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Effective cost minimization strategy and an optimization model of a reliable global supply chain system

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A B S T R A C T

Attributable to high competition in global manufacturing market and outsourcing suppliers, many supply chain systems have become more complex and faced with high risks and low performance. Many financial losses and failures are likely to be due to risks among supply chain's components. As a prescription to improve quality, performance, and profitability of the supply chain, companies would like to measure and optimize the reliability of the entire supply chain system. Also, companies are interested in minimizing the cost of processes and improvement throughout the supply chain system. This paper explains a statistical method that measures the reliability rate of each part in the system as well as the entire supply chain. Moreover, the paper elucidates a mathematical model that improves the reliability of the supply chain through minimization of cost components. The results and findings of this study confirm that the proposed model can be applied to improve the supply chain system. Also, the system can be improved to reach a designed reliability rate as given target to the model. The illustrated methodology can be used as a guide on how to develop a reliable supply chain system plan with low possible costs.

1. Introduction

Globalization has a tremendous effect on manufacturing for both local and international industries. Through expanding marketplace and high competition, globalization has put pressure on factories to increase quality, flexibility, and serviceability, while maintaining competitive costs (Laosirihongthong & Dangayach, 2005). More than 50% of the cost of the products are now tied to supply chain delivery systems. Hence, companies are focused on reducing the costs associated with the supply chain and to also mitigate the impact of uncertainty of demands using analytics and optimization of supply chain system design. One of the most popular methods for maintaining a competitive advantage is to enhance the value of suppliers, manufactures, and customers while efficiently performing supply chain system activities. Consequently, most of the manufacturers show increasing concern about their supply chain management applications (Goh & Pinaikul, 1998). An efficient supply chain management is a significant multi-disciplinary subject in recent industrial fields and academic research. It increases productivity and profit of organizations through the revolution of managing the companies with

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sustained competitiveness (Gunasekaran et al., 2001, 2004). Supply chain system has become more important in the industrial world which supply and deliver products to the final customers (Waller, 2003). Supply chain management is easier to conceptualize in manufacturing, since the physical flow of product is there (Waller, 2003; Christopher et al., 2011).

The typical supply chain includes a network of suppliers providing raw materials, parts, components, assemblies, subassemblies, and final products combined together with process and clients (Mentzer et al., 2001, 2004). Effective supply chain includes carrying the right number of the right type of product to the right destination at the required time while considering the minimum related costs throughout different levels (Saad et al., 2002). The reliability of the supply chain system is one of the metrics for determining its effectiveness. Reliability has various key roles to play through the supply chain in order to have reliability rate (Liu & Peng, 2009). Even though the concept of supply chain reliability measurement is not easy as an approach to measure the reliability of each activity in the chain, this concept can help to identify indicators that have important contributions in order to measure the reliability of supply chain (Cooper et al., 1997; Gu et al., 2013).

According to So (2000), it can be costly to deliver outstanding time performance when delivery time performance depends on the operating efficiency of the system and the available capacity. In the situation of time-sensitive products for example, products with various characteristics require appropriate methods of managing the supply chain for such products. Moreover, these methods have to take into consideration both the operational (and other) costs and the time as well. Therefore, companies need to improve the adequacy of its delivery system to achieve the desired time performance by spending minimum cost of operating (Eruguz et al., 2013).

Most of the research discuss measuring the reliability of a system from a subjective perspective. Most of the studies focused on single-product supply chain system. Thus, there is a lack of significant studies investigating the reliability evaluation and cost minimization in supply chain system. This research aims to apply and develop an integrated supply chain reliability assessment framework and reduction cost minimization strategy (Kleijnen & Smits, 2003). The method evaluates supply chain system by taking different types of uncertainties into consideration. Thus, the proposed method has the potential to accurately calculate the reliability of the whole supply chain. Besides, this method will enable companies to make enhanced supply chain management decisions at any levels and to calculate the reliability against each reliability computation factor. To achieve the overall objective of this research, two main points were considered. First, we develop a methodology for ensuring the reliability of the supply chain system, by improving the reliability of its entities. Secondly, we ensure that the methodology also optimizes the cost of the supply chain system while achieving the required reliability.

2. Literature Review

2.1 Uncertainty of Global Supply Chain Systems

Supply chains are systems that operate within and across other systems, creating the operational networks that may strengthen and develop or break and produce a negative effect on the organizations. At this point, uncertainty is the greatest risk that a company can face, because it entails increase of risky decision-making and controversial results from all parts of the production line. Although there is no perfect supply chain either locally or globally, it is possible to approach the most appropriate conditions by assessing various scenarios and developing action plans for diverse situations that are more or less likely to occur to reduce uncertainty. This review studies the global supply chain as an appropriate method to reduce cost and produce high-quality product. In addition, due to high uncertainty and ambiguity, the global supply chain has negatively affected each component in the chain as well as the overall supply chain. Consequently, in term of optimization, any improved model should be more accurate and sensitive in order to build an effective global supply chain. Many challenges lead to better understanding the risks and uncertainty in global supply chain which impact the competition in today's business and market.

The previous findings reviewed for assessment of supply chain and risk avoidance demonstrated that outsourcing could be a valuable and cost-efficient strategy (Li et al., 2014). The forecasts for the short-term period suggest that outsourcing has a tendency to increase rapidly compared to the previous results, because supply chain can be effectively optimized using proper resources, personnel, materials, equipment, facilities, and even laws (some countries offer tax vacation or other privileges or bonuses). Outsourcing has several benefits for the organizations, especially in the period or crisis or other disruptions, including reduction of costs in a short-term perspective (usually, it concerns the current financial period), and better access to assets. The history knows many examples of outsourcing that is usually perceived negatively by local population that loses jobs and opportunities because companies transfer their production lines to more appropriate locations that enable them to reduce transportation and production costs. The present situation shows that outsourcing can also become a competitive advantage that reduces production costs and brings the organization ahead of the competitors, enabling the company to focus on the quality of their products and customer satisfaction and customer loyalty.

To conclude, supply chain and supply chain management have a number of categories that might connect them to logistics, operations management, procurement, and other integrate parts of the production process. While some scholars focus on the need to identify the terms accurately and differentiate between supply chain and logistics, it is important to remember that the major difference between these two concepts lies in the drives that push them and make them progress, as well as the scale of decisions made based on certain data available. As such, logistics is the tactical decision-making that does not have long-term perspectives and is more flexible in terms of changes and adjustments. At this point, supply chain is the strategic decision-making driven by long-term perspectives and the need to consider global and less internationalized networks for smooth operation. In this paper, developing an optimization approach that recognizes the disrupted component that should be optimized in order to fulfill the entire supply chain system reliability requirements with minimum possible cost while taking uncertainty into an account.

2.2 Logistic and Cost of Global Supply Chain Systems

The current business environment creates fierce competition in the global supply chain to maintain cost and to effectively meet customer requirements, forcing companies to focus on their SC logistics. Typically, a supply chain process includes the production of raw products and materials at factories, their further shipment to inventory locations to be kept for storage, and their delivery to retailers. The development of effective supply chain strategies should be based on the consideration of exchanges at different levels in this chain to achieve the reduction of cost and the improvement of robustness, reliability, service, and resilience. The global supply chain should thus be better understood, contributing to both reductions of system-wide cost and compliance with robustness, reliability, service, and resilience requirements. This paper presents the research, which analyzes the implementation of an effective global supply chain and identifies the extent of the effect of the areas associated with robustness, reliability, service, and resilience on the organization’s performance whereas reducing related cost. It was identified that remaining competitive in the modern challenging business conditions in terms of the global supply change requires the development of the supplying strategy to make the supply chain system effective and the focus on the significance of logistics in the process of controlling the system robustness rate, reliability rate, service level, and resilience rate. It will therefore allow for the attainment of cost effectiveness and efficiency throughout all levels of the system.

In fact, there are two different points of view on quality in supply chain logistics: objective and subjective. Objective quality is responsible for adjusting services to the requirements established by the service provider. Quality here means an accurate measurement or assessment of all stages of the supply chain process (Garvin, 1984). Subjective quality implies delivering quality services to the customer, i.e. quality and supply chain logistics represents a global perspective related to the high standard of service (Parasuraman et al., 2004). This paper offers a unique, developed objective quality measurement that involves the robustness rate, reliability rate, service level, and resilience rate. The major aspect of this measurement is its ability to assess the entire supply chain system and all members of the system.

2.3 Reliability Design Optimization of Supply Chain System

According to Tu et al. (1999), numerous engineering designs have included traditional deterministic optimization with the aim of consistently minimizing life-cycle cost and improving system quality. Nevertheless, to avoid inaccuracy, there is a need to achieve variability and variation in material properties, cost, manufacturing process, and system performance quality. The complexity and the nature of processes are the major triggers of the occurrence of uncertainties in engineering design and system. Therefore, robust design optimization (RDO) is necessary to decrease the effect of associated uncertainty, system cost, and control quality. The current deterministic discrete optimization tools are not as effective as RDO in case of uncertainty or dynamic conditions in optimization issues.

RDO represents a cost-saving optimization method, which leads to the reduction of the functional variation of the system and saves the sources of variation. Taguchi was the first to present a robustness method (Hwang et al., 2001; Taguchi, 1987; Taguchi & Phadke, 1988), which contributes to the generation of a robust solution, and it is able to resist against uncertainties. According to Yadav et al. (2010), there are three approaches within RDO: optimization procedures that rely on the series expansion of Taylor, a robust design method that depends on the response surface methodology (Chen et al., 1999; Eggert & Mayne, 1993), and Taguchi's experimental design (Phadke, 1995). All approaches of RDO aim at the minimization of the effect of performance uncertainties (variance) associated with the mean values, retaining the cause of uncertainties to meet performance needs.

The review of literature demonstrates that research should be primarily focused on the cooperation between a linked enterprise, which has an upstream supply chain system, and its effect on the overall performance of the supply chain system. Therefore, the use of RDO plays an important role in a supply chain system, developing a supply chain system with inherent robustness and reducing cost. The implementation of RDO and involvement of its activities and aspects may result in the achievement of a robust supply chain system. Almaktoom et al. (2014) focused on assuring service level robustness of supply chain system. The mathematical model concentrates on reducing uncertainty and obtaining robust system by implementing robust design optimization approach for service level. Generally, RDO for SL mathematical model can be expressed as shown in Eq. (1).

$$
\begin{aligned}
&\min W_1 \times \sigma^2_{TCT\,i,j\,(X_s)} + W_2 \times \mu_{TCT\,i,j\,(X_s)} + W_3 \times C_{i,j} \\
&\text{subject to} \\
&SL_{i,j\,(X_s)} \geq Q_{i,j\,(X_s)} \qquad i = 1,2,\dots,I \\
&X^L_s \leq X_s \leq X^U_s, j = 1,2,\dots,J \\
&X_s \geq 0, s = 1,2,\dots,S \\
&\sum W_n = 1
\end{aligned}
\tag{1}
$$

The objective function of Almaktoom's (2017) mathematical model minimizes uncertainty and processing time. The main constraints maintain required service level and the rest of the constraints limit the model to run within allowed boundaries. Also, the decision maker has the advantage to weight the objective function and move the model to focus on the desired part of the system. However, the model has some consequences for the financial aspect in the organization which may raise the cost of achieving robust supply chain system. In addition, the mathematical model has less ability to be applicable for different sectors of businesses since most of the manufacturing facilities focus on a reasonable (depends on types of product and organization goals) level of quality, high profit, and low expenditures. The perspective of minimizing cost in Almaktoom's work is not controlled which leads to carry extremely high cost in order to accomplish the ultimate objective of the model.

3. Research Objective

The objective of this paper is to design a new strategy that improves the reliability of the supply chain system by taking into consideration the minimization of the cost of improvement. The mathematical model will ensure meeting reliability target for the supply chain system. Also, since the reliability rate of the system will be enhanced, an amount of cost shall be invested to reach the required improvement. The model will ensure the minimum possible cost of investment called the cost of reductions. Variation reduction and processing time reduction are the two types of reductions that require costs to improve them. Furthermore, the presented model will minimize these costs and maintain the reliability target that the model to be obtained. Practically, different scenarios are considered in this study in order to test different perspectives and figure out the most effective factors in cost and reliability improvement. In the next section, the model will be explained into three parts. The first part is about the reliability measurement and the function related to it. Then the second part has the mathematical model which includes the objective function and the related constrains. The last part explains the mechanism of the reduction cost function and the related types of costs which covered through the model.

4. Research Method

4.1 Reliability and Cost Optimization Model

The reliability rate of any entity in the supply chain can be calculated using the following equation:

$$Re = \frac{T^T - (\sum_{j=1}^{n} \sigma_j + \sum_{j=1}^{n} \varepsilon_j)}{T^T}, \tag{2}$$

where, Re_j represents the reliability rate of entity number j to finish the required job. T^T represents the due time. σ_j represents the standard deviation (uncertainty) of entity distribution functions for entity number j and ε_j represents the delay time at the same component. The optimization model is designed to optimize the reliability of the supply chain system and minimize the cost of achieving the desired reliability rate. The objective function (Eq. (3)) minimizes the cost of improving reliability of the supply chain system that is associated with mean time reduction and standard deviation reduction. Eq. (4) ensures that the achieved reliability for the supply chain is greater than the target reliability to be achieved.

Eq. (5) ensures that the standard deviation for each entity is bounded by the upper and lower limits of the achievable standard deviation. Eq. (6) ensures that the mean times that are obtained for each entity is between the upper and lower bound of the achievable mean time for that entity. Eq. (7) ensures that the mean time and standard deviation of all entities are not negative.

In this paper, the objective functions of all the entities are assumed to be equally significant. However, cases are different from field to field; therefore, different weightings for objective functions of components have been addressed by other scholars. Examples of unequally weighted objective functions can be found in Deb (2001), Nixon et al., (2012), Rambau and Schade (2010), Konak et al. (2006), Murata et al. (1996) and Yildirim and Mouzon (2012). In this study, the objective function will not be weighted because of the equal importance of the cost at each part of the objective function which ensures reducing mean time and standard deviation as well in the same component. Table 1 demonstrates the summary of the notations used for the proposed method of this paper.

Table 1
Symbols and its description**.**

T^T	the due time or target time that the system required to not exceed
μ_j^U	the upper mean processing time that bounds the model for not exceeding the upper limit
μ_j^L	the lower mean processing time that bounds the model for not exceeding the lower limit
$\boldsymbol{\sigma}_j^U$	the upper standard deviation that limits the model for not exceeding the upper standard deviation
$\boldsymbol{\sigma}_j^L$	the lower standard deviation that limits the model for not exceeding the lower standard deviation
$\mu_{j,i}$	the mean processing time for entity *j* and step interval mean time reduction *i*
$\sigma_{j,k}$	the mean processing time for entity *j* and step interval standard deviation reduction *k*
μ	the mean processing time (decision variable)
σ	the standard deviation (decision variable)
Re_{system}	the reliability rate of the system
Re^T	the reliability target which need to be achieved
$F_{j,i}$	the fixed cost for step interval mean reduction *i* for entity *j*
$V_{j,i}$	the variable cost for step interval mean reduction *i* for entity *j*
$U_{j,k}$	the fixed cost for step interval standard deviation reduction *k* for entity *j*
$C_{j,k}$	the variable cost for step interval standard deviation reduction *k* for entity *j*
j	the entity or component number
i	the number of step interval for mean time reduction at entity *j*
k	the number of step interval for standard deviation reduction at entity *j*

Based on the notations given in Table 1, the proposed model of this paper is presented as follows,

$$\min \quad \sum_{j=1}^{n}\sum_{i=1}^{m}(F_{j,i}+V_{j,i})+\sum_{j=1}^{n}\sum_{k=1}^{h}(U_{j,k}+C_{j,k}) \tag{3}$$

where

$$V_{j,i} = \quad v_{j,i} \quad (\mu_{j,i}-\mu_{j,i+1}) \qquad \forall\, j=1,2,..n\ \&\ i=1,2,\ldots m$$
$$C_{j,k} = \quad c_{j,k} \quad (\sigma_{j,k}-\sigma_{j,k+1}) \qquad \forall\, j=1,2,..n\ \&\ k=1,2,\ldots h$$

subject to

$$Re_{system} \ \geq\ Re^T \tag{4}$$
$$\boldsymbol{\sigma}_j^L \ \leq\ \boldsymbol{\sigma}_j \ \leq\ \boldsymbol{\sigma}_j^U \tag{5}$$
$$\mu_j^L \ \leq\ \mu_j \ \leq\ \mu_j^U \tag{6}$$
$$\mu_j \geq 0 \quad \& \quad \sigma_j \geq 0 \tag{7}$$

The cost function associated with the mean time reduction and the standard deviation function for each entity may be defined as a linear or a nonlinear function. In this study, cost functions are associated with each entity in the supply chain. The optimal reliability rate and the cost associated with achieving the reliability rate for all entities and the supply chain can be determined by implementing the following procedures to:

1. Determine the current cycle time for all processes in the supply chain,
2. Determine the cost function associated with reducing cycle time of all entities in the supply chain,
3. Determine the cost function associated with reducing standard deviation for each entity in the supply chain system,

4. Define distribution function, mean, and standard deviation, based on collected data. Using Monte Carlo Simulation to generate samples for each process,
5. and to Calculate Reliability rate Re_j for each process and for the overall supply chain based on Eq. (2).

We apply the mathematical model using Eq. (3) at different reliability targets, to achieve the required reliability rate for the overall supply chain system with minimum possible cost.

4.2 Reduction Cost Function in the Model

The cost of mean time and standard deviation reductions in the supply chain system fluctuate due to the type of operation, function, or the improvement target on activities. Step functions are used in this model to represent the cost function. This function ensures a fixed cost within certain limits and a variable cost that will be determined by the optimization. The following equations illustrate the step function of the reduction cost initially used in the mathematical model as an objective function. $f(x_j)$ is the cost for mean time reduction for entity j and $f(y_j)$ is the cost for standard deviation reduction for entity j.

$$f(x_j) = \begin{cases} Fixed\ cost_{\ j,i} + Variable\ cost_{j,i} & \mu - t_i \geq x_j > \mu - t_{i+1} \\ Fixed\ cost_{\ j,i+1} + Variable\ cost_{j,i+1} & \mu - t_{i+1} \geq x_j > \mu - t_{i+2} \\ \vdots & \\ \vdots & \\ Fixed\ cost_{\ n,m} + Variable\ cost_{n,m} & \mu - t_{i+(m-1)} \geq x_j > \mu - t_{i+m} \end{cases} \tag{8}$$

$$f(y_j) = \begin{cases} Fixed\ Cost_{j,k} + Variable\ Cost_{j,k} & \sigma - t_k \geq y_j > \sigma - t_{k+1} \\ Fixed\ Cost_{j,k+1} + Variable\ Cost_{j,k+1} & \sigma - t_{k+1} \geq y_j > \sigma - t_{k+2} \\ \vdots & \\ \vdots & \\ Fixed\ Cost_{n,h} + Variable\ Cost_{n,h} & \sigma - t_{k+(h-1)} \geq y_j > \sigma - t_{k+h} \end{cases} \tag{9}$$

The fixed cost may vary from one stage to another in the supply chain system. This is true for the variable cost as well, which can vary based on the reduction in time ‘t’ within each time interval. Initially, the step functions strategy is used to identify the cost for each process. However, a fitted curve solution can be applied to approximate the cost equation for the entire supply chain system that is shown in this study. These cost reduction equations are applied for reducing uncertainties ($\boldsymbol{\sigma}$) throughout the supply chain as represented by Eq. (9) and also for improving mean processing time (μ) as shown in Eq. (8). The following two equations give more understanding of how the mean reduction cost and standard deviation reduction cost will be involved in the objective function of the mathematical model.

$$\sum_{j=1}^{n}\sum_{i=1}^{m}(F_{j,i} + V_{j,i}) \tag{10}$$

$$\sum_{j=1}^{n}\sum_{k=1}^{h}(U_{j,k} + C_{j,k}) \tag{11}$$

where $F_{j,i}$ is the fixed cost of reducing mean time for entity j and $V_{j,i}$ is the variable cost for the same entity and purpose. Also, $U_{j,k}$ is the fixed cost of reducing standard deviation for entity j and $C_{j,k}$ is the variable cost for the same entity and purpose. Moreover, i and k represent the number of step interval of reduction for each factor which are mean and standard deviation respectively. Eq. (10) ensures minimizing the cost of mean time reduction and Eq. (11) ensures minimizing the cost of standard deviation reduction.

5. Case Study and Results

In this section, a case study will be provided in order to test the validity of the methodology that was developed and explained in the previous section of this research.

5.1 Case Study

This case study considers a supply chain system which has seven entities, as shown in flow process (Fig. 1) below. These entities, which are connected in series, consists of the following components: Supplier, shipping route from supplier to factory, factory, shipping route from factory to distribution center, distribution center, shipping route from distribution center to retailer, and then the retailer. The mean time and standard deviation for each entity is given in Table 2.

Table 2
Data used in the model

Process	Mean time (hour)	Standard Deviation. (hour)	Minimum Standard Deviation	Maximum Standard Deviation	Minimum Mean	Maximum Mean
S	95	21	4	25	80	100
R_{1-2}	72	16	3	20	60	90
F	88	18	4	25	75	95
R_{2-3}	90	22	4	30	78	100
DC	101	24	5	30	80	105
R_{3-4}	80	20	2	25	66	90
V	77	13	2	19	65	85

The due time to have one batch delivered to the retailer is 500 hours ($T^T = 500$). The cost of each entity can be classified into two different types: fixed cost and variable cost. The fixed cost is the amount of money that has to be spending in order to reduce the mean time of the operational activities of an entity in the supply chain system to a predefined level. The variable cost at that level of reduction is the variable cost of reducing processing time per unit time of reduction. The same concept of fixed cost and variable costs for each level of reduction is applied to standard deviation reduction as well. Thus, both cost functions for mean time reduction and standard deviation reduction use a step function in order to represent the combined cost at each stage. The overall cost for time reduction can be calculated by adding the cost for all entities in the supply chain system. The objective of this case study is to measure the system reliability and to identify the optimal cost of the system by utilizing the developed model. Another aim of this case is to demonstrate the efficiency of the performed methodology for assessing and optimizing the reliability of each entity in the system, as well as the overall system. Moreover, the model can be used to calculate the minimum cost of the processes through the supply chain system at different reliability rates. The target reliability rate of the case study is to reach at 90% zone at the minimum possible cost.

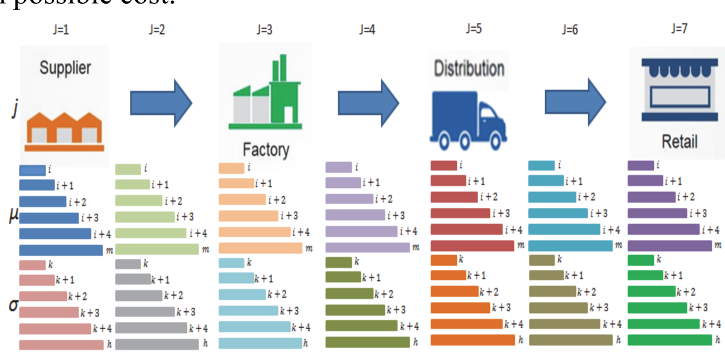

Fig.1. Case study's components.

Fig. 1 shows the entity of the supply chain system under study. The parameters used in the equations as follows:

S denotes the supplier's entity which is the first entity in the supply chain.
F denotes the factory's entity which is the third entity in the supply chain.
DC represents the distribution center which is the fifth entity.
V denotes the retailer which is the seventh entity in the supply chain.
R denotes route which is the second, fourth, and sixth entity in the supply chain.

In this case, it is assumed that the factory does not start manufacturing the required parts until it has received all required materials. For instance, factory *F* cannot start working until it receives the required raw materials from the supplier. The parameters used in this case study were assumed to be normally distributed. Each entity in the supply chain system has a mean time to finish the required job. Also, the standard deviation has to be identified for each entity. Before the optimization of cost can be performed, the costs associated with each level of reduction have to be identified. The data of costs for each entity in the supply chain system are provided (see Appendix A). MATLAB was used to model and solve this case study. The model has calculated the reliability rate and obtained minimum cost to reach reliability target for each entity as well as for the overall system.

5.2 Results of Case Study

The current reliability of the supply chain system was calculated using Eq. (2). Based on the data and by applying the developed model, it has been determined that the initial cycle time is 840 hours, and the initial reliability rate of the system is steady at 60.09% (see Table 3). Also, the initial delays reached 103 hours, which means that when a retailer made a request for a batch of products, it could take 840 hours and have possibly 103 hours as the delay. Hence, to improve the reliability, the optimization model was utilized to reach the reliability that was required and to determine the minimum cost at different reliability targets while taking the uncertainty into consideration.

Table 3
Initial output of the model.

	Initial Cycle Time	Initial Delay	Initial Reliability Rate
Entire System	840	103	0.609

The model was implemented at three different reliability rates which are 70, 80, and 90 to see the increase in cost as the reliability improved. Also, taking the uncertainty into account is necessary in term of system reliability optimization. When attempting to reach a 70% reliability rate, the model achieved 73.8% reliability rate. The following values also were indicated as the optimal mean and standard deviation with their reduction cost intervals for each of the entity in the system.

$$(\text{Mean Time Reduction}) = \begin{cases} 1000 + \big(70 \quad (95-90)\big) = 1{,}350 & 90 \geq S_{j=1} > 87 \\ 700 + \big(20 \quad (72-70)\big) = 740 & 72 \geq R_{j=2} > 69 \\ 800 + \big(70 \quad (88-83)\big) = 1{,}150 & 85 \geq F_{j=3} > 82 \\ 800 + \big(30 \quad (90-85)\big) = 950 & 87 \geq R_{j=4} > 84 \\ 1000 + \big(70 \quad (101-94)\big) = 1{,}490 & 95 \geq DC_{j=5} > 92 \\ 1100 + \big(50 \quad (80-71)\big) = 1{,}550 & 71 \geq R_{j=6} > 68 \\ 800 + \big(70 \quad (77-73)\big) = 1{,}080 & 74 \geq V_{j=7} > 71 \end{cases}$$

$$(\text{Standard Deviation Reduction}) = \begin{cases} 900 + \big(50 \quad (21-16)\big) = 1{,}150 & 18 \geq S_{j=1} > 15 \\ 800 + \big(50 \quad (17-09)\big) = 1{,}200 & 11 \geq R_{j=2} > 08 \\ 1100 + \big(80 \quad (18-8)\big) = 1{,}900 & 09 \geq F_{j=3} > 06 \\ 900 + \big(60 \quad (22-12)\big) = 1{,}500 & 13 \geq R_{j=4} > 10 \\ 1100 + \big(80 \quad (24-14)\big) = 1{,}900 & 15 \geq DC_{j=5} > 12 \\ 900 + \big(50 \quad (20-12)\big) = 1{,}300 & 14 \geq R_{j=6} > 11 \\ 1300 + \big(80 \quad (14-5)\big) = 2{,}020 & 05 \geq V_{j=7} > 02 \end{cases}$$

The model recorded 64.5 as delay time in hours for the entire processes with a cycle time of 697 hours. In Fig. 2, the performance and reliability rate of the system is at 73.8.

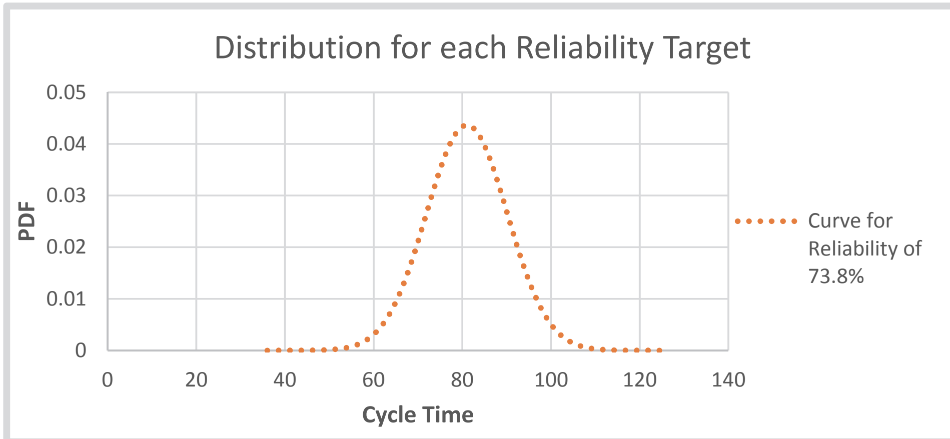

Fig.2. Distribution of mean total cycle time.

After applying the model, the reliability rate of each entity was improved in order to achieve the target which successfully obtained 73.8%. Also, the model ensured minimum cost of improving the supply chain system which was only $ 19,280 to achieve the required target. Table 4 shows the initial reliability rate for each entity in the system and the obtained reliability rate for the same entities when the target reliability for the entire system is 70%. Table 5 shows the final achieved reliability for the system along with the additional cost required to achieve the target reliability rate of 70%.

Table 4
Initial and optimal reliability rates each entity.

Entity	Initial Reliability Rate	Obtained Reliability Rate
Supplier j=1	0.958	0.968
Route j=2	0.933	0.960
Factory j=3	0.929	0.962
Route j=4	0.921	0.954
D Center j=5	0.893	0.949
Route j=6	0.925	0.955
Customer j=7	0.939	0.968

Table 5
The overall initial and optimal reliability rates.

Initial Reliability	Reliability Target	Obtained Reliability Rate	Total Cost
60.9%	70%	73.8%	$ 19,280

The second required reliability target was 80% but after running the mathematical model, it achieved 84.2%. This optimal rate was obtained when the model picked up the optimal values for mean and standard deviation with their costs which were the minimum possible cost to achieve the goal. The following values identify the optimal mean and standard deviation with their reduction cost intervals.

$$
(\text{Mean Time Reduction}) = \begin{cases} 1100 + \big(80 \;\; (95 - 85)\big) = 1{,}980 & 87 \geq S_{j=1} > 84 \\ 1000 + \big(40 \;\; (72 - 64)\big) = 1{,}360 & 66 \geq R_{j=2} > 63 \\ 1000 + \big(80 \;\; (88 - 79)\big) = 1{,}720 & 79 \geq F_{j=3} > 76 \\ 1100 + \big(50 \;\; (90 - 81)\big) = 1{,}550 & 81 \geq R_{j=4} > 78 \\ 1200 + \big(80 \;\; (101 - 88)\big) = 2{,}240 & 89 \geq DC_{j=5} > 86 \\ 1000 + \big(40 \;\; (80 - 73)\big) = 1{,}360 & 74 \geq R_{j=6} > 71 \\ 800 + \big(70 \;\; (77 - 72)\big) = 1{,}150 & 74 \geq V_{j=7} > 71 \end{cases}
$$

$$(\text{Standard Deviation Reduction}) = \begin{cases} 1200 + \left(80 \ \ (21-7)\right) = 2{,}320 & 09 \ \geq S_{j=1} > 06 \\ 900 + \left(60 \ \ (17-6)\right) = 1{,}560 & 08 \ \geq R_{j=2} > 05 \\ 1200 + \left(80 \ \ (18-5)\right) = 2{,}240 & 06 \ \geq F_{j=3} > 03 \\ 1000 + \left(70 \ \ (22-8)\right) = 1{,}980 & 10 \ \geq R_{j=4} > 07 \\ 1300 + \left(100 \ \ (24-08)\right) = 2{,}900 & 09 \ \geq DC_{j=5} > 06 \\ 1100 + \left(70 \ \ (20-7)\right) = 2{,}010 & 08 \ \geq R_{j=6} > 05 \\ 1300 + \left(80 \ \ (14-3)\right) = 2{,}180 & 05 \ \geq V_{j=7} > 02 \end{cases}$$

84.2% reliability rate was obtained with recording 616 hours as cycle time for the entire supply chain system. The delay was minimized and reached to 37 hours. The performance and reliability rate of the system at 84.2% (Fig. 3).

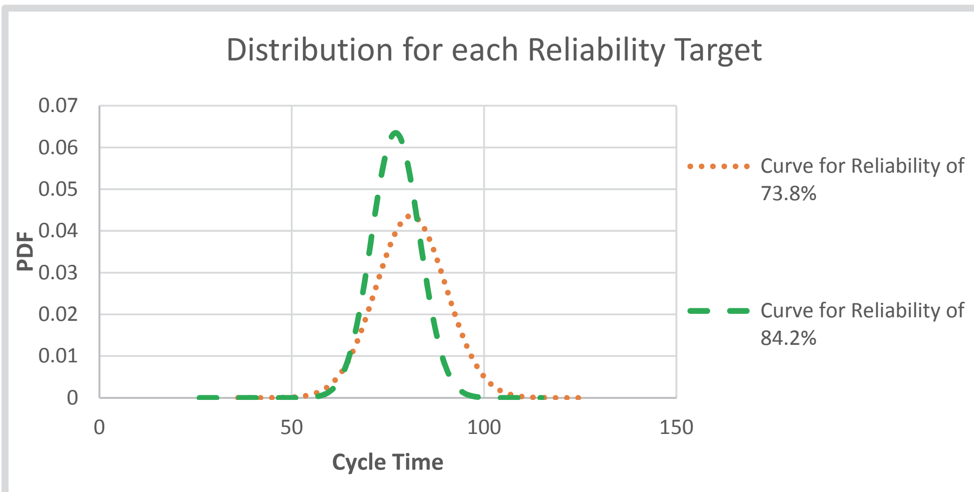

Fig.3. Distribution of mean total cycle time

By running the model, the reliability rate of each entity was improved which achieved value beyond the target and recorded 84.2%. Also, the cost of improving the supply chain system to reach a reliability rate of 84.2% was $ 26,550. Table 6 and Table 7 show the initial and improved values.

Table 6
The initial and optimal reliability rates each entity

Entity	Initial Reliability Rate	Obtained Reliability Rate
Supplier j=1	0.958	0.986
Route j=2	0.933	0.974
Factory j=3	0.929	0.976
Route j=4	0.921	0.969
DC j=5	0.893	0.970
Route j=6	0.925	0.972
Customer j=7	0.939	0.980

Table 7
The overall initial and optimal reliability rates.

Initial Reliability	Reliability Target	Obtained Reliability Rate	Total Cost
60.9%	80%	84.2%	$26,550

Since the objective of this case study is to lead the system to 90 reliability rate zone as well as obtaining minimum possible cost, the reliability target was changed to 90%. The following values identify the optimal mean and standard deviation with their reduction cost intervals.

$$
(\text{Mean Time Reduction}) = \begin{cases} 1200 + \big(80 \;\; (95-83)\big) = 2{,}160 & 84 \geq S_{j=1} > 81 \\ 1100 + \big(50 \;\; (72-62)\big) = 1{,}600 & 63 \geq R_{j=2} > 60 \\ 1000 + \big(80 \;\; (88-77)\big) = 1{,}960 & 79 \geq F_{j=3} > 76 \\ 1100 + \big(50 \;\; (90-80)\big) = 1{,}600 & 81 \geq R_{j=4} > 78 \\ 1400 + \big(90 \;\; (101-82)\big) = 3{,}110 & 83 \geq DC_{j=5} > 80 \\ 1100 + \big(50 \;\; (80-70)\big) = 1{,}600 & 71 \geq R_{j=6} > 68 \\ 1200 + \big(80 \;\; (77-64)\big) = 2{,}240 & 65 \geq V_{j=7} > 62 \end{cases}
$$

$$
(\text{Standard Deviation Reduction}) = \begin{cases} 1300 + \big(80 \;\; (21-5)\big) = 2{,}580 & 06 \geq S_{j=1} > 03 \\ 1000 + \big(70 \;\; (17-4)\big) = 1{,}910 & 05 \geq R_{j=2} > 03 \\ 1200 + \big(80 \;\; (18-5)\big) = 2{,}240 & 06 \geq F_{j=3} > 03 \\ 1100 + \big(80 \;\; (22-5)\big) = 2{,}460 & 07 \geq R_{j=4} > 04 \\ 1400 + \big(110 \;\; (24-6)\big) = 3{,}380 & 06 \geq DC_{j=5} > 03 \\ 1300 + \big(80 \;\; (20-4)\big) = 2{,}580 & 05 \geq R_{j=6} > 02 \\ 1500 + \big(100 \;\; (14-2)\big) = 2{,}700 & 02 \geq V_{j=7} > 00 \end{cases}
$$

Also, the obtained cycle time was 571 hours with recording only 20 hours as delay time for the overall supply chain system. The performance and reliability rate of the system at 90.59% is represented by the line legend in Fig. 4.

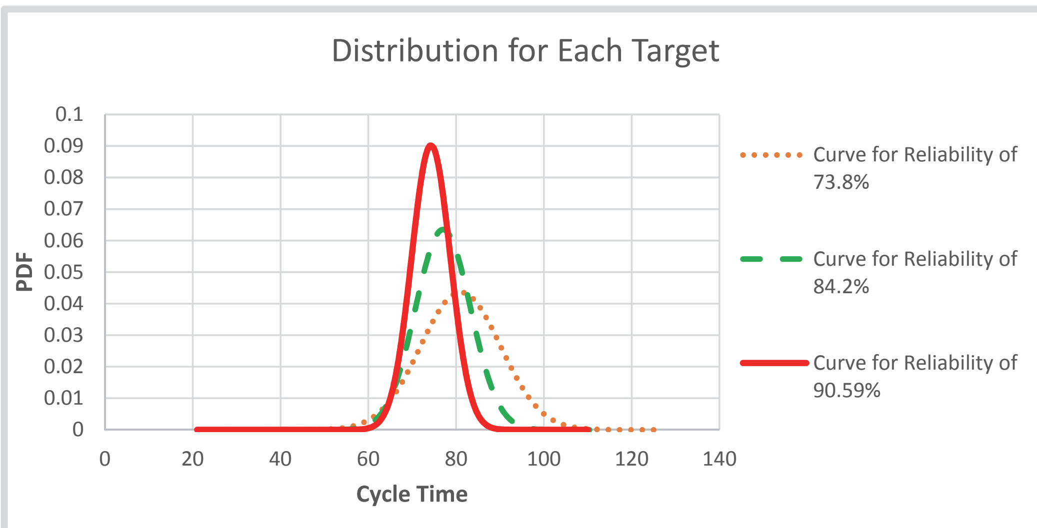

Fig.4. Distribution of mean total cycle time

After running the model, the reliability rate of each entity was improved to achieve the target of 90.59% as an overall rate. Also, the model ensured possible minimum cost of improving the entire supply chain which was only $ 32,120 to achieve the required target. Table 8 and Table 9 show the initial and improved reliability rates.

Table 8

Initial and optimal reliability rates each entity.

Entity	Initial Reliability Rate	Obtained Reliability Rate
Supplier j=1	0.958	0.990
Route j=2	0.933	0.986
Factory j=3	0.929	0.984
Route j=4	0.921	0.984
Distribution Center j=5	0.893	0.982
Route j=6	0.925	0.986
Customer j=7	0.939	0.991

Table 9
The overall initial and optimal reliability rates.

Initial Reliability	Reliability Target	Obtained Reliability Rate	Total Cost
60.9%	90%	90.59%	$32,120

It is clear, that there is a negative correlation between cost and time in the model. In order to improve processing activities, which results in reducing cycle time, additional money has to be invested. Also, to reduce the uncertainty factors money has to be invested as well. Fig. 5 shows the different total cost at different reliability targets. By applying the MATLAB model, the cycle time of each process in supply chain system is acquired as well as the overall cycle time.

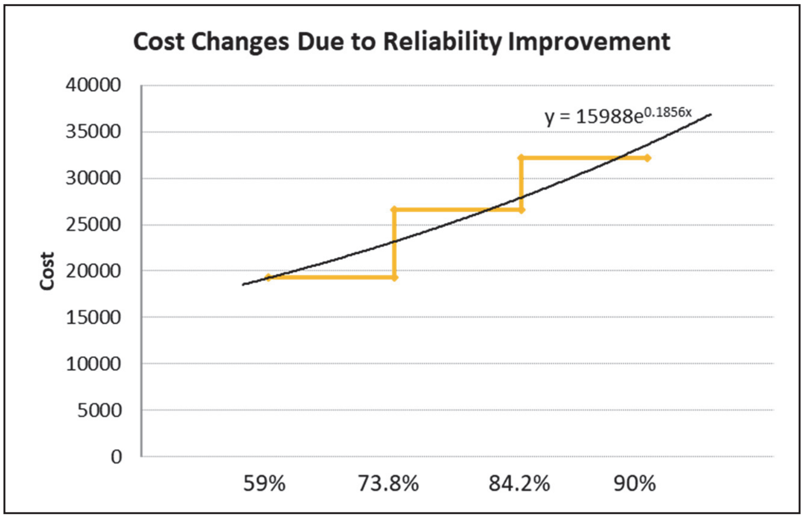

Fig. 5. Cost of optimizing reliability rate of supply chain system

It is obvious that there are varied differences in cost between the different reliability targets achieved after applying the model. The system at first target spent $ 19,280 as reduction cost while the optimized system at 90.59% reliability rate recorded about $ 32,120 as cost for time reduction. The results of the case study are shown in Table 10. Table 10 shows the initial mean time at each entity, as well as the optimal mean time. For example, the supplier's initial mean time reached to 95, whereas the optimal mean time for the same entity recorded minimum value, which was steady at 83 hours.

Table 10
Initial and optimal mean time.

Process	Initial Mean time	Optimal Mean Time
S	95	83
R_{1-2}	72	62
F	89	77
R_{2-3}	90	80
DC	101	82
R_{3-4}	80	70
V	77	66

In addition, each achieved reliability target has also identified the cycle time that has to be obtained in order to achieve the reliability target. Table 11 and Fig. 6 shows the improvement in cycle time as well as the reliability rate.

Table 11
The optimal cycle time with obtained reliability rate

Optimal Cycle Time hour	840	696	616	571
Reliability Rate	60.9%	73.8%	84.2%	90.59%

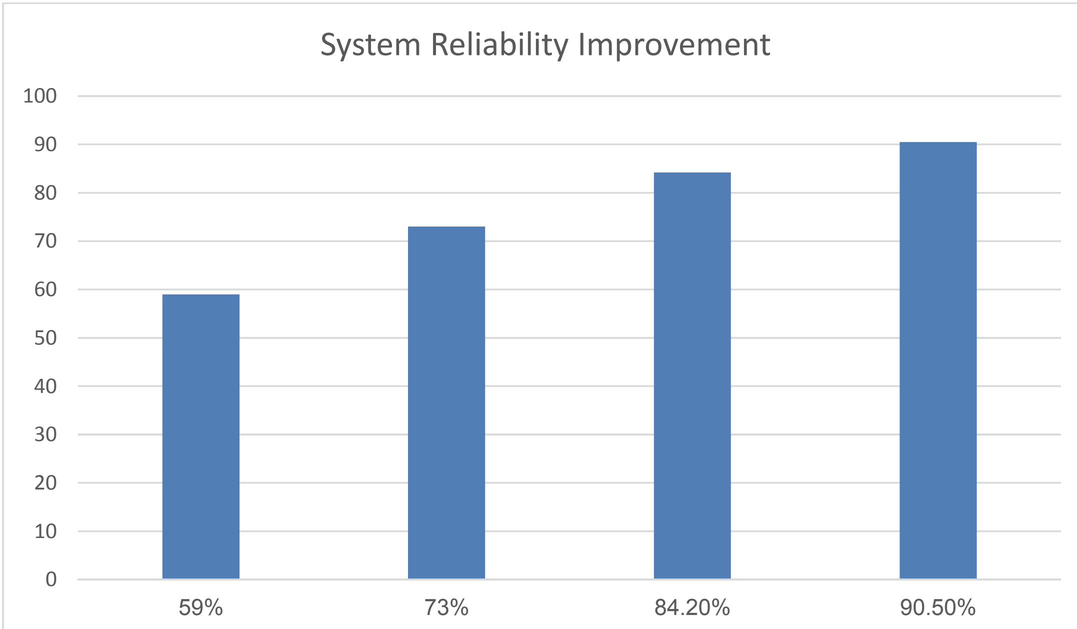

Fig. 6. illustrates System Reliability Improvement

From Table 11, while the initial cycle time for delivering one batch was 840 hours, with optimization the cycle time has been reduced to 571 hours. The delay recorded is only 20 hours per batch. Also, the reliability rate increased to reach the rate of 90.59%. Hence, all constraints and requirements, such as the overall supply chain system reliability rate and the optimal total cost, were satisfied.

6. Conclusion and Future Study

There is always a need to address the reliability concept in supply chain system as more companies, departments, organizations, and other divisions are being involved in the supply chain's structure. Also, from a business perspective, minimizing costs is a significant matter that has to be addressed to have reliable and robust supply chain system. This research has concentrated on evaluating reliability rates at each entity through the supply chain system. Also, this work explains how the supply chain system optimization model could be applied to obtain minimum possible total cost while fulfilling the reliability requirements. Moreover, applying different scenarios of reliability targets makes the model more applicable to utilize for different business sectors. The effects of uncertainty driven by production and transportation on overall reliability were examined in the paper as well. Results and analysis of this study have accentuated that the presented mathematical model can be applied to rebuild the supply chain system where the system can be improved to reach a desired reliability target, which can be used as a guide to design supply chain systems that reduces costs. In conclusion, the optimization approach that has been presented in this study is to provide an appropriate method that helps to satisfy the reliability requirements at the minimum possible cost. Also, the mathematical model has the flexibility and the potential to be implemented for any supply chain system regardless to the complexity or the type of the system. As a future study, this study will spend more investigation in how reliability performance affects the total cost of managing internal and external subsystems in the supply chain, as well as for the overall supply chain system. Also, it will continue to consider multi-products factor and multi-levels (complex) supply chain systems.

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Appendix A

Costs of Reduction for Each Entity in The Supply Chain System

Amount of Time Intervals Reduction and Associated Costs of Reduction

Mean Time Reduction for Supplier (S)

$$
(\text{Mean Time Reduction}) = \begin{cases} 700 + \left(50 \quad (95-93)\right) & 95 \geq S_{j=1} > 93 \\ 800 + \left(60 \quad (95-90)\right) & 93 \geq S_{j=1} > 90 \\ 1000 + \left(70 \quad (95-87)\right) & 90 \geq S_{j=1} > 87 \\ 1100 + \left(80 \quad (95-84)\right) & 87 \geq S_{j=1} > 84 \\ 1200 + \left(80 \quad (95-81)\right) & 84 \geq S_{j=1} > 81 \\ 1300 + \left(80 \quad (95-78)\right) & 81 \geq S_{j=1} > 78 \\ 1400 + \left(80 \quad (95-75)\right) & 78 \geq S_{j=1} > 75 \end{cases}
$$

Standard Deviation Reduction for Supplier (S)

$$
(\text{Standard Deviation Reduction}) = \begin{cases} 800 + \left(40 \quad (21-18)\right) & 21 \geq S_{j=1} > 18 \\ 900 + \left(50 \quad (21-15)\right) & 18 \geq S_{j=1} > 15 \\ 1000 + \left(70 \quad (21-12)\right) & 15 \geq S_{j=1} > 12 \\ 1100 + \left(80 \quad (21-9)\right) & 12 \geq S_{j=1} > 09 \\ 1200 + \left(80 \quad (21-6)\right) & 09 \geq S_{j=1} > 06 \\ 1300 + \left(80 \quad (21-3)\right) & 06 \geq S_{j=1} > 03 \\ 1400 + \left(80 \quad (21-2)\right) & 03 \geq S_{j=1} > 02 \end{cases}
$$

Mean Time Reduction for <u>Route (R)</u>

$$(\text{Mean Time Reduction}) = \begin{cases} 700 + \left(20\ \ (72-69)\right) & 72 \geq R_{j=2} > 69 \\ 800 + \left(30\ \ (72-66)\right) & 69 \geq R_{j=2} > 66 \\ 1000 + \left(40\ \ (72-63)\right) & 66 \geq R_{j=2} > 63 \\ 1100 + \left(50\ \ (72-60)\right) & 63 \geq R_{j=2} > 60 \\ 1200 + \left(60\ \ (72-57)\right) & 60 \geq R_{j=2} > 57 \\ 1300 + \left(70\ \ (72-54)\right) & 57 \geq R_{j=2} > 54 \\ 1400 + \left(80\ \ (72-51)\right) & 54 \geq R_{j=2} > 51 \end{cases}$$

Standard Deviation Reduction for <u>Route (R)</u>

$$(\text{Standard Deviation Reduction}) = \begin{cases} 600 + \left(30\ \ (17-14)\right) & 17 \geq R_{j=2} > 14 \\ 700 + \left(40\ \ (17-11)\right) & 14 \geq R_{j=2} > 11 \\ 800 + \left(50\ \ (17-08)\right) & 11 \geq R_{j=2} > 08 \\ 900 + \left(60\ \ (17-5)\right) & 08 \geq R_{j=2} > 05 \\ 1000 + \left(70\ \ (17-3)\right) & 05 \geq R_{j=2} > 03 \\ 1100 + \left(80\ \ (17-0)\right) & 03 \geq R_{j=2} > 00 \end{cases}$$

Mean Time Reduction for <u>Factory (F)</u>

$$(\text{Mean Time Reduction}) = \begin{cases} 800 + \left(50\ \ (88-85)\right) & 88 \geq F_{j=3} > 85 \\ 800 + \left(70\ \ (88-82)\right) & 85 \geq F_{j=3} > 82 \\ 1000 + \left(70\ \ (88-79)\right) & 82 \geq F_{j=3} > 79 \\ 1000 + \left(80\ \ (88-76)\right) & 79 \geq F_{j=3} > 76 \\ 1200 + \left(80\ \ (88-73)\right) & 76 \geq F_{j=3} > 73 \\ 1300 + \left(90\ \ (88-70)\right) & 73 \geq F_{j=3} > 70 \\ 1400 + \left(80\ \ (88-67)\right) & 70 \geq F_{j=3} > 67 \end{cases}$$

Standard Deviation Reduction for <u>Factory (F)</u>

$$(\text{Standard Deviation Reduction}) = \begin{cases} 800 + \left(40\ \ (18-15)\right) & 18 \geq F_{j=3} > 15 \\ 900 + \left(50\ \ (18-12)\right) & 15 \geq F_{j=3} > 12 \\ 1000 + \left(70\ \ (18-09)\right) & 12 \geq F_{j=3} > 09 \\ 1100 + \left(80\ \ (18-6)\right) & 09 \geq F_{j=3} > 06 \\ 1200 + \left(80\ \ (18-3)\right) & 06 \geq F_{j=3} > 03 \\ 1300 + \left(80\ \ (18-0)\right) & 03 \geq F_{j=3} > 00 \end{cases}$$

Mean Time Reduction for <u>Route (R)</u>

$$(\text{Mean Time Reduction}) = \begin{cases} 700 + \left(20\ \ (90-87)\right) & 90 \geq R_{j=4} > 87 \\ 800 + \left(30\ \ (90-84)\right) & 87 \geq R_{j=4} > 84 \\ 1000 + \left(40\ \ (90-81)\right) & 84 \geq R_{j=4} > 81 \\ 1100 + \left(50\ \ (90-78)\right) & 81 \geq R_{j=4} > 78 \\ 1200 + \left(60\ \ (90-75)\right) & 78 \geq R_{j=4} > 75 \\ 1300 + \left(70\ \ (90-72)\right) & 75 \geq R_{j=4} > 72 \\ 1400 + \left(80\ \ (90-69)\right) & 72 \geq R_{j=4} > 69 \end{cases}$$

Standard Deviation Reduction for <u>Route (R)</u>

$$(\text{Standard Deviation Reduction}) = \begin{cases} 600 + \left(30\ \ (22-19)\right) & 22 \geq R_{j=4} > 19 \\ 700 + \left(40\ \ (22-16)\right) & 19 \geq R_{j=4} > 16 \\ 800 + \left(50\ \ (22-13)\right) & 16 \geq R_{j=4} > 13 \\ 900 + \left(60\ \ (22-10)\right) & 13 \geq R_{j=4} > 10 \\ 1000 + \left(70\ \ (22-7)\right) & 10 \geq R_{j=4} > 07 \\ 1100 + \left(80\ \ (22-4)\right) & 07 \geq R_{j=4} > 04 \end{cases}$$

Mean Time Reduction for <u>Distribution (DC)</u>

$$(\text{Mean Time Reduction}) = \begin{cases} 800 + \left(50\ \ (101-98)\right) & 101 \geq DC_{j=5} > 98 \\ 800 + \left(70\ \ (101-95)\right) & 98 \geq DC_{j=5} > 95 \\ 1000 + \left(70\ \ (101-92)\right) & 95 \geq DC_{j=5} > 92 \\ 1000 + \left(80\ \ (101-89)\right) & 92 \geq DC_{j=5} > 89 \\ 1200 + \left(80\ \ (101-86)\right) & 89 \geq DC_{j=5} > 86 \\ 1300 + \left(90\ \ (101-83)\right) & 86 \geq DC_{j=5} > 83 \\ 1400 + \left(90\ \ (101-80)\right) & 83 \geq DC_{j=5} > 80 \end{cases}$$

Standard Deviation Reduction for Distribution (DC)

$$(\text{Standard Deviation Reduction}) = \begin{cases} 800 + \left(40 \quad (24-21)\right) & 24 \geq DC_{j=5} > 21 \\ 900 + \left(50 \quad (24-18)\right) & 21 \geq DC_{j=5} > 18 \\ 1000 + \left(70 \quad (24-15)\right) & 18 \geq DC_{j=5} > 15 \\ 1100 + \left(80 \quad (24-12)\right) & 15 \geq DC_{j=5} > 12 \\ 1200 + \left(90 \quad (24-09)\right) & 12 \geq DC_{j=5} > 09 \\ 1300 + \left(100 \quad (24-06)\right) & 09 \geq DC_{j=5} > 06 \\ 1400 + \left(110 \quad (24-03)\right) & 06 \geq DC_{j=5} > 03 \end{cases}$$

Mean Time Reduction for Route (R)

$$(\text{Mean Time Reduction}) = \begin{cases} 700 + \left(20 \quad (80-77)\right) & 80 \geq R_{j=6} > 77 \\ 800 + \left(30 \quad (80-74)\right) & 77 \geq R_{j=6} > 74 \\ 1000 + \left(40 \quad (80-71)\right) & 74 \geq R_{j=6} > 71 \\ 1100 + \left(50 \quad (80-68)\right) & 71 \geq R_{j=6} > 68 \\ 1200 + \left(60 \quad (80-65)\right) & 68 \geq R_{j=6} > 65 \\ 1300 + \left(70 \quad (80-59)\right) & 65 \geq R_{j=6} > 62 \\ 1400 + \left(80 \quad (80-56)\right) & 62 \geq R_{j=6} > 59 \end{cases}$$

Standard Deviation Reduction for Route (R)

$$(\text{Standard Deviation Reduction}) = \begin{cases} 700 + \left(30 \quad (20-17)\right) & 20 \geq R_{j=6} > 17 \\ 800 + \left(40 \quad (20-14)\right) & 17 \geq R_{j=6} > 14 \\ 900 + \left(50 \quad (20-11)\right) & 14 \geq R_{j=6} > 11 \\ 1000 + \left(60 \quad (20-08)\right) & 11 \geq R_{j=6} > 08 \\ 1100 + \left(70 \quad (20-5)\right) & 08 \geq R_{j=6} > 05 \\ 1300 + \left(80 \quad (20-2)\right) & 05 \geq R_{j=6} > 02 \\ 2000 + \left(90 \quad (20-0)\right) & 02 \geq R_{j=6} > 00 \end{cases}$$

Mean Time Reduction for Customer (V)

$$(\text{Mean Time Reduction}) = \begin{cases} 800 + \left(50 \quad (77-74)\right) & 77 \geq V_{j=7} > 74 \\ 800 + \left(70 \quad (77-71)\right) & 74 \geq V_{j=7} > 71 \\ 1000 + \left(70 \quad (77-68)\right) & 71 \geq V_{j=7} > 68 \\ 1000 + \left(80 \quad (77-65)\right) & 68 \geq V_{j=7} > 65 \\ 1200 + \left(80 \quad (77-62)\right) & 65 \geq V_{j=7} > 62 \\ 1300 + \left(90 \quad (77-59)\right) & 62 \geq V_{j=7} > 59 \\ 1400 + \left(90 \quad (77-56)\right) & 59 \geq V_{j=7} > 56 \end{cases}$$

Standard Deviation Reduction for Customer (V)

$$(\text{Standard Deviation Reduction}) = \begin{cases} 1000 + \left(40 \quad (14-11)\right) & 14 \geq V_{j=7} > 11 \\ 1100 + \left(50 \quad (14-08)\right) & 11 \geq V_{j=7} > 08 \\ 1200 + \left(70 \quad (14-5)\right) & 08 \geq V_{j=7} > 05 \\ 1300 + \left(80 \quad (14-2)\right) & 05 \geq V_{j=7} > 02 \\ 1500 + \left(100 \quad (14-0)\right) & 02 \geq V_{j=7} > 00 \end{cases}$$