.00
234	239.39	239.39	277	-108.08	0.00
235	232.24	232.24	278	-120.98	0.00
236	225.10	225.10	279	-133.88	0.00
237	217.96	217.96	280	-146.79	0.00

# Days	Inventory Level		# Days	Inventory Level	
	On-Hand Calculation	Simulation Result		On-Hand Calculation	Simulation Result
281	-159.69	0.00	324	465.02	465.02
282	-172.59	0.00	325	457.02	457.02
283	-185.50	0.00	326	449.02	449.02
284	-198.40	0.00	327	441.02	441.02
285	-211.30	0.00	328	433.02	433.02
286	387.10	387.10	329	425.02	425.02
287	374.19	374.19	330	417.02	417.02
288	361.29	361.29	331	609.02	609.02
289	348.39	348.39	332	601.02	601.02
290	335.48	335.48	333	593.02	593.02
291	322.58	322.58	334	585.02	585.02
292	309.68	309.68	335	577.02	577.02
293	296.77	296.77	336	569.02	569.02
294	283.87	283.87	337	561.02	561.02
295	270.97	270.97	338	553.02	553.02
296	258.06	258.06	339	545.02	545.02
297	440.67	440.67	340	537.02	537.02
298	423.28	423.28	341	529.02	529.02
299	605.89	605.89	342	521.02	521.02
300	588.50	588.50	343	513.02	513.02
301	571.11	571.11	344	505.02	505.02
302	553.72	553.72	345	497.02	497.02
303	536.33	536.33	346	489.02	489.02
304	518.93	518.93	347	481.02	481.02
305	501.54	501.54	348	473.02	473.02
306	484.15	484.15	349	465.02	465.02
307	466.76	466.76	350	457.02	457.02
308	449.37	449.37	351	449.02	449.02
309	431.98	431.98	352	441.02	441.02
310	414.59	414.59	353	433.02	433.02
311	397.19	397.19	354	425.02	425.02
312	379.80	379.80	355	417.02	417.02
313	362.41	362.41	356	409.02	409.02
314	345.02	345.02	357	401.02	401.02
315	537.02	537.02	358	393.02	393.02
316	529.02	529.02	359	385.02	385.02
317	521.02	521.02	360	377.02	377.02
318	513.02	513.02	361	369.02	369.02
319	505.02	505.02	362	361.02	361.02
320	497.02	497.02	363	353.02	353.02
321	489.02	489.02	364	345.02	345.02
322	481.02	481.02	365	337.02	337.02
323	473.02	473.02	366	533.02	533.02

Appendix B: Example of simulation input for Brand E

# Days	Data Value		# Days	Data Value	
	Delivery Qty	Demand (qty/day)		Delivery Qty	Demand (qty/day)
25	100.00	3.33	66	0.00	11.11
26	0.00	3.33	67	0.00	11.11
27	0.00	3.33	68	0.00	33.93
28	0.00	3.33	69	0.00	33.93
29	0.00	3.33	70	400.00	33.93
30	0.00	3.33	71	200.00	33.93
31	0.00	3.33	72	0.00	33.93
32	0.00	3.33	73	0.00	33.93
33	0.00	3.33	74	0.00	33.93
34	0.00	3.33	75	0.00	33.93
35	0.00	3.33	76	0.00	33.93
36	0.00	3.33	77	0.00	33.93
37	0.00	3.33	78	0.00	33.93
38	0.00	3.33	79	0.00	33.93
39	0.00	3.33	80	0.00	33.93
40	0.00	3.33	81	0.00	33.93
41	0.00	3.33	82	0.00	33.93
42	0.00	3.33	83	0.00	33.93
43	0.00	3.33	84	0.00	33.93
44	0.00	3.33	85	0.00	33.93
45	0.00	3.33	86	0.00	33.93
46	0.00	3.33	87	0.00	33.93
47	0.00	3.33	88	0.00	33.93
48	0.00	3.33	89	0.00	33.93
49	0.00	3.33	90	350.00	33.93
50	0.00	3.33	91	0.00	33.93
51	0.00	11.11	92	0.00	33.93
52	0.00	11.11	93	0.00	33.93
53	200.00	11.11	94	0.00	33.93
54	0.00	11.11	95	0.00	33.93
55	0.00	11.11	96	0.00	33.93
56	0.00	11.11	97	0.00	33.93
57	0.00	11.11	98	0.00	33.93
58	0.00	11.11	99	0.00	4.88
59	0.00	11.11	100	0.00	4.88
60	0.00	11.11	101	200.00	4.88
61	0.00	11.11	102	0.00	4.88
62	0.00	11.11	103	0.00	4.88
63	0.00	11.11	104	0.00	4.88
64	0.00	11.11	105	0.00	4.88
65	0.00	11.11	106	0.00	4.88

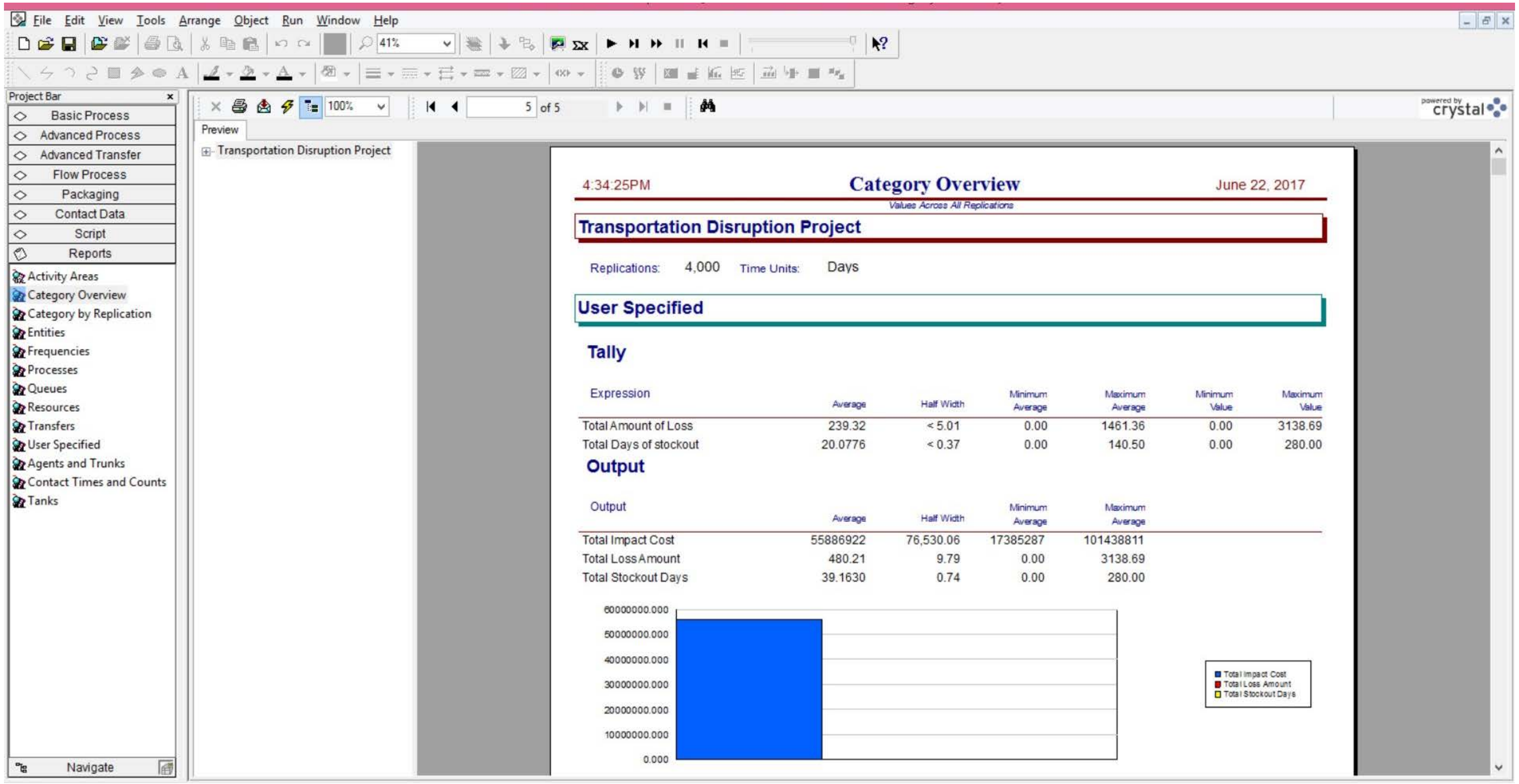
# Days	Data Value		# Days	Data Value	
	Delivery Qty	Demand (qty/day)		Delivery Qty	Demand (qty/day)
107	0.00	4.88	150	0.00	7.69
108	0.00	4.88	151	0.00	7.69
109	0.00	4.88	152	0.00	7.69
110	0.00	4.88	153	0.00	7.69
111	0.00	4.88	154	0.00	7.69
112	0.00	4.88	155	0.00	7.69
113	0.00	4.88	156	0.00	7.69
114	0.00	4.88	157	0.00	7.69
115	0.00	4.88	158	0.00	7.69
116	0.00	4.88	159	0.00	7.69
117	0.00	4.88	160	0.00	7.69
118	0.00	4.88	161	0.00	7.69
119	0.00	4.88	162	0.00	7.69
120	0.00	4.88	163	0.00	5.26
121	0.00	4.88	164	0.00	5.26
122	0.00	4.88	165	100.00	5.26
123	0.00	4.88	166	0.00	5.26
124	0.00	4.88	167	0.00	5.26
125	0.00	4.88	168	0.00	5.26
126	0.00	4.88	169	0.00	5.26
127	0.00	4.88	170	0.00	5.26
128	0.00	4.88	171	0.00	5.26
129	0.00	4.88	172	0.00	5.26
130	0.00	4.88	173	0.00	5.26
131	0.00	4.88	174	0.00	5.26
132	0.00	4.88	175	0.00	5.26
133	0.00	4.88	176	0.00	5.26
134	0.00	4.88	177	0.00	5.26
135	0.00	4.88	178	100.00	5.26
136	0.00	4.88	179	0.00	5.26
137	0.00	4.88	180	0.00	5.26
138	0.00	4.88	181	0.00	5.26
139	0.00	4.88	182	0.00	5.26
140	0.00	4.88	183	0.00	5.26
141	0.00	4.88	184	0.00	5.26
142	0.00	4.88	185	0.00	5.26
143	0.00	7.69	186	0.00	5.26
144	0.00	7.69	187	0.00	5.26
145	100.00	7.69	188	0.00	5.26
146	0.00	7.69	189	0.00	5.26
147	100.00	7.69	190	0.00	5.26
148	0.00	7.69	191	0.00	5.26
149	0.00	7.69	192	0.00	5.26

# Days	Data Value		# Days	Data Value	
	Delivery Qty	Demand (qty/day)		Delivery Qty	Demand (qty/day)
193	0.00	5.26	236	0.00	7.14
194	0.00	5.26	237	0.00	7.14
195	0.00	5.26	238	0.00	7.14
196	0.00	5.26	239	0.00	7.14
197	0.00	5.26	240	0.00	7.14
198	0.00	5.26	241	0.00	7.14
199	0.00	5.26	242	0.00	7.14
200	0.00	5.26	243	0.00	7.14
201	0.00	5.26	244	0.00	7.14
202	0.00	5.26	245	0.00	7.14
203	0.00	5.26	246	0.00	7.14
204	0.00	5.26	247	0.00	7.14
205	0.00	14.29	248	0.00	7.14
206	0.00	14.29	249	0.00	7.14
207	200.00	14.29	250	0.00	7.14
208	0.00	14.29	251	0.00	7.14
209	0.00	14.29	252	0.00	7.14
210	0.00	14.29	253	0.00	7.14
211	0.00	14.29	254	0.00	7.14
212	0.00	14.29	255	0.00	7.14
213	0.00	14.29	256	0.00	7.14
214	0.00	14.29	257	0.00	7.14
215	0.00	14.29	258	0.00	7.14
216	0.00	14.29	259	0.00	7.14
217	0.00	14.29	260	0.00	7.14
218	0.00	14.29	261	0.00	7.14
219	0.00	7.14	262	0.00	7.14
220	0.00	7.14	263	0.00	7.14
221	300.00	7.14	264	0.00	7.14
222	0.00	7.14	265	0.00	7.14
223	0.00	7.14	266	0.00	7.14
224	0.00	7.14	267	0.00	12.90
225	0.00	7.14	268	0.00	12.90
226	0.00	7.14	269	200.00	12.90
227	0.00	7.14	270	200.00	12.90
228	0.00	7.14	271	0.00	12.90
229	0.00	7.14	272	0.00	12.90
230	0.00	7.14	273	0.00	12.90
231	0.00	7.14	274	0.00	12.90
232	0.00	7.14	275	0.00	12.90
233	0.00	7.14	276	0.00	12.90
234	0.00	7.14	277	0.00	12.90
235	0.00	7.14	278	0.00	12.90

# Days	Data Value		# Days	Data Value	
	Delivery Qty	Demand (qty/day)		Delivery Qty	Demand (qty/day)
279	0.00	12.90	322	0.00	8.00
280	0.00	12.90	323	0.00	8.00
281	0.00	12.90	324	0.00	8.00
282	0.00	12.90	325	0.00	8.00
283	0.00	12.90	326	0.00	8.00
284	0.00	12.90	327	0.00	8.00
285	0.00	12.90	328	0.00	8.00
286	0.00	12.90	329	200.00	8.00
287	0.00	12.90	330	0.00	8.00
288	0.00	12.90	331	0.00	8.00
289	0.00	12.90	332	0.00	8.00
290	0.00	12.90	333	0.00	8.00
291	0.00	12.90	334	0.00	8.00
292	0.00	12.90	335	0.00	8.00
293	0.00	17.39	336	0.00	8.00
294	0.00	17.39	337	0.00	8.00
295	200.00	17.39	338	0.00	8.00
296	0.00	17.39	339	0.00	8.00
297	200.00	17.39	340	0.00	8.00
298	0.00	17.39	341	0.00	8.00
299	0.00	17.39	342	0.00	8.00
300	0.00	17.39	343	0.00	8.00
301	0.00	17.39	344	0.00	8.00
302	0.00	17.39	345	0.00	8.00
303	0.00	17.39	346	0.00	8.00
304	0.00	17.39	347	0.00	8.00
305	0.00	17.39	348	0.00	8.00
306	0.00	17.39	349	0.00	8.00
307	0.00	17.39	350	0.00	8.00
308	0.00	17.39	351	0.00	8.00
309	0.00	17.39	352	0.00	8.00
310	0.00	17.39	353	0.00	8.00
311	0.00	8.00	354	0.00	8.00
312	0.00	8.00	355	0.00	8.00
313	200.00	8.00	356	0.00	8.00
314	0.00	8.00	357	0.00	8.00
315	0.00	8.00	358	0.00	8.00
316	0.00	8.00	359	0.00	8.00
317	0.00	8.00	360	0.00	8.00
318	0.00	8.00	361	0.00	8.00
319	0.00	8.00	362	0.00	8.00
320	0.00	8.00	363	0.00	8.00
321	0.00	8.00	364	204.00	8.00

Appendix C: Example of Simulation Report for Brand E

BASE CASE



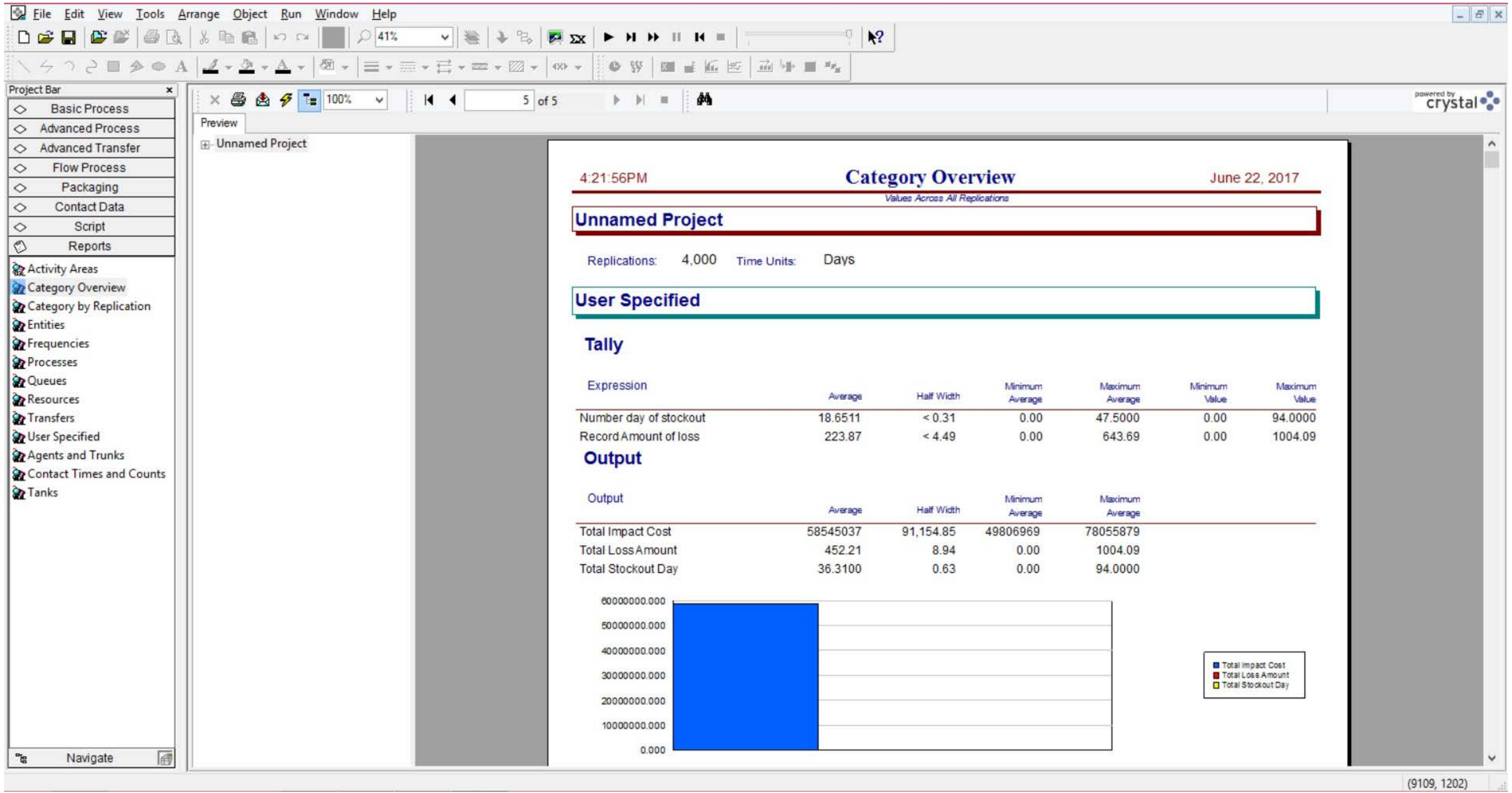
Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Total Amount of Loss	239.32	< 5.01	0.00	1461.36	0.00	3138.69
Total Days of stockout	20.0776	< 0.37	0.00	140.50	0.00	280.00

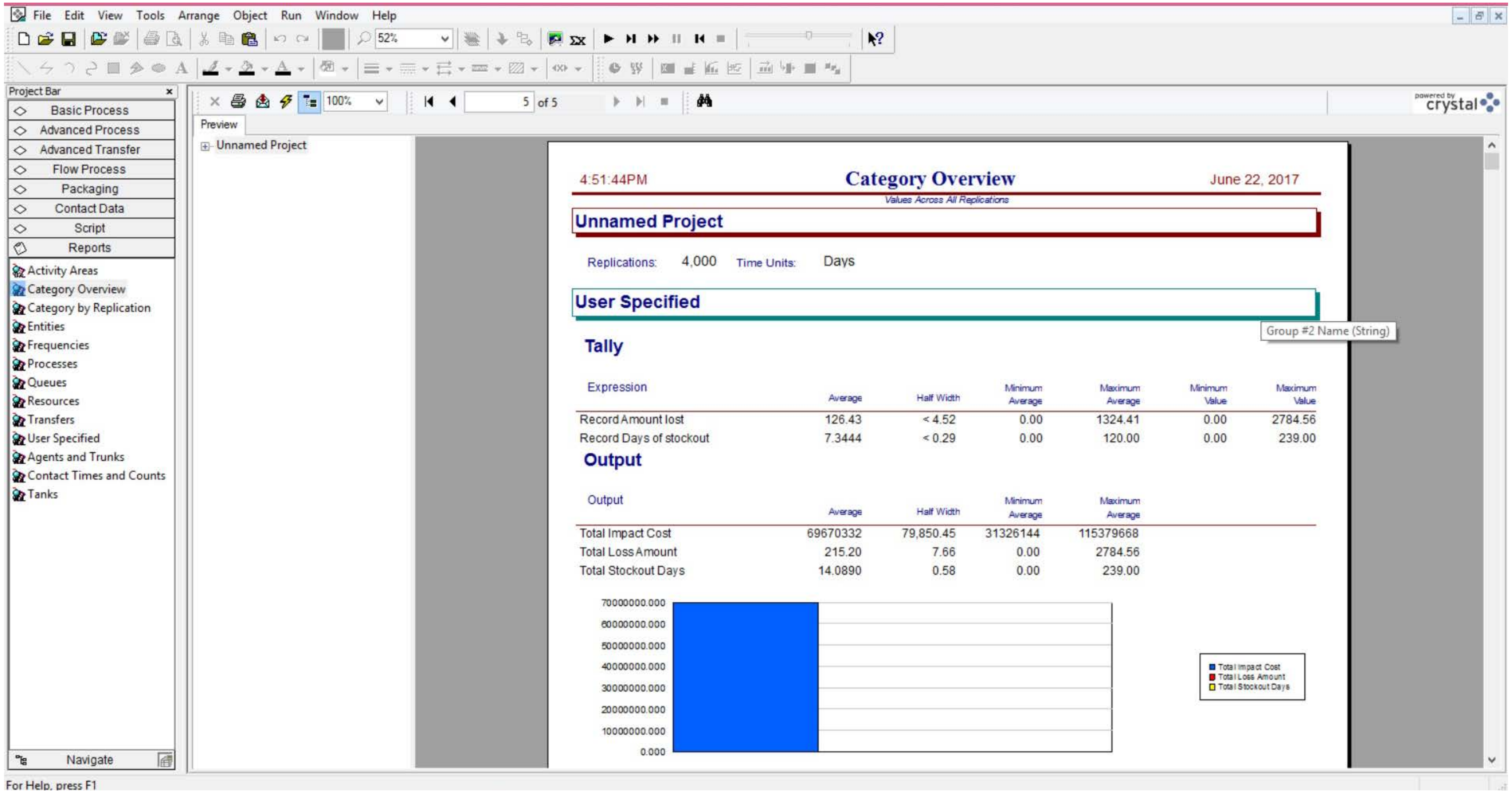
Output

Output	Average	Half Width	Minimum Average	Maximum Average
Total Impact Cost	55886922	76,530.06	17385287	101438811
Total Loss Amount	480.21	9.79	0.00	3138.69
Total Stockout Days	39.1630	0.74	0.00	280.00

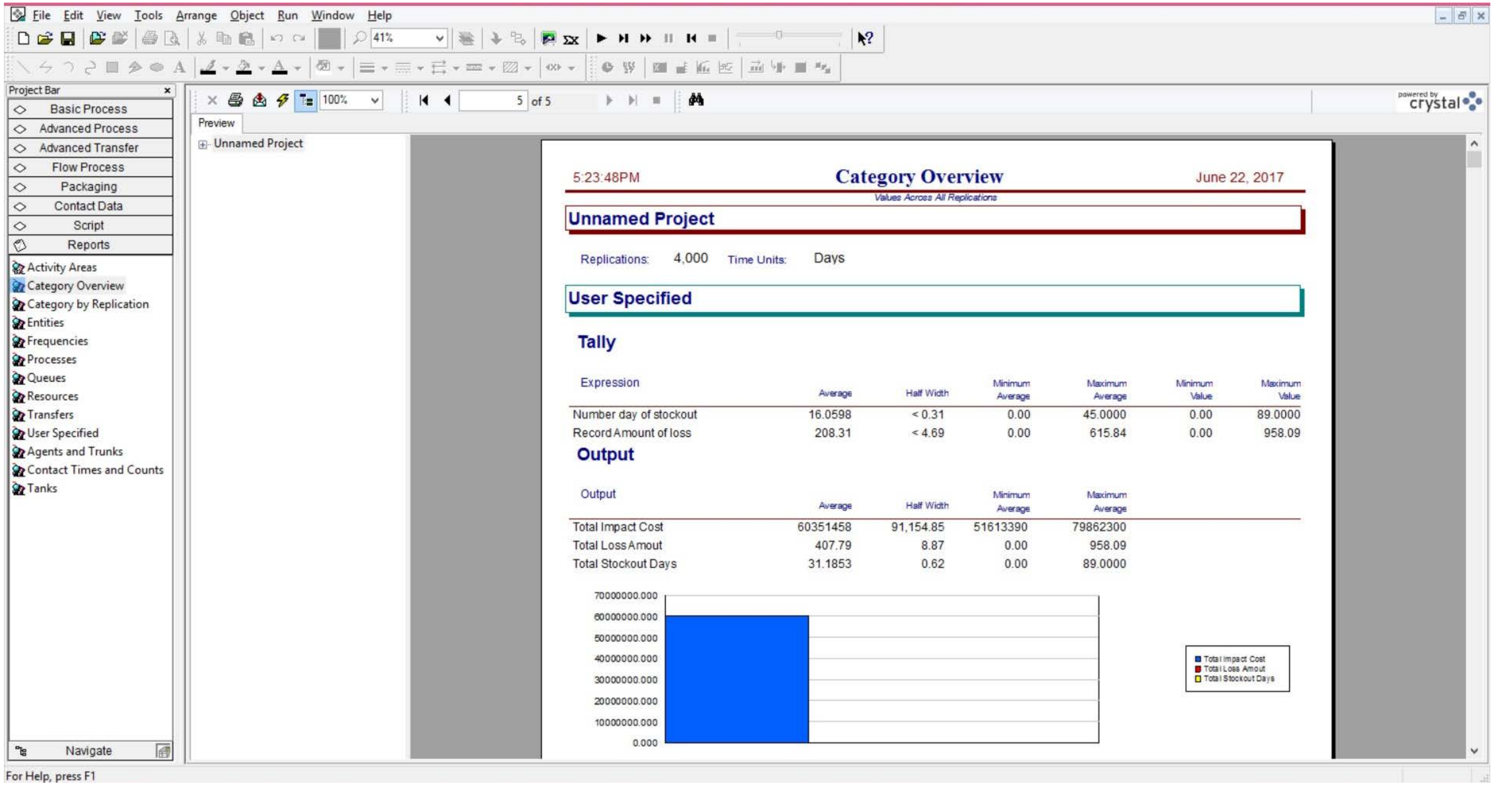
FLEXIBLE ROUTE



REDUNDANT STOCK



REFLEX



Category Overview
5:23:48PM
June 22, 2017
Values Across All Replications
Unnamed Project
Replications: 4,000 Time Units: Days
User Specified
Tally
Expression | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value
Number day of stockout | 16.0598 | < 0.31 | 0.00 | 45.0000 | 0.00 | 89.0000
Record Amount of loss | 208.31 | < 4.69 | 0.00 | 615.84 | 0.00 | 958.09
Output
Output | Average | Half Width | Minimum Average | Maximum Average
Total Impact Cost | 60351458 | 91,154.85 | 51613390 | 79862300
Total Loss Amout | 407.79 | 8.87 | 0.00 | 958.09
Total Stockout Days | 31.1853 | 0.62 | 0.00 | 89.0000
Project Bar
Basic Process
Advanced Process
Advanced Transfer
Flow Process
Packaging
Contact Data
Script
Reports
Activity Areas
Category Overview
Category by Replication
Entities
Frequencies
Processes
Queues
Resources
Transfers
User Specified
Agents and Trunks
Contact Times and Counts
Tanks
Navigate
For Help, press F1

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Gustav Albertzeth received his undergraduate degree in Logistics and Supply Chain Management from Industrial Engineering Department of Universitas Atma Jaya Yogyakarta (UAJY) in 2013 by completing his Final Assignment (T.A) "*Application of Particle Swarm Optimization on Capacitated Team Orienteering Problem*". In 2015 decided to pursue a Master Program on Operations and Supply Chain Engineering (OSCE) in Industrial Engineering Department of Institut Teknologi Sepuluh Nopember Surabaya. During the completion of the Master Program for 2 years (4 semesters), he decided to continuing his area of research since the undergraduate level which is transportation in supply chain, by completing his Thesis "*Cost-Effective Strategy to Mitigate Transportation Disruption in Supply Chain*". Author can be reached by email: gustav.albertzeth@gmail.com.

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