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# Design of Supply Chain Network to Reduce Impacts of Damages during Shipping

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**Abstract**
Recently, the expand of industrial market has led to have long supply chain network. During the long shipment, the probability of having damaged products is likely to occur. The probability of having damaged products is different between stages and that could lead to higher percentage of damaged products when arrived at retailers. Many companies have rejected the entire shipment because the damaged product percentage was higher than that agreed on. Decision-makers have tried to reduce the percentage of damaged products that happened because the transit, loading unloading the shipment, and natural disasters. Companies started to implement recovery centers in the supply chain network in order to return their system steady statues. Recovery models have been developed in this paper to reduce the damaged percentage at minimum costs to do so. Results show that the possibility of implementing an inspection unit and a recovery centers in the system before sending the entire shipment to the retailer based on examining a sample size that has been selected randomly from the shipment and the minimum cost of committing type I and type II errors. Designing a methodology to minimize the total cost associated with the supply chain system when there is a possibility of damage occurring during shipping is the objective of this research.

**Keywords**
supply chain network, damage recovery scenarios, closed loop supply chain, type I and type II errors.

## Introduction

Because of supply chains network complexity, the need for preventing flaws during transportation has increased. Products might be damaged when on transit because of deficient packaging. The type of shipping and method of packaging influence the kind and extent of damage. Adequate packaging is vital because it makes sure that consumers purchase a product with low risks or without damage. Some of the frequent transportation hazards include handling, accidents, vibrations, and shocks. Damage arising from handling problems and accidents are not entirely within packaging controls. Nevertheless, during transportation and handling, shocks take place such as when transporting goods using trucks, poor roads might cause shocks. Disruptions in the supply chain (SC) are costly. Hence, the need for appropriate measures to reduce the adverse impacts on the SC system has to be considered to have a smooth system performance. Appropriate strategies, which assist in quick recovery of the SC system after disruptions in order to reduce high costs, should be used.

Damages and disruptions may take place in all SC phases. It means that a disruption can occur while shipping when abnormal delays are experienced at the ports or when producing goods in the factories. However, each phase experiences a varying kind of damage and disruption. The outcome is that the number of products, which are damaged during each phase, is also dissimilar. Hence, the result during the last phase depends on the damage, which took place in the previous stages. While on transit, damage accrued can be grouped into three categories, which comprise severe, repairable, and minor. In the severe damage group,

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the damage is so bad that there is no need to consider repair as a choice and the goods are damaged physically. The product can only be recovered as components, which can be used again for other uses; hence, saving some expenses. Under the repairable damage category, the functional ability of the product is affected by the physical damage even though it can be refurbished. In the minor damage stage, there is physical damage to the goods without any functionality loss.

The necessary recovery level needed to salvage the damaged goods is determined by damage level. Depending on the kind of damage, products can be retrieved in a forward SC using various means. For instance, if the product is damaged in a way that its functionality is not affected, it can be shipped back for repairs or it can be supplied along with the dents and scratches.

## Literature review

### Challenges in supply chain design

The design of SCs is plagued by inadequate tools and techniques (Melnyk, Narasimhan, and DeCampos, 2013; Melnyk et al., 2009). Optimization of supply chain network (SCN) configuration is made intricate by the notion that they are typically linkages and at times worldwide networks. As it is acknowledged, even the strategic capacity planning and location for a facility are made up of numerous complicated solutions, which need a hierarchical method to manage them in a reasonable way. The designing of a SCN requires the assistance of mathematical models. Nevertheless, prior to coming up with and formulating and solving the model, many verdicts have to be made. These decisions concern reverse logistics modalities, type of distribution network, production jobs and their circulation, and the goods as well as their modularity. Consequently, undertaking all of these actions require a technique, which if it were to be explained, there is a need for additional work and efforts. we show a review of supply chain network design SCND in the literature under arbitrary disruption risks (Altner et al., 2010; Church et al., 2004; Scaparra and Church, 2008; Church and Scaparra, 2007; Liberatore et al., 2012). The goal is to design a SCN that works proficiently with the most minimal conceivable cost, at usual and with the same disruption conditions. The Start of SCND, which is considered to be under random disturbance risks, is connected to the reliability theory in designing a network that is about maximizing the probability that a link remains associated after random disruptions (Colbourn, 1987; Shier, 1991; Shooman, 2002). The basic role in defining reliable systems is regularly to expand the interest scope.

### Supply chain network design disruption

SCN disturbance has been characterized and tended to in numerous studies and creators have taken different planned on investigating and characterizing those disruption. Some authors have characterized the SCN disturbance conceptual and others have characterized the disturbance behaviors. Likewise, other researchers have characterized and portrayed the disruption types (qualitative). In the table below (Table 1) the definitions are listed.

Table 1
SCN disruption definitions

| Authors | SCN disruption definition |
|---|---|
| Jüttner et al. (2003) | The disruption (vulnerability) "the propensity of risk sources and risk drivers to outweigh risk mitigating strategies, thus causing adverse SC consequences" |
| Christopher and Peck (2004) | Disruption as an exposition to genuine unsettling influence |
| Craighead et al. (2007) | According to this author disruption as unplanned and unexpected occasions that disturb the ordinary stream of products and the raw materials inside a SCN. |
| Kovács and Tatham (2009) | Disruption characterized as substantial scale unpredicted occasions and a sort of SC risks, not quite the same as operational vulnerabilities. |
| Ellis et al. (2010) | Disruption as unanticipated occasions, which meddle with all typical stream of merchandise or/and the major resources inside an inventory network |
| Wagner and Neshat (2010) | Disruption as an important activator, leads to the occurrence of risk. |
| Zhao et al. (2011) | Disruption influences all typical processes and they either are unplanned or planned. |
| Tang (2006) | Disruption not officially characterized but rather just alluded to as a main consideration that is considered to have long term negative impacts on a company's financial performance |

Snyder and Daskin (2005) examined SCND, which was done under random disruption, founded on traditional facility site issues, in which a distribution center (DC) may fail (as a result of a disturbance event) with a defined probability. They assumed that in a situation where a DC falls, it can no longer give any item, and the clients assigned to it have to be reassigned to another DC, which is not disrupted. The goal was to reduce a measured total of ostensible expenses by disregarding disturbances furthermore the normal expense of a disruption circumstance where the normal extra transportation expense was represented to disturbed DCs.

One essential streamlining suspicion of approach is that the entire DCs have disruption probabilities that are similar (Snyder and Daskin, 2005). Computing expected transportation cost without this presumption in a disruption circumstance turns out to be altogether complicated. Snyder and Daskin (2006) developed their works that consider disruption probabilities of dependent sits. They utilized the situation way to deal with plan the issue. Likewise, they presented the idea of stochastic p-robustness where the qualified misgiving is constantly not as much as p for any possible situation. As the situation approach lists the majority of the disturbance situations, the expansive and the large development of the issue volume through an expansion in the DCs quantity is one of its subjects. Moreover, Berman et al. (2007) projected the p-median problem whereby the target capacity aimed at decreasing the interest subjective charge of transportation. Additionally, they built up what they did in the past and expected that customers do not distinguish which DCs are disrupted and should venture out from a DC up to another approaching that they may discover a one that is not disrupted.

Likewise, reference Cui et al. (2010) suggested a plan for the issue with the site disruption probabilities. Not at all like the model proposed by Berman et al. (2007) that comprises of selected multifarious increased choice determinants, a main non-linear term, which is given to their selected model, is a product has decision variable of a single a product of a single continuous and a single discrete and continuum approximation (CA) were utilized to define the prototype and approach. Using the guess approach, customers are distributed consistently all through various geographical locations, and the major parameters are communicated as an element of the area. Supplanting unequivocal disturbance probabilities with probabilities relying upon locations permits the normal transportation charge or distance to be computed by not utilizing any evaluation method. Lagrangian relaxation was utilized to settle this simulation. Another study examined the SCND under random variability if having disruptions considering inventory control decisions by (Qi et al., 2010). It was accepted that if retailers are disturbed, any stocks available to the vendors are annihilated furthermore the unachieved requests of clients relegated to a trader are accumulated with a penalty cost. The subsequent simulation was an inward reduction issue as well as the Lagrangian relaxation model was executed to resolve the issue.

## Error types

### Type I error

Type I disruption also known as a false positive disruption occurs when there are faults in the inspection systems and thus incorrectly identifying a threat. Also, the analytical system may wrongly identify, for example, a food threat, which makes a harmless product from being excluded from the SCN (Nganje and Skilton, 2011).

### Type II error

Type II disruptions also known as a false negative usually takes place when a product with a defect is supplied to consumers and leads to injury that is huge enough to bring about market failure. The harm results from the inaccuracy of the inspection system to detect the threat and failure to give proper diagnostics. Therefore, the false negative leads to increased risks to the buyers (Nganje and Skilton, 2011).

## Recovery centers and return products

In the recent past of about a decade there has been much attention in the disruption of supply chain. A number of the disruptions such as tsunamis, quakes and tornados have shown a lower chance of occurrence as predicted by various researchers. The lower chances of the SC disruptions occurrences are characteristic of being disastrous and usually lead to more expenses. However, during the shipment loses maybe high from the resulting damages. Shear et al. (2002), asserts that the products worth $100 billion or more are returned annually. Together with Guide Jr. et al. (2006), Shear et al. (2002) explain the various reasons that lead to the return of the products. The common reasons include satisfaction from consumers, evaluation of products, damage caused during the shipment, damaged merchandise and the completion of lease period and life. The goods can be recovered through refurbishing, repair, reassembling, recycling and cannibalization (Thierry et al., 1995). Guide Jr. et al. (2006) and Shear et al. (2002) extensively explained the process remanufacturing the goods and making them in a perfect condition to give the new look. Further, the remanufacturing supply depends on the amount of available returned products. Since it may be difficult in forecasting quality, the amount, and the time for returned products there is usually an increased inaccuracy in line with the demanding risks related to the recovery methods. The various types used in the packaging while transporting the goods, for example paper-pulp trays, polystyrene-soft-cell trays, wood bins, corrugated fiberboard and bulk bins. As Singh and Xu (1993) explain using apples as an example, 80% of the fruits can be damaged when a truck is used in the shipment. The example emphasizes on the kind of packaging, the mode of transportation, and the arrangement of the packages as the major factors determining the amount of damage caused in the shipment.

### Analyze of damaged cost

While these SC disruptions happen with low probability, the outcomes are ordinarily deplorable and lead to high expenses. Azad and Davoudpour (2010) considered a facility with irregular disturbance issue to outline a reliable SCN. They concentrated on disruption in appropriation focuses by area and capacity, described the issue as a non-linear integer- programming model, and after that linearized it to have an optimal solution. They considered two unique calculations to comprehend random disruption risks for huge size cases: tabu search and simulated annealing algorithms. They found a better solution by utilizing the tabu search method. They considered the transportation costs between reliable/unreliable DCs in this model.

Aryanezhad et al. (2012) composed a SCN considering an unreliable suppliers and DC. They found that the number of items conveyed may reduce due to unreliable DC. Using a nonlinear integer program to reduce the total costs (Aryanezhad et al., 2012). They considered the expenses of area, transportation, stock, and lost contracts. They developed Lagrangian relaxation and a genetic algorithm in order to solve the issue. In their model, they decided the area of ideal DCs and the subset of customers to be served, doled out (assign) customers to DC, and decided the request amount. The authors assumed a DC will serve an infinite capacity of customers' orders. Darwish et al. (2014) combined the products' quality into two vendor-managed inventory models by considering a single-vendor multi-retailer in an SCN. The main model concentrated on building up a decentralized SC to enhance the seller's profit, and the second attentive to a centralized SC to improve the system benefit. Daehy et al. (2019) developed an optimization approach that recognizes the disrupted component that should be optimized in order to fulfill the entire supply chain system SCS reliability requirements with minimum possible cost while taking uncertainty into an account.

## Methodology

The objective of this research is to develop a methodology for designing the SC while minimizing the total costs associated with the SCS when there is a possibility of damages occurring during shipping. In this research, attention is focused on costs such as shipping cost, cost of rejection, and costs of Type I and Type II error during sampling. Type I error occurs when based on inspection of the sample – a good lot is rejected. Type II error occurs when a bad lot is accepted, based on the inspected sample. The shipping costs include the cost of shipping per mile, the packing cost, and sampling inspection cost. The cost of rejection is the total expenses of shipping the lot back from the rejection point.

### Statistical sampling test (Methodology 2.1)

Taking a sample from the entire package will help to decide whether to ship the entire package to the retailer or to send it back to the factory as a rejected shipment. Two different scenarios will be considered in making the final decision:

- The probability of rejecting the sample when the sample is defective, and the entire shipment is acceptable (i.e., type I error ($\alpha$)).
- The probability of accepting the shipment because the sample is within limits while shipment has more defects than acceptable limit (i.e., type II error ($\beta$)).

After calculating the probabilities of committing type I and II errors, the expected costs of type I and II errors at each stage in the SC will help to identify the ideal stage to locate the inspection point.

$d_{ij}$ traveling distance from node $i$ to node $j$
$C_{ij}$ traveling cost per mile from node $i$ to node $j$
$U_n$ quantity shipped for product $n$
$H$ the sample size
$Z_n$ disassembly cost for product $n$
$R_i$ repairing cost of damages at stage $i$ per unit
$T$ total repairing and repackaging costs of damages at stage $i$

| | |
|---|---|
| $P_{a,n}$ | packaging cost using type $a$ packaging for product $n$ |
| $S_{ij}$ | shipping cost from node $i$ to node $j$ |
| $M_n$ | cost of product $n$ |
| $h$ | the half width |
| $s$ | the standard deviation |
| $R_e$ | teordering cost |
| $X_{ijk}$ | the mean defective Percentage while shipping from node $i$ to node $j$ and $k$ |
| $\sigma_{ij}$ | the standard deviation of the mean defective percentages while shipping from node $i$ to $j$ |
| $Q_{ik}$ | shipping cost from inspection stage $i$ to recovery center $k$ |
| $\alpha$ | the probability of committing *type I error* |
| $\beta$ | the probability of committing *type II error* |
| $Y_i\%$ | the acceptance percentage at stage $i$ for the sample |
| $A_i\%$ | damage percentage at stage $i$ for the lot |
| $N$ | number of replications |
| $G$ | cost of goodwill |

### Research objective (Methodology 2.2)

The objective of this research is to develop a methodology for the design of SCS, that minimizes the total costs associated with the SCS when there is a possibility of damages to occur during shipping.

### Key research objectives (Methodology 2.3)

- Design the SC to minimize cost when considering sampling tests for acceptance or rejection of a lot.
- The cost of type I and type II errors will be used in the design of the SC.
- Identifying the optimal location for implementing inspection centers in the SC.

Minimize objective function:

- Min cost = Expected cost of type 1 Error + Expected cost of type II error.

$$\text{Min Cost} = EC_\alpha + EC_\beta\,. \tag{1}$$

- Expected Cost of type I error = Probability of making a type I error ∗ (the cost of inspection + the total packaging cost + the shipping costs from inspection to recovery and back from recovery to inspection stage).

$$EC_\alpha = \alpha\% * (C_I + C_P + (Q_{ik} * 2)). \tag{2}$$

- Expected Cost of type II error = Probability of making a type II error ∗ (the shipping cost from retailer back to factory + the reorder cost + the cost of goodwill)

$$EC_\beta = \beta\% * (S_{ij} + R_e + G). \tag{3}$$

### Mathematical processes and equations (Methodology 2.4)

In order to determine the costs involved in the design of the SC, the total cost of shipping and packaging will be calculated first. The number of products that arrive at final stage in good condition will be also calculated. Recovery models will be used to implement a recovery center between stages to minimize the percentage of the damaged products, in order to ensure the rejection limit is within the acceptance range. The cost associated with the damaged units as well as the entire shipping costs.

### Calculation of number of replications (Methodology 2.5)

The number of replications necessary for any given system simulation is calculated using the equation below (Toledo et al., 2003).

$$N = t^2_{((\alpha/2),\,H-1)}\, s^2/h^2, \tag{4}$$

where $N$ is the number of replication, and $s$ is the standard deviation. While $h$ is the half width of the observed value, and $t^2_{((\alpha/2),\,H-1)}$ is the t-distribution value at $n-1$ degree of freedom.

### Calculate the Type I and Type II error percentages (Methodology 2.6)

The simulation is run for the appropriate number of replications. The results of the simulation will be used to calculate $\alpha\%$ and $\beta\%$, two condition will be applied to get the type I and II errors percentages:

- Type 1 error occurs when:

$$D\% > Yi\% \quad \text{and} \quad Yi\% \le A.$$

- Type 2 error errors occurs when:

$$D\% \le Yi\% \quad \text{and} \quad Yi\% > A,$$

where $D\%$ is the defective percent in the sample and $Yi\%$ is the acceptance percentage at stage $i$, and $A$ is the total defective percentage in the shipment lot. After determining the $\alpha\%$ and $\beta\%$ for each stage, the expected costs of $\alpha\%$ and $\beta\%$ at each stage in the SC is calculated. The model will run for $N$ times which is the number of replications and using the conditions mentioned above the type I and II errors percentages will be observed. The identification of the need for additional inspection along the SC and its location will be based on identifying the SC stage that minimizes the cost of the system.

**Calculate the overall shipping costs (Methodology 2.7)**

- The cost of packaging

$$C_P = (U_n * P_a). \tag{5}$$

The packaging cost is equal to the number of units in the lot multiply by the cost of packing per unit.

- The cost of sample inspection

$$C_{IH} = (H * I_i). \tag{6}$$

The sample inspection cost is the cost of inspecting per unit multiply by the number of unit in the sample size.

- The cost of shipping between stages

$$S_{ij} = U_n \left( \sum_{i}^{j} d_{ij} * C_{ij} \right). \tag{7}$$

The shipping cost is the number of units in the lot multiply with the summation of the traveling distance into the cost per mile.

- Shipping cost from Inspection to Recovery

$$Q_{ik} = (U_n) \left( \sum_{i}^{k} d_{ij} * C_{ik} \right). \tag{8}$$

The shipping cost is the number of units in the lot multiply with the summation of the traveling distance from inspection stage to the recovery unit multiply with the shipping cost per mile.

- Inspection cost

$$C_I = U_n * I_i\,. \tag{9}$$

The total inspection cost is the cost of inspecting per unit multiply with the number of unit in the lot.

- Repairing cost and for damaged products

$$T = (D\% * U_n)(R_i). \tag{10}$$

The total repairing and repackaging costs is the defective percentage multiply with the number of units in the lot. Then multiply the results with the repairing cost per unit and the packaging cost per unit.

**Damage recovery scenarios (Methodology 2.8)**

After making the statistical sampling test, the decision makers will have to determine and select the optimal solution in order to minimize the overall cost. Each one of the three different decisions has costs must be calculated.

Table 2
Different damage recovery scenarios

| | |
|---|---|
| First Scenario | If the damage percentage exceeds the acceptance limit for the retailer, send the lot back to the factory as shown in Fig. 1. |
| Second Scenario | If the damage percentage exceeds the rejection limit and the decision is to send the lot to a recovery center see Fig. 1. |
| Third Scenario | If the damage percentage does not exceed the rejection limit, send the lot to the retailer as shown in Fig. 1. |

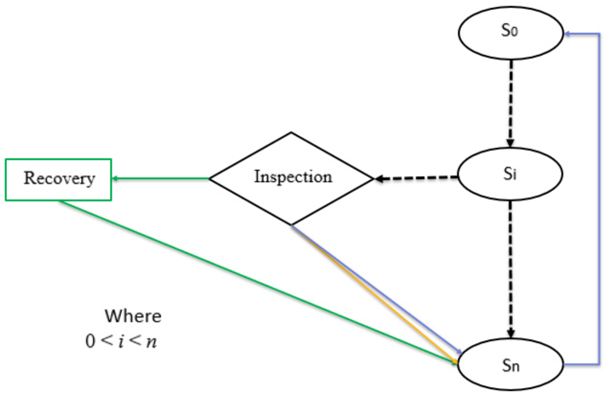


Fig. 1. Different damage recovery scenarios

## Case study and results

In this case study, the lot size that is shipped is 1,000 units. The SC network consists of 6 stages and the probability of having damaged products at each stage was determined from historically available data. The rejection level is set at 10% at the final stage. The sample size for testing at any stage in the SC is 50 units. If the defective units of the selected sample exceed the rejection level, a recovery center will be implemented between stages based on the total costs of rejection of the entire shipment. The parameters of the case study are provided in Table 3. For this case study, it is assumed that the costs per unit distance are varied for each legs of the SC. The mean of the percent defective at the end of each leg of the SC is 5%, 9%, 12% and 14% – i.e., at stage 1, 2, 3, and 4 based on historical data. The standard deviations of these values are 2%, 2.5%, 1%, and 1%.

Table 3
Input data for the case study

| Parameters | Values | Parameters | Values |
|---|---|---|---|
| $C_{f,1}$ (\$) | 0.05 | $Y_1$ | 0.05 |
| $C_{1,2}$ (\$) | 0.03 | $Y_2$ | 0.09 |
| $C_{2,3}$ (\$) | 0.01 | $Y_3$ | 0.12 |
| $C_{3,4}$ (\$) | 0.03 | $Y_4$ | 0.14 |
| $C_{4,R}$ (\$) | 0.02 | $X_{f,1}$ (%) | 5 |
| $C_{i,k}$ (\$) | 0.01 | $X_{1,2}$ (%) | 4 |
| $\sigma_{f,1}$ (%) | 2 | $X_{2,3}$ (%) | 3 |
| $\sigma_{1,2}$ (%) | 2.5 | $X_{3,4}$ (%) | 2 |
| $\sigma_{2,3}$ (%) | 1 | $X_{4,R}$ (%) | 1 |
| $\sigma_{3,4}$ (%) | 1 | Pa | 8 |
| $\sigma_{4,R}$ (%) | 0.5 | $H$ | 50 |
| $I_1$ (\$) | 5 | $M$ (\$) | 40 |
| $I_2$ (\$) | 8 | $G$ (\$) | 10,000 |
| $I_3$ (\$) | 12 | Re | 20 |
| $I_4$ (\$) | 15 | Confidence level | 95% |


Fig. 2. SCN for the case study

The steps that were followed to obtain all the possible scenarios' costs are listed below.

**Step 1:** Calculating the number of replication for the system. The number of replications was calculated using Eq. (5) (Toledo et al., 2003).

**Step 2:** Calculate the type I and II percentage.

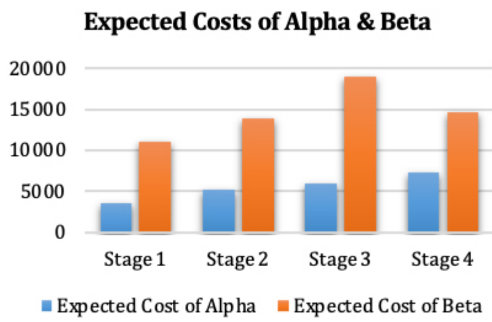


Fig. 3. Type I error and type II error

The simulation was replicated 200 times to calculate the type I and II error percentages at each stage in the supply chain system. For each replication a random sample is taken from the lot. Based on the inspection data for the random sample in each replication, a decision to accept or reject the lot is made. By examining the entire lot, it can be determined if a type I or type II error has been made. The results of the experiment for this case study is shown in Table 4. For example, after Stage 1, the average type I error percentage was found to be 30%, while the average type II error percentage was 20%.

Table 4
Type I and type II error percentages

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
|---|---|---|---|---|
| ($\alpha$ %) | 27.5 | 33 | 20 | 31.5 |
| ($\beta$ %) | 15.5 | 19.5 | 26.5 | 20.5 |

**Step 3:** Calculate the expected costs of type I and II errors.

The expected costs of type I and II errors at each stage are calculated and the results are shown in Fig. 4.

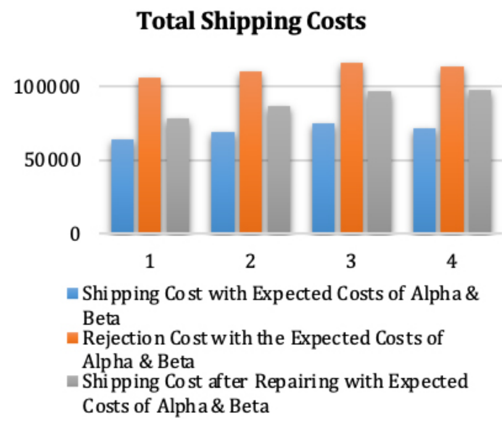


Fig. 4. Total shipping costs

It can be seen that the minimum expected costs of type I and II errors is when making inspection at stage 1. However, to validate this point, calculate the total shipping costs adding to them the expected costs of type I and type II errors of all the three possible scenarios at all stages.

After calculating the all possible scenarios' costs which are sending the lot to retailer, sending the lot to inspection and recovery center, and the cost of rejection at retailer stage, the costs showed that the rejection cost would be costly if the shipment was rejected at retailer stage as shown in Fig. 5. The blue bars represent the total costs of shipping plus the expected costs of type I and II errors from the factory to the retailer stage when the rejection limit is not exceeded at all stages, and the results were calculated. While the gray bars represent the total cost of shipping after repairing plus the expected costs of type I and II errors when the rejection limit is exceeded and that were obtained and the orange bars represent the cost of rejection with the expected costs of type I and II errors at retailer stage when the rejection limit is exceeded, and that were obtained.

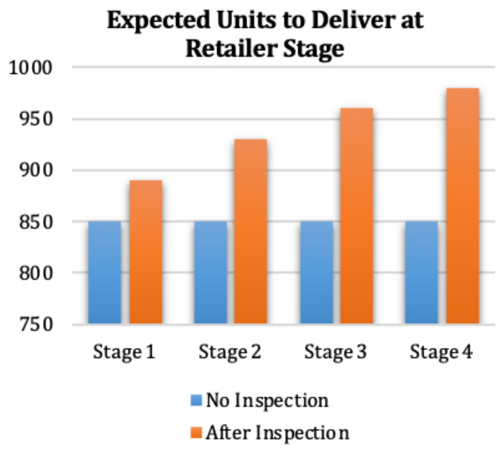


Fig. 5. Expected number of units in good condition

The expected number of units that arrive in good condition at the retailer stage based on the probability of number of damaged units is presented in the diagram was calculated and drew in Fig. 6. If the SCS does not conduct an inspection, the expected number of units that arrive in good condition at the retailer stage (R) is 850. If inspection is carried out at Stage 1, Stage 2, Stage 3, or Stage 4 the expected number of units that arrive in good condition at the retailer stage (R) is 890, 930, 960, or 980 units respectively.

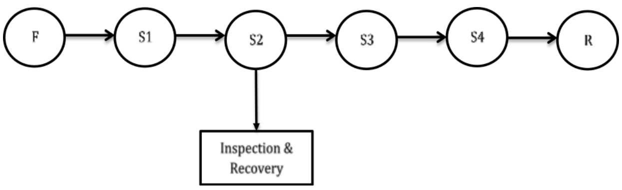


Fig. 6. Recommended SCN design

As a result, implementing the inspection and recovery center at stage 2 would ensure having the minimum expected cost of type I and II errors and the rejection limit will not be exceeded. The final design of the SCN for the given case study is below. Even thought, the minimum expected cost of type I and II errors was at stage 1, the expected number of good units to be arrived at retailer stage after making the inspection and recovery unit at stage 1 would not be within the acceptance limit. Since the shipping cost and the distance between S1 and S2 were not high, and the probability of having damage were high, making the inspection and recovery unit at stage 2 would ensure delivering most of the products to retailer stage in good condition.

## Discussion

Alsobhi et al. (2017) developed different models to reduce the defective products and to maximize the profit in the SCN. One of the limitations that they had in the design of the SCN was that they assumed a 100% inspection, of all units. This could be expensive and not often used in practice. This could also lead to increased the lead time in the SC. It could also lead to increased inspection costs and packaging costs.

In this research, statistical sampling tests are used to determine the probability of units damaged during each stage of shipping. The results showed that calculating the expected costs of type I and type II errors in order to determine where the optimal location to implement the inspection center and recovery unit were beneficial. The decision has been made on the location that would ensure having the minimum costs of committing type I and type II errors and would ensure delivering the shipment without exceeding the acceptance limit. So, the recovery unit will ensure a higher yield in the SCS and lead to better customer satisfaction.

## Conclusions

This paper is concerned about designing a methodology to help in designing an efficient SCN in order to ensure delivering the highest amount of products to customers. Since the probability of having damages between stages are different, inspection units were implemented in various places in SC to inspect for the percentages of damages in the shipment. Using sampling statistical test at different stages with respect to the probability of committing type I and type II errors when making final decisions was applied in this work. The results show that there is a possibility of implementing recovery units at various stages to repair the defective products then shipping them to the final destination. Thus, the SC decision makers can reduce the chances of having return products. The shipping cost per mile plays role in determining the optimal location to implement the inspection and recovery center. Also, the sample size can increase or decrease the probability of committing type I and type II errors in the system.

## References


Alsobhi, S.A., Krishnan, K.K., Dhuttargaon, M., and Gupta, D. (2017). *Design of Supply Chain Damage Recovery Systems*. Journal of Supply Chain and Operations Management, 15, 1, 79–100.

Altner, D.S., Ergun, Ö., and Uhan, N.A. (2010). *The maximum flow network interdiction problem: Valid inequalities, integrality gaps, and approximability*. Operations Research Letters, 38, 1, 33–38, doi: 10.1016/j.orl.2009.09.013.

Aryanezhad, M.B., Naini, S.G.J., and Jabbarzadeh, A. (2012). *An integrated model for designing supply chain network under demand and supply uncertainty*, African Journal of Business Mmanagement, 6, 7, 2678.

Azad, N., and Davoudpour, H. (2010). *A two-echelon location-routing model with considering value-at-risk measure*. International Journal of Management Science and Engineering Management, 5, 3, 235–240.

Berman, O., Krass, D., and Menezes, M.B.C. (2007). *Operations research: INFORMS*. Operations Research, doi: 10.1287/opre.1060.0348.

Christopher, M., and Peck, H. (2004). *Building the resilient supply chain*. The International Journal of Logistics Management, 15, 2, 1–14, doi: 10.1108/09574090410700275.

Church, R.L. and Scaparra, M.P. (2007). *Protecting critical assets: The r-interdiction median problem with Fortification*. Geographical Analysis, 39, 2, 129–146, doi: 10.1111/j.1538-4632.2007.00698.x.

Church, R.L., Scaparra, M.P., and Middleton, R.S. (2004). *Identifying critical infrastructure: The median and covering facility interdiction problems*. Annals of the Association of American Geographers, 94, 3, 491–502, doi: 10.1111/j.1467-8306.2004.00410.x.

Colbourn, C. (1987). *The combinatorics of network reliability*. New York: Oxford University Press.

Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J., and Handfield, R.B. (2007). *The severity of supply chain disruptions: Design characteristics and mitigation capabilities*. Decision Sciences, 38, 1, 131–156. doi: 10.1111/j.1540-5915.2007.00151.x.

Cui, T., Ouyang, Y., and Shen, Z.-J.M. (2010). *Reliable facility location design under the risk of disruptions*. Operations Research, 58 (4-part-1), 998–1011. doi: 10.1287/opre.1090.0801.

Daehy, Y., Krishnan, K., Alsaadi, A., and Alghamdi, S. (2019). *Effective cost minimization strategy and an optimization model of a reliable global supply chain system*. Uncertain Supply Chain Management, 7, 3, 381–398.

Darwish, M.A., Odah, O.M., and Goyal, S.K. (2014). *Vendor managed inventory models for single-vendor multi-retailer supply chains with quality consideration*. International Journal of Industrial and Systems Engineering, 18, 4, 499–528.

Ellis, S.C., Henry, R.M., and Shockley, J. (2010). *Buyer perceptions of supply disruption risk: A behavioral view and empirical assessment*. Journal of Operations Management, 28, 1, 34–46, doi: 10.1016/j.jom.2009.07.002.

Guide, V.D.R., Jayaraman, V., Srivastava, R., and Benton, W.C. (2000). *Supply-chain management for recoverable manufacturing systems*. Interfaces, 30, 3, 125–142, doi: 10.1287/inte.30.3.125.11656.

Jüttner, U., Peck, H., and Christopher, M. (2003). *Supply chain risk management: outlining an agenda for future research*. International Journal Of Logistics: Research and Applications, 6, 4, 197.

Kovács, G. and Tatham, P. (2009). *Responding to disruptions in the supply network-from dormant to action*. Journal of Business Logistics, 30, 2, 215–229, doi: 10.1002/j.2158-1592.2009.tb00121.x.

Liberatore, F., Scaparra, M.P., and Daskin, M.S. (2012). *Hedging against disruptions with ripple effects in location analysis*. Omega, 40, 1, 21–30.

Melnyk, S.A., Narasimhan, R., and DeCampos, H.A. (2013). *Supply chain design: Issues, challenges, frameworks and solutions*. International Journal of Production Research, 52, 7, 1887–1896, doi: 10.1080/00207543.2013.787175.

Melnyk, S.A., Lummus, R.R., Vokurka, R.J., Burns, L.J., and Sandor, J. (2009). *Mapping the future of supply chain management: A Delphi study*. International Journal of Production Research, 47, 16, 4629–4653, doi: 10.1080/00207540802014700.

Nganje, W.E. and Skilton, P. (2011). *Food risks and type I & II errors*. International Food and Agribusiness Management Review, 14, 5, 109–124, https://www-ifama.org.proxy.wichita.edu/publications/journal/IFAMRArchive.aspx.

Qi, L., Shen, Z.-J., and Snyder, L.V. (2010). *The effect of supply disruptions on supply chain design decisions*. Transportation Science, 44, 2, 274–289, doi: 10.1287/trsc.1100.0320.

Shear, H., Speh, T., and Stock, J. (2002). *Many happy (product) returns*. Harvard Business Review, 80, 7, 16–17.

Shier, D.R. (1991). *Network reliability and algebraic structures*. Clarendon Press.

Shooman, M.L. (2002). *Reliability of computer systems and networks: fault tolerance, analysis, and design*. John Wiley & Sons.

Singh, S. and Xu, M. (1993). *Bruising in apples as a function of truck vibration and packaging*. Applied Engineering in Agriculture, 9, 5, 455–460.

Snyder, L.V. and Daskin, M.S. (2005). *Reliability models for facility location: the expected failure cost case*. Transportation Science, 39, 3, 400–416.

Snyder, L.V., and Daskin, M.S. (2006). *Stochastic p-robust location problems*. Iie Transactions, 38, 11, 971–985.

Tang, C.S. (2006). *Perspectives in supply chain risk management*. International Journal of Production Economics, 103, 2, 451–488.

Thierry, M., Salomon, M., Van Nunen, J., and Van Wassenhove, L. (1995). *Strategie issues in product recovery management*. California Management Review, 37, 2, 114–135.

Toledo, T., Koutsopoulos, H.N., Davol, A., Ben-Akiva, M.E., Burghout, W., Andréasson, I., ... and Lundin, C. (2003). *Calibration and validation of microscopic traffic simulation tools: Stockholm case study*. Transportation Research Record, 1831, 1, 65–75.

Wagner, S.M. and Neshat, N. (2010). *Assessing the vulnerability of supply chains using graph theory*. International Journal of Production Economics, 126, 1, 121–129, doi: 10.1016/j.ijpe.2009.10.007.

Zhao, K., Kumar, A., Harrison, T.P., and Yen, J. (2011). *Analyzing the resilience of complex supply network Topologies against random and targeted disruptions*. IEEE Systems Journal, 5, 1, 28–39, doi: 10.1109/jsyst.2010.2100192.