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Cost & Risk Tradeoff Based Model Proposal for Mitigating the Risks of Transport Networks

Oğuzhan KIRILMAZ
Gazi University
Department of Industrial Engineering
Ankara, Turkey
okirilmaz@yahoo.com

Serpil EROL
Gazi University
Department of Industrial Engineering
Ankara, Turkey
serpiler@gazi.edu.tr

***Abstract*—Reduction of costs and enhancement of customer satisfaction are two main conflicting objectives of the firms in today's competitive market. Running of the supply chain without disruption has enormous effect on these two objectives and necessitates supply chain risk management. Transport networks are a very important part of the supply chains that connect the actors and are risk sources that must be analyzed elaborately. In this study, the risk management process is examined and a procedure is proposed that reduces the risk profile of the transport network. In the first phase of the procedure, the risk profile of each transportation route is identified via the risk management process and the minimum cost transportation plan is obtained via a linear programming model. In the second phase, a reduction in the transport network risk profile is investigated at the expense of a cost increase, amount of which is determined by the decision maker. The proposed procedure enables proactive planning in order to reduce the severity of a risky event. The procedure also contributes to the decision making process by offering decision alternatives that provide tradeoff between cost and risk.**

Keywords—Cost & Risk Tradeoff, Risk Management Process, Risk Mitigation, Transport Networks

I. INTRODUCTION

Supply chain management is amongst the main administrative functions of management and has a paramount effect on enhancing the customer service level and increasing the profit. In our competitive trade circumstance, companies that make use of this function and manage the supply chain (SC) effectively gain advantage over others. On the other hand, SCs which are not flexible, inefficient and unprepared for the risks cause great harm to the companies or lead to bankruptcy.

Popular trends of our age such as lean manufacturing, JIT production, improving optimization techniques, shortening of product life, and extending transport networks while shortening lead times all expose SCs to more risks. The very dramatic example of this is the 9/11 terrorist attacks in USA. Many firms' SCs were severely affected by this incident and productions were disrupted for long times. The tsunami in Indonesia in 2004, Haiti earthquake in 2010, as well as the earthquake and tsunami in Japan in 2011 show that companies must give importance to supply chain risk management (SCRM) in order to survive.

Financial effects of unprecedented and unforeseen events are perceived in all actors of SC. Research in North America suggests that when companies experience disruptions to their supply chains, the impact on their share price can be significant once the problem becomes public knowledge. The research suggests that companies experiencing these sorts of problems saw their average operating income drop 107%, return on sales fall 114% and return on assets decrease by 93%. In 2003 the Gartner Group, a US-based research and consultancy company, predicted that one in five businesses would be impacted by some form of supply chain disruption and that, of those companies, 60% would go out of business as a result [1].

Distribution is associated with the transportation of a product or service to the upstream and/or downstream. The last element of SC is the customer and the main aim of all SC partners should be to make the product/service ready at the right place, in the right time and with the right quantity for the customer. Transportation modes such as road, water, rail, air and pipelines link the actors of a SC and hence are a very important component of it. Therefore, a disruption in any route will presumably affect the following echelons. For example, on 27 October 2004 the 66.433-tonne container ship was sailing from Valletta, Malta to Felixstowe, UK, when it ran into storm force 11 weather off Brittany. The ship rolled by 30^0 as it moved through 30-meter seas and winds of 65 knots. When it reached the container port of Felixstowe, it was clear that 31 full 40-foot containers had been lost overboard and another 29 had been severely damaged. Each year an estimated 10.000 containers are lost over the side of container ships, generally the result of high seas, improper stowage, fire or even pirates. The cost of these losses runs into billions of dollars [2].

In this study, a unique decision support procedure is proposed as a risk mitigation technique. In the first step of this procedure, which enables proactive planning to construct a robust supply chain, a risk management process is performed and risk profiles of all routes are identified. The effect of risk is usually identified in terms of finance in literature. However, in the proposed system, it can also be identified as performance loss, physical loss, social loss and time loss. In the second step, the transportation plan with minimum cost is obtained via a linear programming model and a transport network risk profile is identified regarding this initial plan. Finally, cost and risk tradeoff decision points are identified via a mixed integer programming model. By the help of this decision support system, the decision maker (DM) has the opportunity to decrease the network risk profile at the expense of cost increase. Thus, the probability of disruption and the level of risk impact can be reduced by this procedure. Finally, the model is tested with hypothetical data sets that are randomly generated in computer.

In the second part of the study, methodology of the procedure is explained regarding the five step SCRM process. In the third part, the numerical application of the procedure is performed and conclusions and suggestions are presented in the fourth part of the study.

II. METHODOLOGY

SCRM is the management of SC risks through coordination or collaboration among the SC partners so as to ensure profitability and continuity [3]. SC managers should consider every element of the SC while planning and executing SCRM. Since every unit in a SC (supplier, manufacturer, warehouse, retailer, customer, etc.) wants to achieve their own goals individually, the goal of one may increase the risk of another. Hence, SC managers should see and evaluate the whole picture and navigate every unit to the same direction in terms of risk management.

The risk management process generally consists of three steps; risk identification, risk evaluation, and risk mitigation [3-5]. The risk monitoring and control phase has also been included into the process in recent studies. Some academics also categorize SCRM process in 5 steps by separating the evaluation phase into two parts: risk measurement and evaluation. In this study, the SCRM process we examine contains 5 steps (Figure-1).

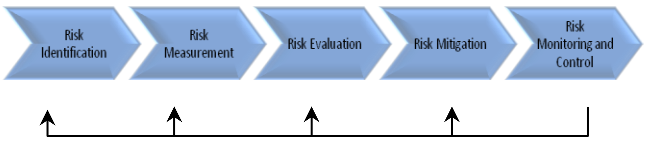

Figure-1: SCRM Process

Risk Identification

Risk identification is the first and the most important phase of the SCRM process because the remaining phases depend on the risks identified in this step. Since firms may have contingency plans for the identified risks, the main threat to a firm is not the risks that it is aware of, but those it is unaware of. Therefore, the risk identification phase should be performed meticulously. Kern et al. have suggested and proven in their study that supply chain risk identification activities have a positive impact on SC risk assessment [6].

Although all categorizations contain the same risks, supply chain risks are categorized differently by academics according to their sources and impacts. Mason-Jones and Towill (1998) categorizes them as internal risks, risks within the SC, or risks in the external environment [7]. Internal risks arise from operations within a company. SC risks are external to the company and originate from other SC partners such as suppliers, customers, etc. External risks are external to the SC and originate from the environment such as natural disasters, accidents, legislation, etc. Waters, D. (2011) categorizes SC risks as physical risks, financial risks, information risks and organizational risks. Physical risks are associated with the movement and storage of materials such as late deliveries, shortage of stock, accidents, etc. Financial risks are associated with the flows of money such as shortage of cash, unpaid bills, etc. Information risks are about the systems and flows of information such as missing data, systems failure, breaches of data security, while organizational risks arise from the links between members of the SC such as lost customers, disagreements over contracts, legal disputes and so on.

World Economic Forum disseminates periodicals on global risks. They categorize SC risks and identify the triggers of SC disruptions as in Figure-2 [8].

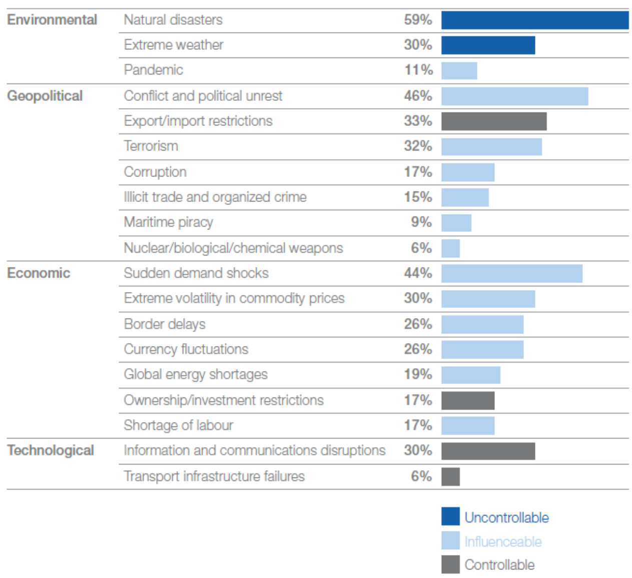

Figure-2: Triggers of Global Supply Chain Disruptions

According to a survey conducted by World Economic Forum, conflict and political unrest were identified as a key concern by 46% of respondents. Persistent military conflict can cause disruption to major transport routes or production hubs. According to the International Energy Agency, escalating violence in Libya's oil production would not make it to market [9]. Areas where terrorism or limited law enforcement is prevalent – whether in trade routes such as the Malacca Straits, or countries such as Indonesia – pose risks to employees and goods within the SC.

Maritime piracy is an increasing concern for supply chain professionals and transport providers, and is estimated to be costing the international economy between US$ 7 billion and US$ 12 billion per year [10]. The International Maritime Bureau reported a 36% increase in the number of attacks in the first half of 2011, and noted an increasingly organized and sophisticated approach [11]. While the threat has tended to be regionalized, union strike action as a result of threats to employee security is a growing possibility, and shipping companies are increasingly accepting the additional costs of rerouting via much longer distances.

Internet sites developed for this purpose can also be used to identify risks. Jereb et al. have presented the web-based risk catalogue in their paper [12]. All kinds of risks are listed elaborately in this site and risk managers can use this catalogue effectively in order to prevent the ignorance of any risk.

SC mapping should be done meticulously before the risk identification phase. The most important issue in here is the determination of the risk assessment level. Risk managers should identify the actors or the part of a SC to be assessed. These parts can be suppliers, customers, warehouses, transportation routes, as in this study, or a combination of these. Not only managers, but all organization members should contribute to the risk management process. The contribution of each individual, even the operators, is very important for risk identification, data collection, and risk mitigation. Since total quality management is a critical issue for effective risk management, ideas and experiences of a machine operator can best define the source of a breakdown, an accident or a failure. Likewise, a driver must be consulted to define the sources of transportation disruption such as accidents, customs delays, vandalism, or any other issues.

Jüttner and Ziegenbein mention that the risk identification phase is composed of three sequential steps, as in Figure-3 [13].

Figure-3: Risk Identification Steps

Various methods have been developed in literature for the systematic identification of risks. They are as follows [2];

- Analysis of historical data,
- Brainstorming,
- Cause-and-effect analysis,
- Fault trees,
- Process mapping,
- Likelihood-impact matrices,
- Pareto analysis,
- Scenario planning,
- Group meetings,
- Interviews,
- Delphi method,
- SC mapping and audit,
- Critical path identification,
- Relative importance to the customer,
- Relative importance to the supplier.

The risk identification phase requires a detailed planning and arrangement. The critical issue in this step is to what extent the risks can be defined, because hundreds of risks can be defined for an entity in a SC. Identifying too many risks, some of which might be irrelevant, leads to the unnecessary consumption of sources, time, and effort on the one hand; and ignorance of the identification of relevant risks may likely cause severe results on the other hand. Risk management performance may be useless in latter case. The risk manager is responsible for determining the relevancy level and the number of risks to be identified. In this tough situation, they should refer to the literature, past records of their company and other companies in the same sector, as well as the views and experiences of experts. The best approach to this problem may be identifying the relevant risks at a maximum level rather than ignoring a risk that may have severe impact in the future. In any case, redundant identifications, probability, and impact of which are measured low, will be eliminated swiftly in the risk measurement phase.

Risk Measurement

The aim of risk measurement is determining the severity of risk quantitatively or qualitatively. The two components of risk severity are the probability and the impact. Expected impact is used for identifying the risk profile and is the product of probability and impact. Measuring the impact and probability of a risk is a tough job because the former is related to future and the future is unknown and the latter requires a detailed data record and elaborate analysis. In a workshop performed by World Economic Forum, participants identified the importance of being able to quantify and measure the risk exposure of SC and transport networks. A lack of metrics has left companies struggling to quantify the risk exposure of their own organization or to compare providers. Over 25% of the respondents to the World Economic Forum survey do not know the annual financial impact of disruptions on their business. A recognized set of supply chain and transport risk quantification metrics needs to be developed to enable businesses and governments to obtain an accurate understanding of risk to networks, better prioritized risk management activities, and the alignment of incentives, exposure and risk appetite. As far as possible, these risk metrics should be consistent within and across organizations to enable comparisons. In the commercial sector, the revenue or gross profit at risk as a result of supplier failure is a useful measure to help senior management understand their risk exposure [8]. The assessment model of risks must be simple because estimation of the probability and the effect of the risk are based on subjective estimation. The model must therefore be understood as a method that provides direction. The primary aim of the model is not to provide an absolute value of risk, but rather to provide support in the decision-making process (Hallikas *et al*., 2002) [14]. Thun and Hoenig expressed that since a precise assessment of the probability of occurrence and their effect is hardly possible, it is advisable to evaluate the identified risk at least in a qualitative way [15].

Risk is the effect of uncertainty on objectives and an effect is a deviation from the expected — positive and/or negative [16]. The types of losses resulting from a risk are [17];

- Financial loss
- Performance loss
- Physical loss
- Psychological loss
- Social loss
- Time loss

When a risk occurs, more than one of these losses may happen and some of them can also be converted to and identified in terms of financial loss. For example, a natural disaster causes physical loss, but since this result in disruption to production, supply and storage, all effects can be identified financially.

Since the measurement of the impact of a risk is difficult, qualitative descriptions are widely and effectively used in literature. For instance, Waters identifies the impact qualitatively in six categories [2] (Table-1);

CATEGORY	**DEFINITION**
NEGLIGIBLE	An insignificant effect on the working of the supply chain
MINOR	Causing some inconvenience with minor disruptions, delays and increased costs to some parts of the chain, but with most functions unaffected
MODERATE	Causing some disruption to parts of the supply chain, but with the main functions continuing to meet requirements
SERIOUS	Major disruptions to the essential operations of the supply chain, causing serious delays and a high cost of recovery
CRITICAL	Failure of the whole supply chain for an extended time, with major cost and effort needed for recovery
CATASTROPHIC	Causing complete and irrecoverable failure of the supply chain and possibly whole organizations

Table-1: Qualitative Impact Categories

These categories can be weighted from 1 to 6, 1 representing negligible and 6 representing catastrophic impact. Tummala and Schoenherr have also defined the risk impact in four categories which are related with the performance of a firm that is exposed to a risky event and have weighted the categories from 1 to 4 [18].

The second component of severity is the probability of risk. A probability distribution function or occurrence frequency of a risky event is used in finding the probability criteria. In order to use probability functions, we must have historical data of that event first. The type of distribution function must be identified by fitting tests. Then the parameters of the distribution function should be calculated and the probability of a risky event can be found. Although the probability values found by this method are more reliable and accurate, it might be difficult to find the type of distribution function due to a lack of required data. Data might be available for some risks such as currency rate and lead time, but it might be insufficient for a healthy evaluation for rare events such as earthquakes, terrorism, and other geographical risks. In this situation, the likelihood of an event can be used. Likelihood is related to the frequency of occurrence of an event in a specific time interval. This method is more practical and might be as accurate as the former when experts evaluate the risky event meticulously.

Tummala and Schoenherr identify probability in terms of occurrence frequency of an event in a specified time period (Table-2) [18].

Risk probability categories	Qualitative description The identified risk factor could occur on an average of .	Probability index	HTP code
Often	. once per week	4	J
Infrequent	. once per month	3	K
Rare	. once per year	2	L
Extremely rare	. once per decade	1	M

Table-2: Probability Categories and Indexes

As mentioned earlier, expected impact is the product of impact and probability of risky event.

Severity or Expected Impact (R) = I x P

A probability-impact matrix is a useful tool to visualize and define the expected impacts and is widely used in literature. The probability-impact matrix used by Lavalle-Pierceau, a transport company based in the south of France, is shown in Table-3.

A risky event which is unlikely, but has a high impact has an index of 8 out of 25. Both the likelihood and impact index of a risky event increases as we move towards the lower right of the matrix.

		Impact				
		Very low 1	Low 2	Medium 3	High 4	Very high 5
Likelihood	Very Unlikely 1	1	2	3	4	5
	Unlikely 2	2	4	6	8	10
	Medium 3	3	6	9	12	15
	Likely 4	4	8	12	16	20
	Very likely 5	5	10	15	20	25

Table-3: Probability–impact matrix for Lavalle-Pierceau

Risk Evaluation

A supply chain is exposed to various risks and it is impossible to take the same level of measure for all of them. Therefore, they should be prioritized and a decision for each risk should be given according to this prioritization.

In the risk evaluation phase, the result of risk analysis is compared to the risk criteria of the firm to determine whether the risk and/or its magnitude is acceptable or tolerable. Risk criteria are based on organizational objectives and can be derived from standards, laws, policies and other requirements [16]. Each manager has a different risk attitude. Some like to take risks and determine a high level of risk criteria, while some refrain from risk and determines a low level. In addition, risk attitude may depend on the features of the sector. For instance, the firms which have low product flow velocity, are independent of assembly lines, and have a workshop production system have a high risk tolerance. The firms which have high product flow velocity, mass production, and are dependent to assembly lines such as automotive and newspaper sectors have a low risk tolerance because the latter are affected from a disruption much more severely than the former.

Risk profile is a measure that indicates the risk level of a unit (i.e. supplier, transportation route, warehouse, etc.). It is calculated by summing the risk indices greater than the risk criteria of the firm.

$$R_t = \sum_{k=1}^{K} R_k * Z_k \qquad (2.1)$$

R_t=Total risk value

$$Z_k = \begin{cases} 0, & R_k \text{ is less than the risk criteria of the firm} \\ 1, & R_k \text{ is greater than or equal to the risk criteria of the firm} \end{cases}$$

R_k = Index of a risk

k= Identified risks from 1 to K

When the severity of a risk is identified qualitatively as described in the previous section, risk evaluation is performed by categorizing these qualitative measures according to their severity level. In fact, these categories are formed regarding the risk criteria of the firm. For example, as a result of a survey and interview conducted to managers in an automobile factory, Kirilmaz identified risk evaluation categories as in Table-4 [19].

RISK INDEX	DEFINITION
1 – 2	Acceptable, no action required
3 – 4 – 5	Acceptable but should be monitored
6 – 8 – 9 – 10 – 12 – 15	Undesirable and strict measures must be taken
16 – 20 – 25	Unacceptable

Table-4: Risk Evaluation Categories

This categorization and the actions regarding risk indices can vary according to sector and the managers' risk attitude.

At the end of the risk evaluation phase, a risk owner can select one of the four different strategies;

- Avoid risk,
- Reduce probability and/or impact of risk,
- Accept occurrence of risk,
- Prepare contingency plans [20].

Water, D. also identifies the responses to a risk: ignore or accept risk, reduce probability of risk, reduce or limit consequences, transfer, share or deflect risk, make contingency plans, adapt to it, oppose a change, or move to another environment [2].

Selection of a strategy mainly depends on the trade-off between the expected impact and the cost associated with the implementation of the selected strategy.

Risk Mitigation Strategy

The decision of performance of a risk mitigation strategy may be given at the end of risk evaluation phase. The aim of these strategies is to reduce the impact and/or probability of risky event.

Risk mitigation makes use of the data collected in the previous step to address potential risks with the right countermeasures. This includes classic mitigation strategies which are implemented before the risky event and contingency plans implemented after the risky event [21]. Kleindorfer and Saad argue that prevention is better than cure, requiring risk managers to act fast and treat urgent risks first [5].

Risk mitigation strategies can be classified into two groups: reactive and proactive. In a reactive approach, no action is taken before the occurrence of a risky event, but it is implemented to mitigate the impact and/or probability after it occurs. In these kinds of strategies, there is no plan to reduce the probability of risk. Although there are plans to reduce the impact, they are implemented after the occurrence of the risky event. In a proactive approach, plans are implemented to mitigate the risks before they occur. This approach may include the performance of plans either to decrease the probability or to reduce the impact of the risky event in advance or both.

Jüttner *et al.* summarize examples of some risk mitigation strategies as in Table-5 [22].

Avoidance	Dropping specific products/geographical markets/supplier and/or customer organizations
Control	Vertical integration
	Increased stockpiling and the use of buffer inventory
	Maintaining excess capacity in productions, storage, handling and/or transport
	Imposing contractual obligations on suppliers
Co-operation	Joint efforts to improve SC visibility and understanding
	Joint efforts to share risk-related information
	Joint efforts to prepare SC continuity plans
Flexibility	Postponement
	Multiple sourcing
	Localized sourcing

Table-5: Risk Mitigation Strategies in Supply Chains

Risk exposure of organizations must be carefully analyzed against objective and transparent criteria and costs must be weighed against the benefits of potential risk mitigation methods [8].

The proposed procedure in this study is a proactive approach, in other words, pre-disruption preparation. In this procedure, cost is considered to be the first priority and risk is considered to be the second priority goal. Risk profiles of all transport routes are identified as described in preceding sections first. Then, a minimum cost transportation plan is achieved via linear programming and, finally, the initial minimum cost plan is revised regarding risk profiles of transport routes in order to reduce the total risk of transport network. By this way, risk criterion is also included in the planning activity. A flowchart of the proposed procedure is shown in Figure-4.

The proposed procedure enables decision makers to trade-off between cost and risk and to select a decision point among alternatives. While the risk taker managers prefer low cost and consent with the current risk profile, risk-averse managers prefer to reduce the risk profile of the transport network and construct a more robust supply chain at the expense of increased transportation cost. The procedure has the logic of sensitivity analysis indeed.

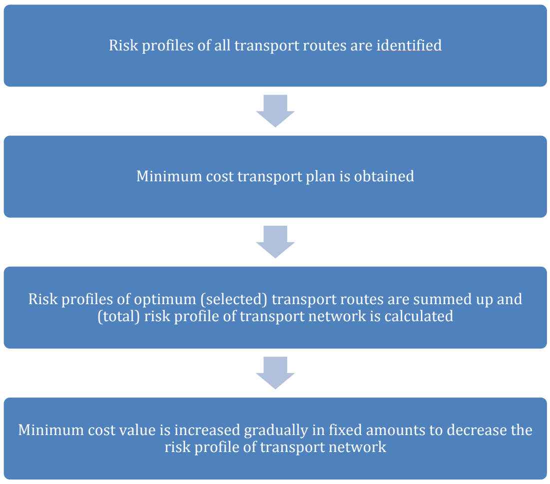

Figure-4: Flowchart of the Proposed Procedure

In the first step, risk profiles of all alternative transport routes are identified as described in preceding sections. Risk impact varies according to transportation mode and risk type. For example, in water transport, since the shipping is in big amounts, a disruption affects supply chain more severely than small amount shipping. For road transport, accident risk is less severe than the political risk because accident risk affects only a few trucks, but political risk may halt all route flow and cause severe impact.

A transport network is shown in Figure-5.

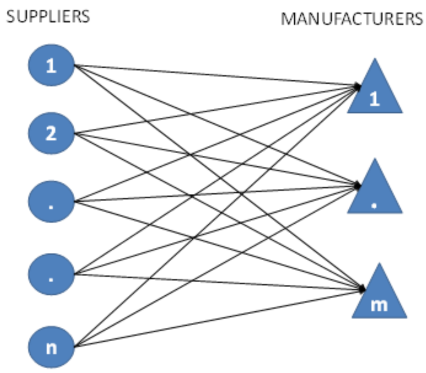

Figure-5: n*m Transport Network

In the second step, an initial minimum cost transport plan is created by a linear programming model. The problem can be modeled through a bipartite complete directed graph , where the vertices in V_1 stand for the suppliers, the vertices in V_2 represent the manufacturing/assembly plants and the arcs in A = V_1 x V_2 are associated with the product flows between the suppliers and the manufacturing plants.

$$Min\ z_1 = \sum_i^I \sum_j^J T_{ij} * y_{ij} \tag{2.2}$$

$$\sum_j^J y_{ij} \leq S_{Ri}\ \forall i \tag{2.3}$$

$$\sum_i^I y_{ij} \geq D_j\ \forall j \tag{2.4}$$

$$y_{ij} \geq 0 \tag{2.5}$$

y_{ij}; The product quantity to be transported from supplier i to manufacturer j.

T_{ij}; Unit cost of transporting a product from supplier i to manufacturer j.

S_{Ri}; The total quantity to be supplied from supplier i.

D_j; Total demand of manufacturer j.

In the third step, the total risk profile of the transport network is calculated. m+n-1 transport routes are selected (basic variables) in optimum solution. Since the risk profile of each transport route was identified in step 1, total risk profile of transport network can be found as;

$$R_N = \sum_{BV=1}^{K} R_{BV} \quad (2.6)$$

R_N= Risk profile of transport network,

BV= Basic variables

K= (m+n-1) basic variable

In the fourth step, decision points are created regarding the cost and risk trade-off. The minimum cost value (z_1) is increased gradually in a fixed amount that is determined by the decision maker and reduced risk profile values are presented as alternative decision points. The linear programming model used for this purpose is as follows:

$$Min\ r = \sum_i^I \sum_j^J R_{ij} * a_{ij} \quad (2.7)$$

$$\sum_i^I \sum_j^J T_{ij} * y_{ij} \leq z_1 + d \quad (2.8)$$

$$\sum_j^J y_{ij} \leq S_{Ri}\ \forall i \quad (2.9)$$

$$\sum_i^I y_{ij} \geq D_j\ \forall j \quad (2.10)$$

$$y_{ij} \leq M * a_{ij}\ \forall\ i\ ,j \quad (2.11)$$

$$y_{ij} \geq 0 \quad (2.12)$$

$$a_{ij}; 0\ or\ 1$$

R_{ij}; Risk profile of the transport route from supplier i to manufacturer j,

a_{ij}; Binary variable 0, if the transport route from supplier I to manufacturer j is not used, 1 otherwise

z_1; Minimum cost value obtained in step 1,

d; The amount of cost increase determined by the decision maker,

M; Substantially big number.

The objective function (Eq. 2.7) minimizes the total risk profile of the transport network. The risk profile of a route is added if it is used, not otherwise. Eq.2.8 relaxes the cost of z_1 "d" units and implicitly enables the objective function to reduce the transport network risk profile calculated in step 1. Eq. 2.9 and Eq. 2.10 are supply capacity and demand satisfaction constraints. Eq. 2.11 satisfies the condition that if a route is used its profile is added to objective function value (r), not otherwise. When the expected impact (severity) of a risky event can be identified financially (eg. $100 000), it can be included in the objective function as a fixed cost with a binary variable. The decision of whether a route is used and how many products will be transported can be given via linear programming model. A critical issue in here is that a transport route can be eliminated directly if its risk profile is in the "unacceptable" category.

Risk Monitoring and Control

The risk management process is a cycle and the risk monitoring and control is the phase that enables this process to be alive. Since risk is related to the future, events should be observed and the data about events should be updated and assessed all the time. This phase includes both observations about previous assessments and observations about changing situations and environments. By the help of this phase, new risks may be identified and/or judgments about previously identified risks may be revised. For efficient monitoring and control, information systems should be utilized and a high coordination and information sharing system should be established. Real time observation and tracking is also very critical for an efficient risk monitoring and control.

III. NUMERICAL APPLICATION

Numerical application is performed in a single echelon supply chain shown in Figure-6.

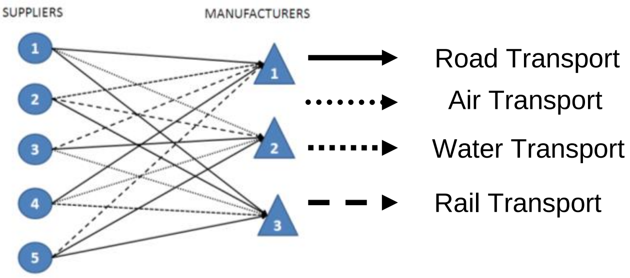

Figure-6: Single Echelon Supply Chain

Let suppliers and manufacturers be intercontinental units located in different geographical areas. Transport modes can be air, water, road or rail. Parameters such as transportation cost, supply capacity, demand, risk probability and impact are generated randomly in a uniform distribution. These hypothetic data are used in the models of both Step 1 and Step 2. The procedure is tested 10 times with different data sets. The first data set and the model are shown explicitly and the results (alternative decision points) of the remaining 9 data sets are presented only graphically.

Risk Identification:

Since the paper is about the risk analysis of transport network, all identified risks in literature are examined, the ones relating to transportation are determined and presented in Table-6.

#	Risk Type	#	Risk Type
1	Accident risk	7	3PL Deficiency Risk
2	Industrial Action Risk (Strike, lockout)	8	Geopolitical Risk
3	Extreme Weather Risk	9	Customs Delay Risk
4	Legislation and Regulation Risk	10	Traffic Congestion or Limited Capacity Risk
5	Natural Disaster Risk	11	Criminal Risk (theft, vandalism, terrorism, piracy)
6	War Risk	12	Fire Risk

Table-6: Transport Network Related Risks

All the risks in Table-6 will be taken into consideration for each transport route.

Risk Measurement and Evaluation:

The impact and probability categorizations used in this study are presented in Table-7 and Table-8, risk evaluation categories are presented in Table-9 [19].

Risk Impact	Definition	Impact Index
Catastrophic	Cease of production for 1 week and more	5
Serious	Cease of production for 2-3 days	4
Moderate	Slowdown of production for 3-5 days	3
Minor	Decrease in customer service level	2
Negligible	Unaffected customer service level due to inventory on hand	1

Table-7: Impact Categories

Risk Likelihood	Definition	Likelihood Index
Usually	At least 1 times a week	5
Often	1-2 times in 1 month	4
Sometimes	1-2 times in 6 months	3
Seldom	Once in a year	2
Rare	Once in every 2 years and up	1

Table-8: Probability Categories

As it is seen from Table-9, the risk criteria of the company is 6. Measures should be taken for the values 6 (incl.) and 15 (incl.) and a route with the risk profile of 16, 20 or 25 can be eliminated directly. Risk measurement and evaluation are performed in view of Table-7, Table-8 and Table-9 and the risk profile of each transport route is identified as in Table-10.

Risk Index	Definition
1 – 2	Acceptable, no action required
3 – 4 – 5	Acceptable, should be monitored
6 – 8 – 9 – 10 – 12 – 15	Undesirable and measures should be taken
16 – 20 – 25	Unacceptable

Table-9: Risk Evaluation Categories

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Risk Identification	**Expected Impact**														
Accident risk	**5**	**3**	10	5	2	8	2	12	1	9	1	3	2	8	5
Industrial Action Risk (Strike, lockout)	**5**	**2**	5	**2**	**3**	**5**	12	**5**	**2**	**3**	**1**	**5**	6	**5**	**8**
Extreme Weather Risk	5	10	5	10	4	4	2	5	15	4	12	15	2	4	4
Legislation and Regulation Risk	4	10	4	3	3	5	2	4	12	4	2	4	3	4	5
Natural Disaster Risk	15	**2**	**4**	**4**	12	**4**	8	**4**	10	**5**	9	**4**	9	**5**	**4**
War Risk	**2**	**4**	3	8	5	2	3	1	1	2	2	8	2	2	2
3PL Deficiency Risk	10	**1**	**15**	**2**	**1**	10	**2**	15	**2**	15	**2**	**1**	**2**	**5**	12
Geopolitical Risk	3	10	10	5	4	10	4	12	8	4	12	**10**	10	10	3
Customs Delay Risk	8	6	4	3	2	4	2	5	8	15	12	12	3	5	4
Traffic Congestion or Limited Capacity Risk	15	1	10	1	2	6	1	12	1	12	1	1	1	10	12
Criminal Risk (theft, vandalism, terrorism, piracy)	8	2	8	15	12	8	10	5	1	9	2	12	8	8	3
Fire Risk	5	3	4	4	10	4	8	4	1	5	2	6	10	6	9
Risk Profile	**56**	**36**	**53**	**33**	**34**	**42**	**38**	**51**	**53**	**60**	**45**	**63**	**43**	**42**	**41**

Table-10: Risk Profiles of Transport Routes

As mentioned before, these risk indices vary according to the features of countries, routes and transportation modes.

The capacity of suppliers, the demand of manufacturers and transportation cost of per unit for each route is presented in Table-11, Table-12 and Table-13 respectively.

S_1	S_2	S_3	S_4	S_5
57947	39474	48579	64000	51000

Table-11: Capacity of Suppliers

M_1	M_2	M_3
101000	87000	73000

Table-12: Demand of Manufacturers

Cost (C_{ij})		Manufacturers (j)		
		1	2	3
Suppliers (i)	1	11,0	12,0	9,5
	2	8,0	8,5	8,0
	3	7,5	12,0	10,0
	4	9,0	5,5	7,0
	5	8,0	13,0	5,5

Table-13:Transportation Cost of Per Product from i to j

Minimum cost transportation plan is obtained via the Equations 2.2 – 2.5 and the optimum solution is presented in Table-14.

Total Cost (Z_1) = \$ 1.928.555 Transport Network Risk Profile = 300		Manufacturers (j)		
		1	2	3
Suppliers (i)	1	35947	0	22000
	2	16474	23000	0
	3	48579	0	0
	4	0	64000	0
	5	0	0	51000

Table-14: Optimal Solution for the 1st Data Set

According to the optimum solution, routes R_{11}, R_{13}, R_{21}, R_{22}, R_{31}, R_{42}, R_{53} are used for transport. The total risk profile of this network is the sum of the profile of each route.

R_N=56+53+33+34+38+45+41=300

The decision maker may find this risk profile of the network too high and want to analyze the decision points of trade-off between cost and risk. He/she identifies the increments of \$10.000 and performs sensitivity analysis. The following model is used for cost and risk trade-off.

$$\text{Min } R_N=56R_{11} + 36R_{12} + 53R_{13} + 33R_{21} + 34R_{22} + 42R_{23} + 38R_{31} + 51R_{32} + 53R_{33} + 60R_{41} + 45R_{42} + 63R_{43} + 43R_{51} + 42R_{52} + 41R_{53} \quad (3.1)$$

$$11X_{11} + 12X_{12} + 9{,}5X_{13} + 8X_{21} + 8{,}5X_{22} + 8X_{23} + 7{,}5X_{31} + 12X_{32} + 10X_{33} + 9X_{41} + 5{,}5X_{42} + 7X_{43} + 8X_{51} + 13X_{52} + 5{,}5X_{53} \leq 1.928.555 + c*10.000 \quad (3.2)$$

$$X_{11}+X_{12}+X_{13} \leq 57.947 \quad (3.3)$$

$$X_{21}+X_{22}+X_{23} \leq 39.474 \quad (3.4)$$

$$X_{31}+X_{32}+X_{33} \leq 48.579 \quad (3.5)$$

$$X_{41}+X_{42}+X_{43} \leq 64.000 \quad (3.6)$$

$$X_{51}+X_{52}+X_{53} \leq 51.000 \quad (3.7)$$

$$X_{11}+X_{21}+X_{31}+X_{41}+X_{51} \geq 101.000 \quad (3.8)$$

$$X_{12}+X_{22}+X_{32}+X_{42}+X_{52} \geq 87.000 \quad (3.9)$$

$$X_{13}+X_{23}+X_{33}+X_{43}+X_{53} \geq 73.000 \quad (3.10)$$

$$X_{ij} \leq M * a_{ij} \ \forall\, i\,, j \quad (3.11)$$

$$X_{ij} \geq 0 \quad (3.12)$$

$$a_{ij};\ 0 \ or\ 1$$

c= 1 to n times the fixed increase (10.000, 20.000, 30.000…)

The optimum solution for each “c*d” is found by Microsoft Excel Solver Table and cost & risk trade-off decision points are presented in Figure-7.

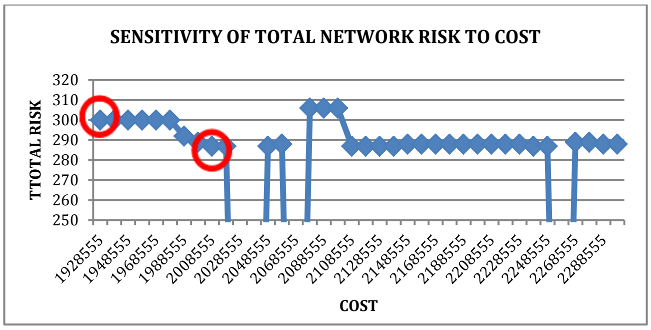

Figure-7: Cost & Risk Trade-off Decision Points

Figure-7 presents very important and critical information to the decision maker about risk and cost trade-off. For example, an increment of \$50.000 in cost makes no difference in total transport risk, but a gradual decrease is obtained after this point. The value of 287 in total transport risk is achieved at the expense of an \$80.000 cost increase (\$2.008.555) and this means a 13% decrease in total risk for 4% increase in total cost. After this level, it is not possible to decrease the risk under this value, at least for a huge amount of money. Some points of increase and infeasible solutions are observed due to binary decision variables (a_{ij}). In this circumstance, the decision maker should select the risk level of 300 for a cost of \$1.928.555 or 287 for a cost of \$2.008.555 and other points result in unnecessary cost. We have presented the optimum transport plan for the risk level of 300 before and if the decision maker selects the level of 287, then the optimum transport plan will be as in Table-15.

Total Cost = \$ 2.008.555 Transport Network Risk Profile = 287		Manufacturers (j)		
		1	2	3
Suppliers (i)	1	0	0	57947
	2	16474	23000	0
	3	48579	0	0
	4	0	64000	0
	5	35947	0	15053

Table-15: Optimum Solution for the Transport Network Risk Profile of 287.

As it is seen from Table-15, the route R_{11}, which was used previously (basic variable) and has a risk index of 56, is closed (become non-basic) and route R_{51}, which has a risk index of 43, has become a basic variable. The amount of 35,947 is transferred from R_{11} to R_{51}.

The figures of decision points, optimal solution of the first model (min. cost) and optimal solution of the selected network risk profile (min. risk) of remaining nine data sets are presented below.

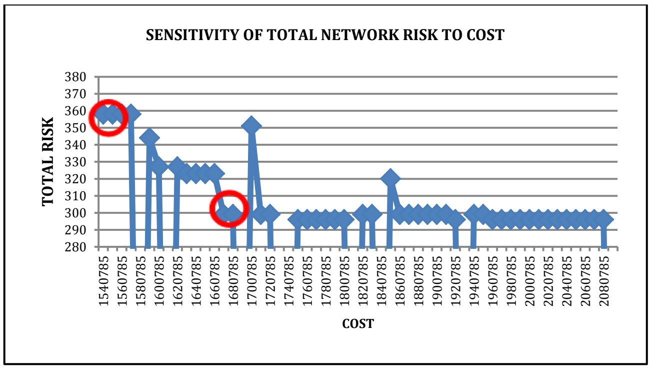

Figure-8: Cost & Risk Trade-off Decision Points for 2nd Data Set

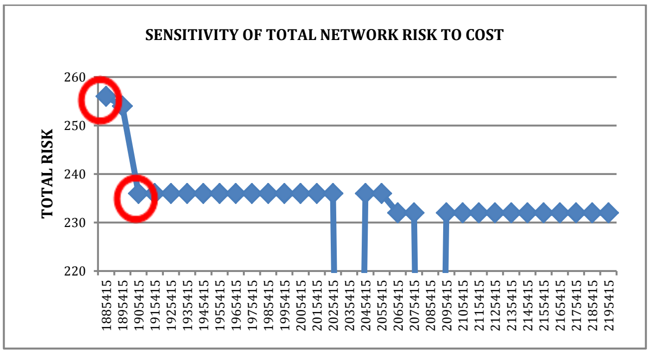

Figure-9: Cost & Risk Trade-off Decision Points for 3rd Data Set

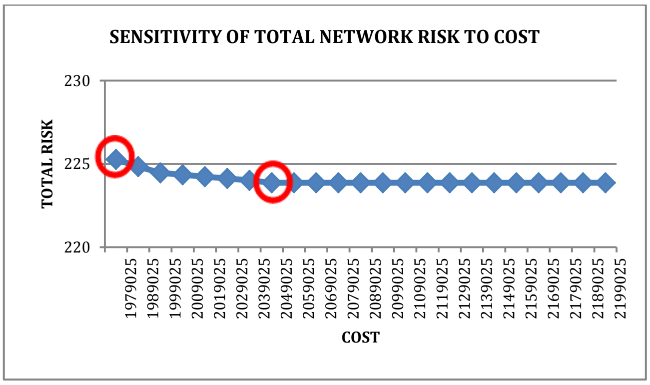

Figure-10: Cost & Risk Trade-off Decision Points for 4th Data Set

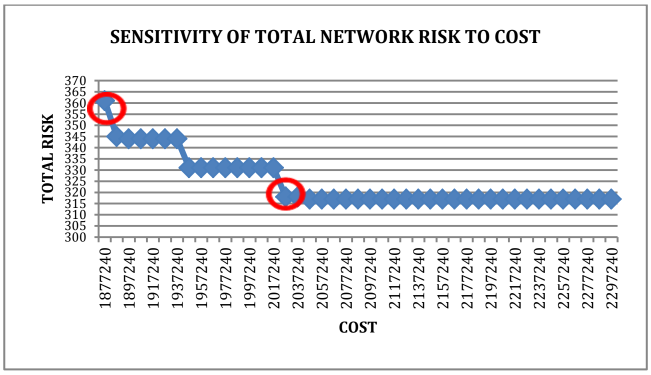

Figure-11: Cost & Risk Trade-off Decision Points for 5th Data Set

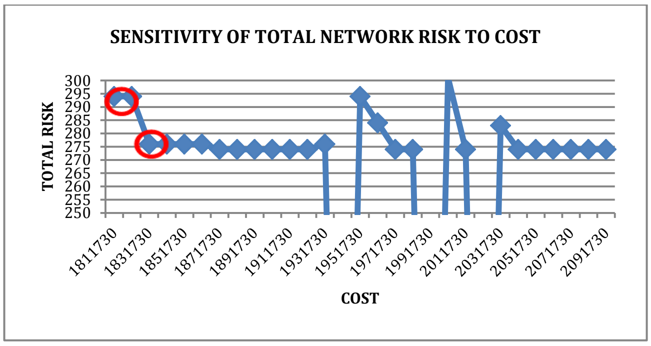

Figure-12: Cost & Risk Trade-off Decision Points for 6th Data Set

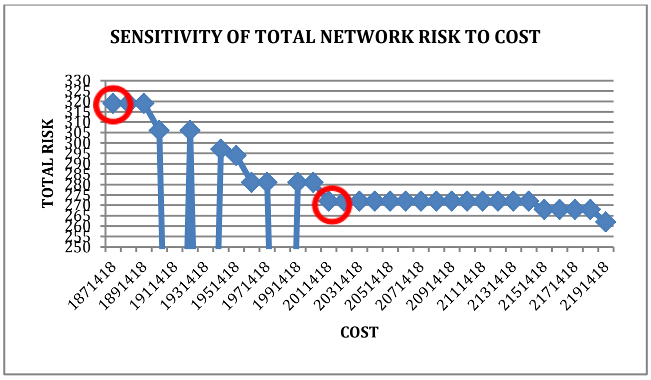

Figure-13: Cost & Risk Trade-off Decision Points for 7th Data Set

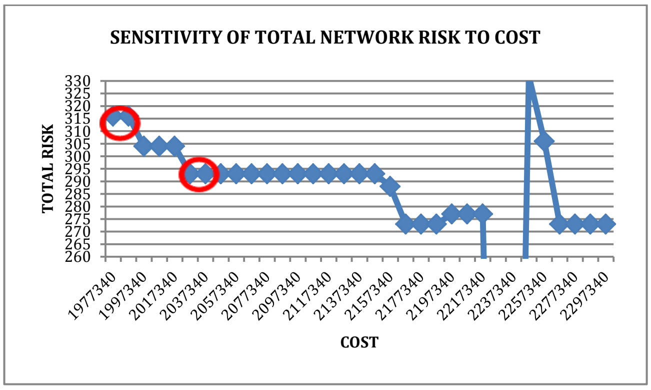

Figure-14: Cost & Risk Trade-off Decision Points for 8th Data Set

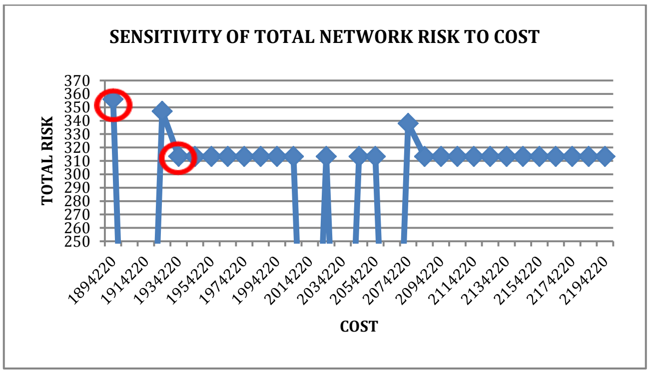

Figure-15: Cost & Risk Trade-off Decision Points for 9th Data Set

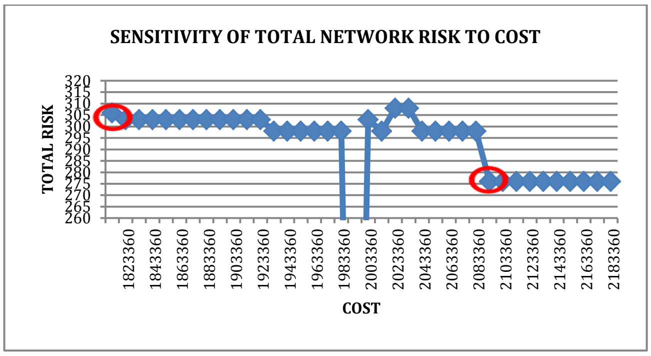

Figure-16: Cost & Risk Trade-off Decision Points for 10th Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min $z_1=\$1.540.785$ $R_N=358$	27060	0	0	0	58030	33940	0	0	43000	33940	0	14060	0	36970	0
Min $R_N=299$ Cost=$\$1.670.785$	12030	15030	0	970	0	91000	0	43000	0	48000	0	0	0	36970	0

Table-16: Optimum Solutions for the 2nd Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min $z_1=\$1.885.415$ $R_N=256$	0	0	0	18000	16915	0	0	0	84000	0	88085	0	41000	0	2000
Min $R_N=236$ Cost=$\$1.905.415$	0	0	0	16000	16915	2000	0	0	84000	0	88085	0	43000	0	0

Table-17: Optimum Solutions for the 3rd Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min $z_1=\$1.979.025$ $R_N=225$	22700	0	7000	0	0	83000	0	45000	0	45750	0	0	23550	6000	0
Min $R_N=223$ Cost=$\$2.049.025$	29700	0	0	0	0	83000	0	45000	0	39750	6000	0	22550	0	7000

Table-18: Optimum Solutions for the 4th Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min $z_1=\$1.877.240$ $R_N=361$	42577	0	0	0	0	41538	0	22788	30462	0	13154	0	52423	8058	0
Min $R_N=318$ Cost=$\$2.027.240$	36981	0	5596	41538	0	0	0	0	53250	0	0	13154	16481	44000	0

Table-19: Optimum Solutions for the 5th Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min $z_1=\$1.811.730$ $R_N=294$	0	0	50000	7160	19000	35000	0	73000	0	43130	0	0	30710	0	0
Min $R_N=276$ Cost=$\$1.831.730$	7160	0	42840	0	19000	42160	0	73000	0	43130	0	0	30710	0	0

Table-20: Optimum Solutions for the 6th Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min $z_1=\$1.871.418$ $R_N=319$	0	0	37380	0	0	56665	0	0	0	46000	33045	14955	0	31955	0
Min $R_N=272$ Cost=$\$2.011.418$	0	0	37380	0	0	56665	0	0	0	29000	65000	0	17000	0	14955

Table-21: Optimum Solutions for the 7th Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min z_1=$1.977.340 R_N=316	17515	0	0	77485	14515	0	0	29140	4655	0	0	75345	0	30345	0
Min R_N=293 Cost=$2.027.340	0	17515	0	92000	0	0	0	33795	0	3000	0	72345	0	22690	7655

Table-22: Optimum Solutions for the 8th Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min z_1=$1.894.220 R_N=356	82000	0	0	0	0	88000	0	0	7652	0	32087	0	23000	14913	8348
Min R_N=313 Cost=$1.934.220	82000	0	0	0	739	87261	0	0	7652	23000	0	9087	0	46261	0

Table-23: Optimum Solutions for the 9th Data Set

	R_{11}	R_{12}	R_{13}	R_{21}	R_{22}	R_{23}	R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{51}	R_{52}	R_{53}
Min z_1=$1.823.360 R_N=306	0	0	65000	0	84821	0	44714	1179	1000	27857	0	0	31429	0	0
Min R_N=276 Cost=$2.103.360	0	65000	0	0	21000	63820	44714	0	2180	27857	0	0	31429	0	0

Table-24: Optimum Solutions for the 10th Data Set

IV. CONCLUSION AND SUGGESTIONS

The main aim of a supply chain is to make a product/service ready at the right location in the right time with the right quantity. The most important element of a supply chain to achieve this aim is transportation. Supply chain disruptions that cause severe impacts generally emanates from transportation risks. Therefore, management of transportation risks has a critical importance in gaining competitive advantage and enhancing the efficiency of a supply chain.

In this study conducted in the light of these ideas, a pre-disruption preparation procedure is proposed that takes risk criterion into consideration along with cost criterion in creating a transportation plan. Risk analysis of all possible routes is performed and risk profiles are identified in the first step of this procedure. The effect of risk is usually identified financially in literature; however, it can also be identified as performance loss, physical loss, social loss and time loss in the proposed system. Then, a minimum cost transportation plan of a single echelon supply chain is obtained via a linear programming model and the risk profile of transport network is calculated by summing the risk profile of each used route (basic variable). Finally, lower network risk profiles are searched by increasing the minimum cost value in fixed amounts that are identified by decision maker.

The proposed procedure is tested with 10 randomly generated hypothetical data sets. Three different cases are observed according to test results

- No considerable reduction in network risk profile is obtained despite considerable cost increase,
- Some reduction is obtained with no change in selected route (basic variable) but with a change in the amount of product transported in that route,
- Reduction is obtained with a change in basic variables (i.e. previously used routes are closed and new routes are opened)

It is observed that which of these cases will occur is determined according to the selected cost increase and risk profiles of routes.

The proposed pre-disruption preparation procedure enables a decision maker to construct a more robust supply chain. The procedure presents very beneficial information to a decision maker. For example, he/she can catch a considerable risk profile decrease at the expense of very low cost increase as in the 3rd and 6th data set and should use the opportunity of designing a less vulnerable supply chain. But in some cases such as the 4th and 10th data set, there is no use in increasing the transport cost because risk cannot be reduced no matter how much transport cost be increased. By using this cost and risk based trade-off model, impact of a transport risk and vulnerability of a supply chain can be reduced by using less risky and more reliable routes.

The effectiveness of the proposed procedure can be tested in a large scale and intercontinental company for further study.

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