JIEMS

Journal of Industrial Engineering and Management Studies

Vol. 2, No. 2, pp. 1-12

www.jiems.icms.ac.ir

Risk measurement in the global supply chain using monte-carlo simulation

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Abstract

Nowadays, logistics and supply chain management (SCM) is critical to compete in the current turbulent markets. In addition, in the global context, there are many uncertainties which affect on the market. One of the most important risks is supplier disruption. The first step to cope with these uncertainties is quantifying them. In this regard many researches have focused on the problem but measurement of the risk in the global SCM is yet a challenge. In the uncertain conditions, simulation is a good tool to study the system. This paper aims to study a global supply chain with related risks and measurement of the risks using simulation. Global aspects considered in the paper are: 1- currency exchange rate, 2- extended leadtime for abroad supplies, 3- regional and local uncertainties. In this regard, two popular risk measurement approaches (VaR and CVaR) are used in the simulation of uncertainties in the global supply chain. Results showed that adopting risk averse behavior to cope with the uncertainties leads to the lower stockouts and also higher costs.

Keywords: Global Supply chain management, Supplier disruption, Simulation, Quantifying the risk.

Received: July 2015-08

Revised: August 2015-12

Accepted: November 2015 -10

1. Introduction

Global supply chain as an extended local supply chain (or a set of several local supply chains), is a complex set of relations which forms an international supply chain. In addition, globalization offers many opportunities to the companies to grow their revenues and decrease their costs. (Chopra and Meindl, 2013). Also Simchi-Levi et al. (2008) explained the main characteristics of a global supply chain as: International distribution systems, International suppliers, offshore manufacturing, fully integrated global supply chain (GSC). Some of the globalization aspects includes: Tariffs/duties, Non-tariff trade barriers, Currency exchange rate, corporate income tax, transportation time, inventory cost, worker skill/ availability (Meixell and Gargeya, 2005).

Based on the best knowledge of authors, the main features of the globalization considered in the literature of supply chain management can be categorized as follows:

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- Duty, Tax, Customs tariffs, Reduction of carbon emissions, Transfer pricing, Currency zone, Exchange rate, Global sourcing, Trade barriers, Cultural differences, Technological differences, Legal constraints, extended leadtimes, etc.

Currency zone, exchange rate and extended leadtimes are the features considered in this paper.

On the other hand, these mentioned opportunities are often accompanied by significant additional risks. Generally, uncertainty in logistics operations can be categorized in 3 levels: strategic, tactical, and operational levels. In this regard, uncertainty of lead times and supplier reliability are two important sources of uncertainty in the global supply chains (Schmidt and Wilhelm 2000). There are two types of risks in the supply chain: quantitative and qualitative (Manuj and Mentzer, 2008-a). Quantitative risks include stock-outs (lost sales), overstocking, obsolescence, customer discounts, and/or inadequate availability of components and materials in the supply chain. Qualitative risks include lack of accuracy, reliability, and precision of the components and materials in the supply chain. Both qualitative and quantitative risks may create the need for atomistic or holistic evaluations of supply chains.

According to Chopra and Meindl (2013), the main related risks in the global supply chain are:

Disruptions, delays, systems risk (such as Information infrastructure breakdown), forecast risk, intellectual property risk, procurement risk, receivables risk (such as Number of customers or financial strength of customers), inventory risk, capacity risk.

In this paper, we will study supplier disruption risk as a main source of the uncertainty in the global supply chain model.

Also Manuj and Mentzer (2008-a) propose a five step process for global supply chain risk management and mitigation:

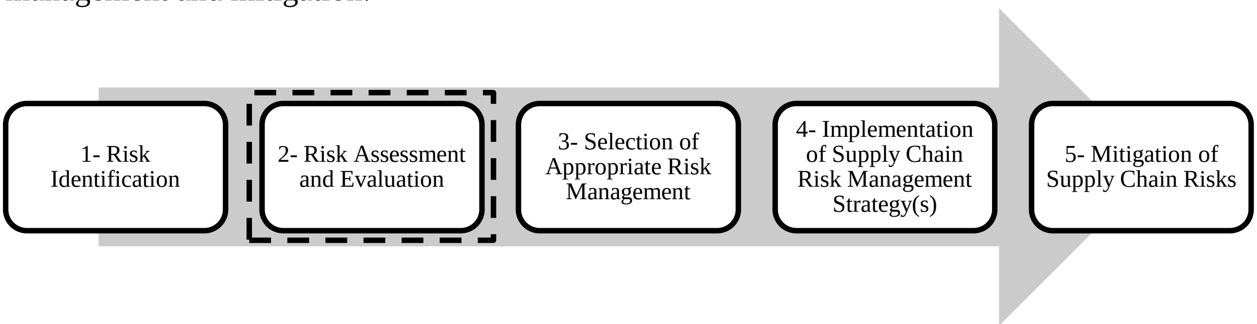

Figure 1. Five step process for global supply chain risk management and mitigation Manuj and Mentzer (2008-a)

This paper aims to focus on the second level of the global supply chain risk management process. In this paper, the approach used is monte-carlo simulation. In the next section, we will review the literature of risk simulation and risk assessment in the supply chain with concentrating to the global aspect of supply chains. Then we will present the proposed risk assessment framework and based on that, risk assessment simulation results will be obtained.

2. Literature review

Global supply chain management is an interesting topic of supply chain management modeling in the recent years. Vidal and Goetschalckx (1997) and Meixell and Gargeya (2005) are two important review papers in this area of research. The first paper generally discussed different models of global supply chain and suggested some improvements in the GSCs such as: inclusion of more stochastic features in modeling, consideration of vendor and transportation channel reliability, inclusion of customer service level, modeling of potential economies of scale, simulation of qualitative factors, etc. The second paper proposed more research on 3 directs: First, the composite supply chain design problem by extending models to include both internal manufacturing and external supplier locations. Second, broader emphasis on multiple production and distribution tiers in the supply chain. Third, broadening performance measures used in global supply chain models in definition to address alternative objectives.

There are many papers in the literature relating to the mathematical modeling of global aspects (Vidal and Goetschalckx, 2001; Sheu 2004; Wu 2010; Peron et al 2010, Hammami et al. 2014, Hammami et al. 2012, etc.). These papers didn't survey uncertainties in the global supply chains. However there are some researches which considered uncertainties in the global supply chains. Goh et al. (2007) presented a stochastic model for risk management in global supply chain networks. They studied a multi-stage global supply chain network problem, incorporating a set of related risks, namely, supply, demand, exchange, and disruption. Sawik (2011), surveyed he optimal selection of supply portfolio in a make-to-order environment in the presence of supply chain disruption risks. Also, Sawik (2015) presented a mathematical supply chain risk model considering different regions for the suppliers to cope with supplier disruption uncertainties. In addition to these papers, there some papers relating to the concept of risk management in the global supply chain. For example Manuj and Mentzer (2008-b) explained Global supply chain risk management strategies. These papers surveyed the concept of risk management without mathematical modeling and their focuses mainly are on the strategic risk management in the global supply chain.

Besides of the papers considered globalization aspects and related risks in the supply chain, there are many papers studied risk management in the supply chain. Fahimnia et al (2015) reviewed quantitative models for managing supply chain risks. They classified the literature as: Upstream supply chain risks, Downstream supply chain risks, Uncertainty modeling in supply chain network design and facility location, Uncertainty modeling in tactical/operational supply chain planning, Supply and demand forecasting analysis, Uncertainty modeling in inventory management and process control, Sustainability risks, Uncertainty in purchasing and retail sourcing. Also Heckmann et al (2015) reviewed supply chain risks. They categorized the risks as Network and process. In the network subcategory based on the stakeholders, the risks are: Supplier-related (disruptions, delays, systems, information processing, intellectual property, procurement, receivables); Internal (disruptions, delays, systems, information processing, and procurement); Customer-related (disruptions, delays, systems, information processing, and receivables).

However, as mentioned by Tang and Musa (2011), quantifying the risk in the supply chain is a challenge. In addition one of the best tools to cope with uncertainty in the supply chain is simulation (Law, 2015). There are some of the researches which surveyed the application of simulation in the supply chain. Thierry et al. (2010) explained different simulation approaches to SCM. Based on their research, there are two important approaches: 1- continuous simulation (e.g. System Dynamics) and 2- discrete event simulation. In recent years, more researches have been focus on the supply chain simulation. For example Ramanathen (2014) investigated the performance of supply chain collaboration using simulation. Also Cigolini et al. (2014) studied supply chain configuration based on the performance by using discrete event simulation.

Therefore, based on the above literature review, quantifying the supply chain uncertainties is an important challenge. In addition, simulation is a proper tool to cope with uncertainties. Monte Carlo simulation is a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making. This approach relies on repeated random sampling to obtain numerical results. Disruptions in the supply chain (as a random event) can be simulated using repeated random sampling. Thus in this paper, we will survey the uncertainties in the global supply chain using monte carlo simulation approach. The paper is organized as follows:

In the third section, the problem and intended supply chain is defined. In section 4, risk assessment process through simulation is presented. In section 5, a numerical example with different risk behaviors and different order policies is surveyed. Conclusions and future works are suggested in section 6.

3. Problem description

The model assumes that there are two suppliers, S1 and S2, and two manufacturers, M1 and M2. Assume that the suppliers are located the different geographical regions.

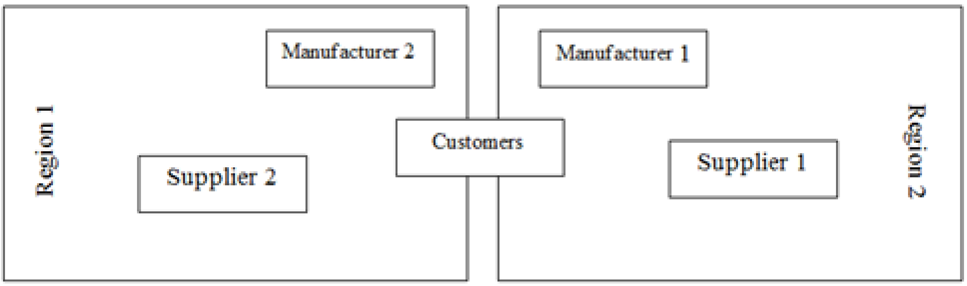

Figure 2. A schematic of the supply chain

Normally, S1 supplies only M1 and S2 supplies only M2. The lead times for orders from these "primary" suppliers are 2 weeks each. However, there are occasional disruptions at the suppliers, and each disruption can last a random number of weeks. If an order is placed during a disruption period, this order is ignored by the supplier, resulting in an increased chance of stockouts at the manufacturer. To mitigate this, the supply chain can "share" suppliers, so that, for example, if M1 places an order with S1 and S1 is experiencing a disruption, the order can be filled by S2, unless S2 is also experiencing a disruption. The model assumes ample capacity at the suppliers, but the lead times are longer from the shared suppliers.

In addition to the disruption of each supplier (denote by P_i), disruption of the supply procedure may stem from the region disruption (denote by P_R). Region disruption will disrupt the supplier. Therefore disruption probability of every supplier (π_i) will be:

$$\pi_i = P_R + (1 - P_R)P_i \quad (1)$$

The model assumes Pert distributed weekly demands at the manufacturers and geometrically distributed times between disruptions at the suppliers, where each disruption lasts for a discrete distributed number of weeks. Each manufacturer uses an order policy characterized by a reorder point and an order quantity. Specifically, if the manufacturer's inventory position (onhand inventory minus stockouts plus items in the delivery pipeline) is less than or equal to the reorder point, an order for the specified quantity is placed.

4. Risk assessment using monte-carlo simulation

One of the popular percentile measures of risk is Value at Risk (VaR). Considering $F_X(z)$ as the cumulative distribution function of X, the VaR of X with confidence level $\alpha \in (0, 1)$ is:

$$\mathrm{VaR}_\alpha(X) = \min\{z | F_X(z) \geq \alpha\} \quad (2)$$

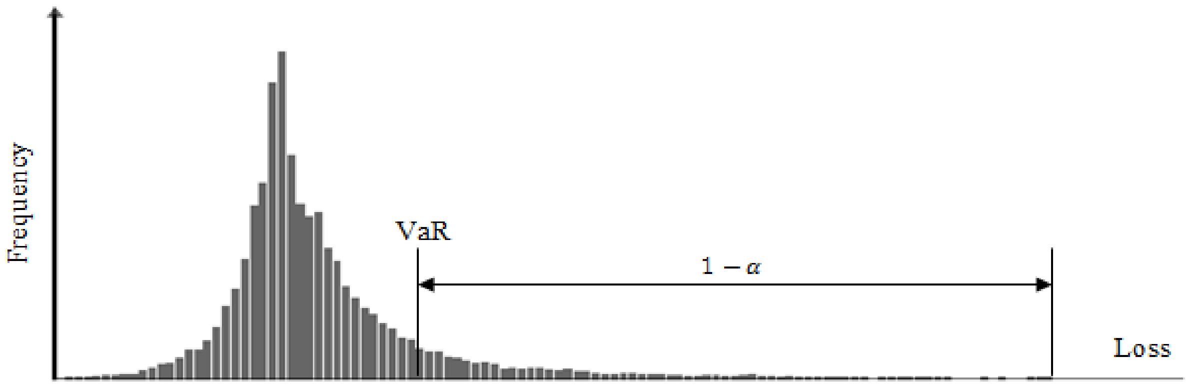

Figure 3. Illustration of VaR

An alternative percentile measure of risk is conditional value-at-risk (CVaR). Indeed, CVaR accounts for losses exceeding VaR. In other words, VaR is a lower bound for CVaR. To define CVaR, we need $\lambda_\alpha(X)$ and $CVaR_\alpha^+(X)$: (Sarykalin et al., 2008)

$$\lambda_\alpha(X) = \frac{F_X(VaR_\alpha(X)) - \alpha}{1-\alpha} \tag{3}$$

$$CVaR_\alpha^+(X) = E[X|X > VaR_\alpha(X)] \tag{4}$$

Therefore:

$$CVaR_\alpha(X) = \lambda_\alpha(X)VaR_\alpha(X) + (1-\lambda_\alpha(X))CVaR_\alpha^+(X) \tag{5}$$

In this paper, cost of the orders ($\sum_t co_t$) and number of stokouts ($\sum_t so_t^1 + so_t^2$) are two variables to calculate the "VaR". In the problem defined in the previous section, uncertain parameters in each period are: $\tilde{d}_t$ (demand of the customers in period t), $\tilde{e}_t$ (exchange rate in period t), π_i (probability of supplier i's disruption), $\tilde{l}_t^i$ (the length of the supplier i's disruption in period t). Also o_{ji}^t is the amount of order manufacturer j from supplier i (i,j=1,2).

The value of o_{ij}^t depends on $\tilde{d}_t$, $\tilde{e}_t$, π_i and $\tilde{l}_t^i$. Also so_t^i depends on all of the above parameters except $\tilde{e}_t$. In this paper, the cost of stockouts is ignored. Thus cost of orders is defined as follows:

$$co_{1t} = g_1 \times o_{11}^t + g_2 \times o_{12}^t \times \tilde{e}_t$$
$$co_{2t} = g_2 \times o_{22}^t + g_1 \times o_{21}^t \times \tilde{e}_t \tag{6}$$

In which $g_1$and $g_2$are the price of the product in region 1 and region 2 respectively.

In addition, probability of the times between two disruptions of supplier i (if it is equal to k weeks) is as follows:

$$P(X_i\text{=k})=(1-\pi_i)^{k-1}\,\pi_i \tag{7}$$

Based on the formulas (2)-(5), risk assessment framework using monte-calro simulation is as follows:

While (stop condition of the simulation)
    Generate disruption probabilities of suppliers and length duration of disruption
    While (stop condition of iterations)
        Check disruptions in the current period
        //Generate the next disruption if it is occurred in the period//
        Check order sharing from the other supplier
        Calculate the cost of the (internal/external) orders and stockouts
        //external orders will be subjected to exchange rate and extended leadtime//
    end
Calculate $F_X(costs)$ and $F_X(stouckouts)$and then VaR_α
end
Calculate $F_X(VaR_\alpha(X))$ and ten $CVaR_\alpha$

Sharing of suppliers will occur when: $\pi_i > \beta$; Indeed β is a threshold to share the suppliers. Setting small values for β results in risk averse manner and setting large amount of β results in accepting the risks. Therefore, in this paper we measure VaR in two scenarios: large amount of β and small amount of β. High value of β will result in more disruptions and therefore more stockouts and conversely for the low value of β.

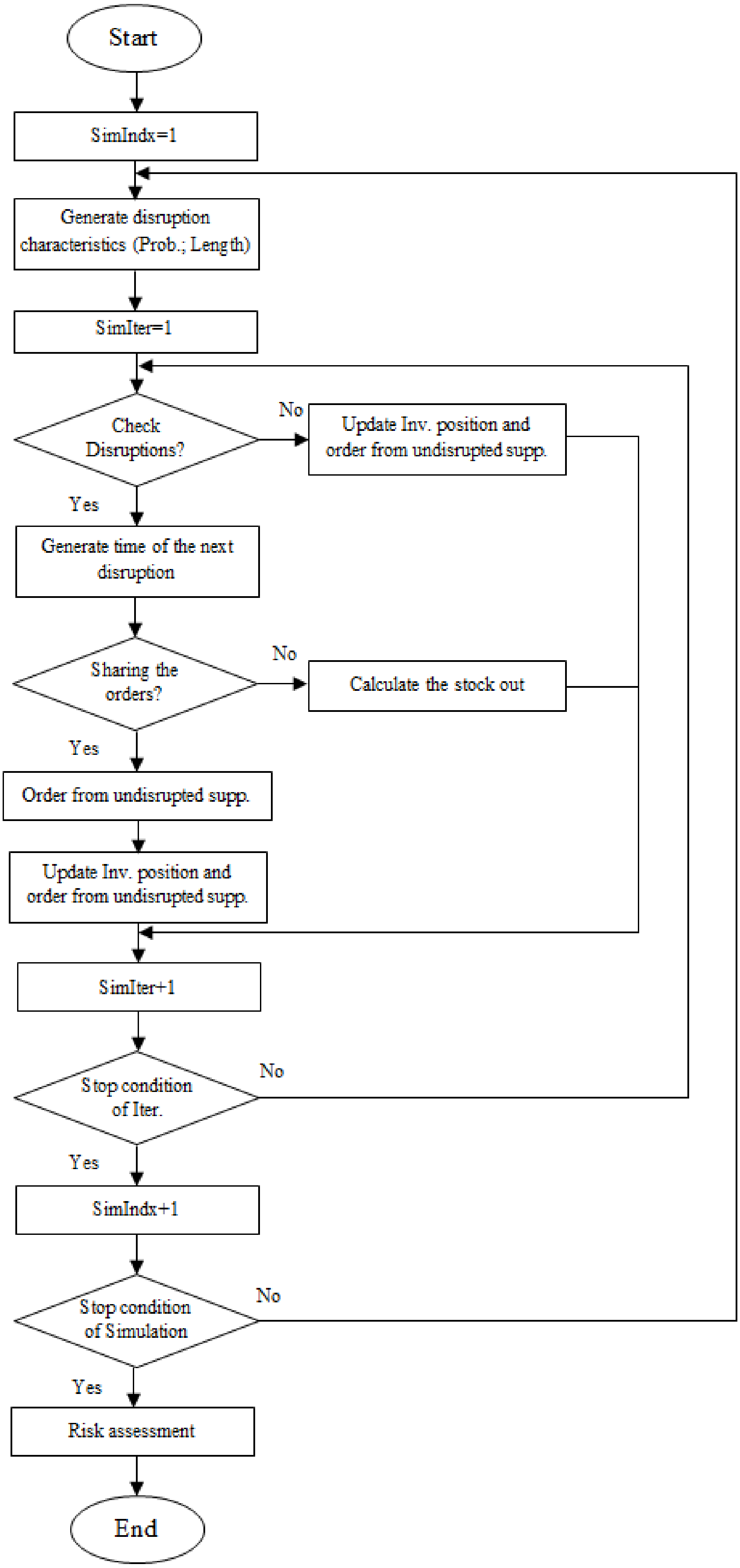

Figure 4. Simulation framework

5. Numerical example

As discussed in the section 3, considered supply chain consists of two different regions. In each region, there are one supplier and one manufacturer. These regions have different exchange rates. Two currency regions considered in the problem are: region 1- US dollar and region, 2- Euro). The price of the product in region 1 is “10 US dollars” and in region 2 is “9.391 Euros” at the first period. For 260 weeks (5 years) between (October 2010 to October 2015), rate of US dollar/Euro is as follows. In the case of sharing the suppliers, manufacturer in a region can order a product under the exchange rate shown in figure 5.

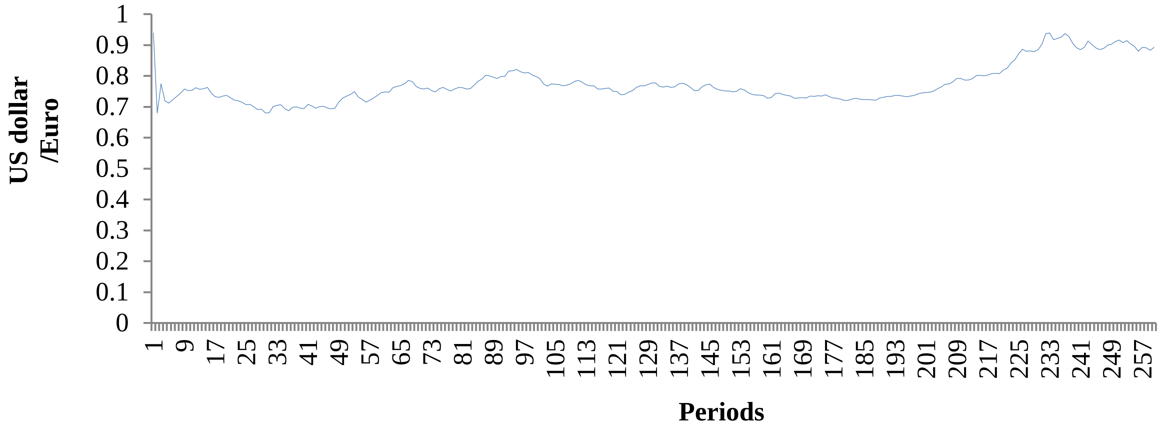

Figure 5. “US dollar/ Euro” changes between October 2010 to October 2015 (World Bank, 2015)

Disruption probabilities of the regions are generated using uniform distribution (U[0.001,0.005]) and local disruption of the suppliers are generated using U[0.0001,0.025]. In each runs of the simulation whenever the disruption probability of each suppliers (π_i) exceed from β (=0.025, 0.02, 0.015, 0.01, 0.05), manufacturers can order from both of the suppliers, otherwise each manufacturer should order from the supplier located in the same region. The time between disruptions is generated using geometric distribution with parameter π_i. In addition the lengths of the disruptions are calculated as follows:

Table 1. length of the local disruptions of supplier 1, 2

Weeks	Probability
1	0.2
2	0.3
3	0.3
4	0.2

Order leadtimes will be as follows:

Table 2. Order leadtimes of manufacturer 1,2 from suppliers 1,2

From\To	M1	M2
S1	2	4
S2	3	2

Note that leadtime of ordering from the other region is larger than order from the same region. The distribution of demands is considered as Triangular distribution with the below parameters.

Table 3. Demands of customers from manufacturer 1,2

	Minimum	Most likely	Maximum
M1	100	150	250
M2	200	300	500

In addition, to minimize sum of mean average onhand inventory and total stockouts in the case where there are no disruption, each manufacturer uses an order policy characterized by a reorder point and an order quantity. If the manufacturer's inventory position (onhand inventory minus stockouts plus items in the delivery pipeline) is less than or equal to the reorder point, an order for the specified quantity is placed.

Table 4. Order policy of manufacturers when there are no disruptions

	M1	M2
Reorder point	380	760
Quantity	210	420

To simulate the supply chain, monte carlo risk simulation software (@risk) is used. 50 simulation runs with 100 iteration in each run using @risk software result in following outputs. The initial inventory of manufacturer 1,2 are considered respectively as: 300, 600.
The number of weeks wherein supplier 1 under β is disrupted is as follows:

Table 5. Average of the weeks with disruption of supplier 1,2

Order policy	Average of the weeks with disruption of supplier 1	Average of the weeks with disruption of supplier 2
$\beta = 0.025$	9.8	9.8
$\beta = 0.02$	10.1	9.7
$\beta = 0.015$	10.1	9.9
$\beta = 0.01$	9.7	9.8
$\beta = 0.005$	10	9.9

In addition, suppliers order from the manufacturers in the other region is as follows:

Table 6. order policy of manufacturers when there are no disruptions

Order policy	Average orders of supplier 1 from manufacturer 2	Average orders of supplier 2 from manufacturer 1
$\beta = 0.025$	2.0	2.0
$\beta = 0.02$	4.6	4.7
$\beta = 0.015$	6.2	6.5
$\beta = 0.01$	6.9	6.9
$\beta = 0.005$	7.2	7.3

The number of supplier 1 not filled orders from manufacturer 2 is:

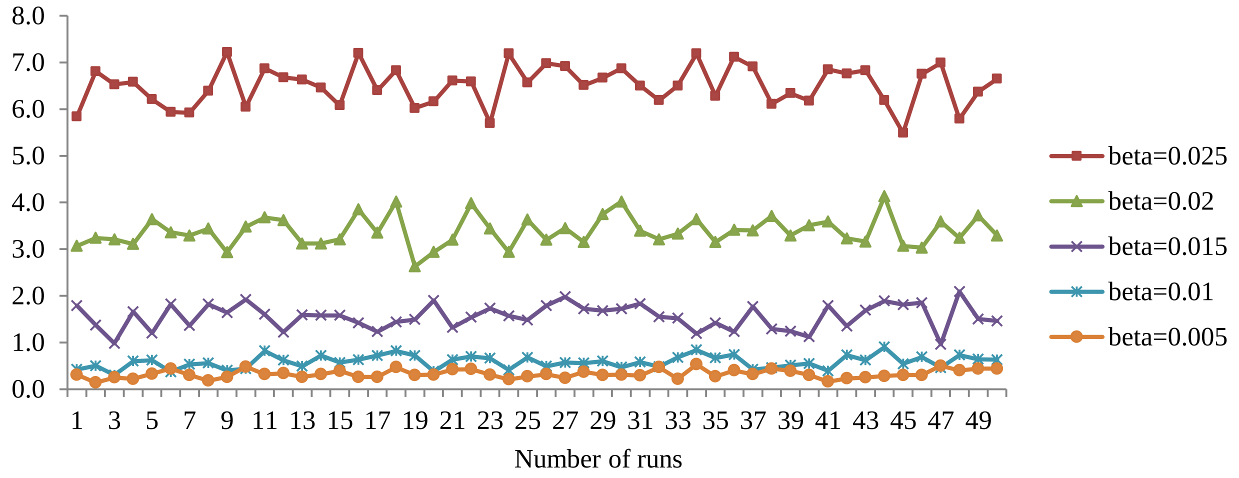

Figure 6. The effect of β on the number of "supplier 1" not filled orders from manufacturer 2

The number of supplier 2 not filled orders from manufacturer 1 is:

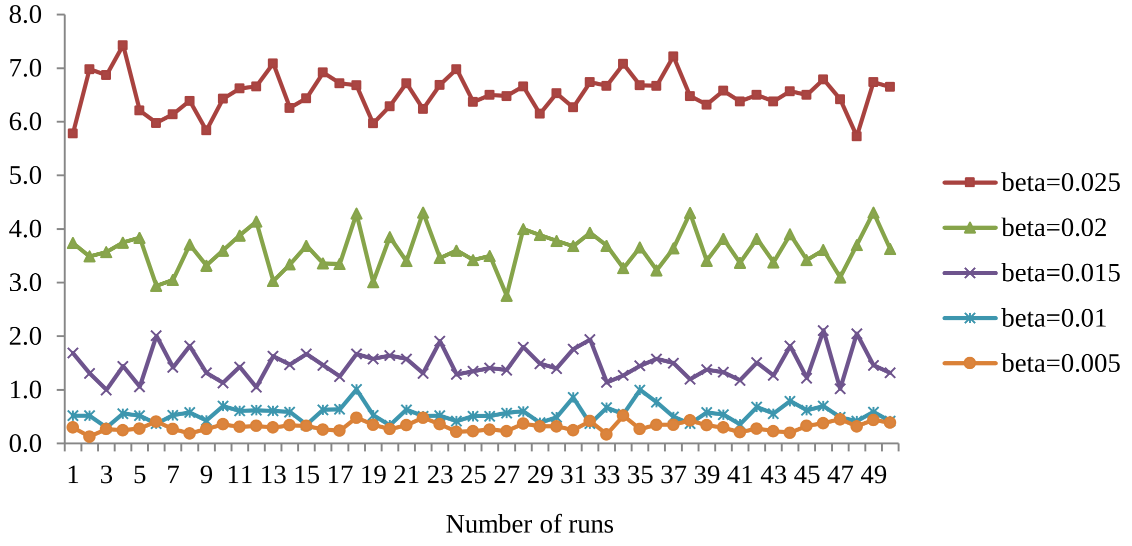

Figure 7. The effect of β on the number of" supplier 2" not filled orders from "manufacturer 1"

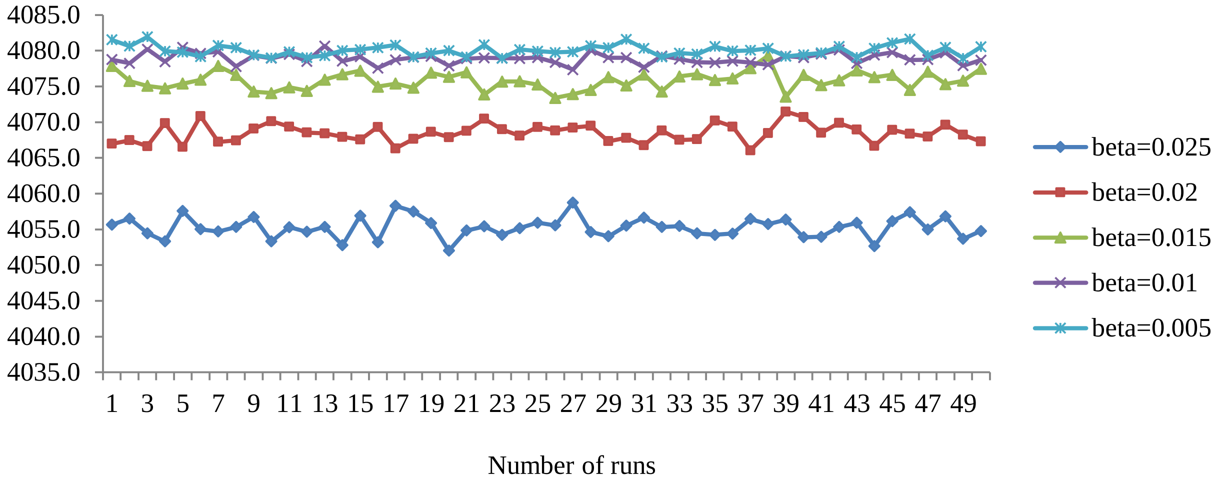

Figure 8. The effect of β on the average cost of ordering in the supply chain

According to figures 6, 7 and 8, $\beta = 0.005$ has the worst cost and has the minimum number of suppliers' not filled orders from manufacturers. Indeed, risk aversion approach increase the cost of ordering and also decrease disruptions. On the other hand, $\beta = 0.025$ will result in the minimum cost and maximum disruptions.

By averaging the amounts of costs and stockouts, we will have:

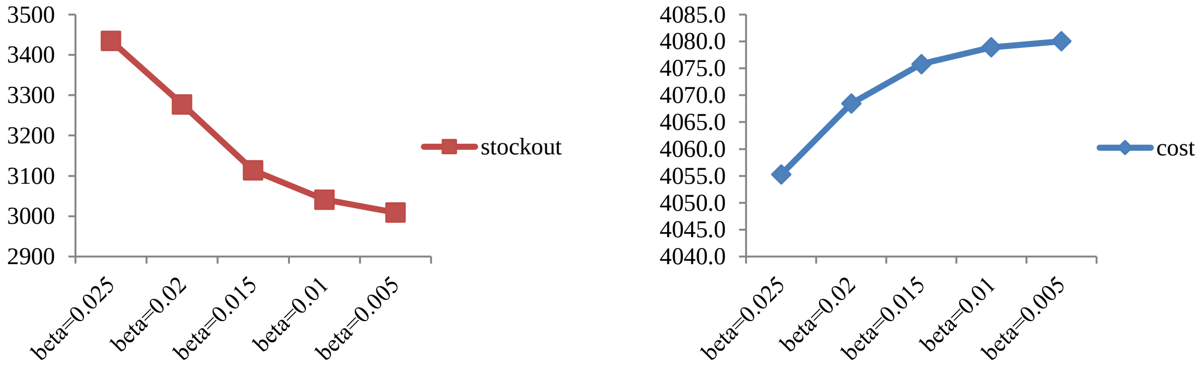

Figure 9. Average costs and average stockouts

Consider basic model discussed before the section 5.1. Based on the relations (2-5) the results of risk measurement with α =0.95, 0.99 is:

Table 7. $VaR_{0.95}$ and $VaR_{0.99}$ for the cost of orders and total stockouts

Order policy	Average cost of orders		Average total stock outs	
	$VaR_{0.95}$	$VaR_{0.99}$	$VaR_{0.95}$	$VaR_{0.99}$
$\beta = 0.025$	4120.473	4147.754	20077.79	30017.36
$\beta = 0.02$	4133.16	4159.51	11294.08	16929.09
$\beta = 0.015$	4140.991	4163.421	7629.39	12507.83
$\beta = 0.01$	4141.811	4160.693	4293.79	7108.66
$\beta = 0.005$	4142.529	4162.213	3646.67	5050.34

To calculate CVaR, we need to obtain $F(VaR_{\alpha})$ and λ_{α} are calculated for each order policies. The results are obtained as follows:

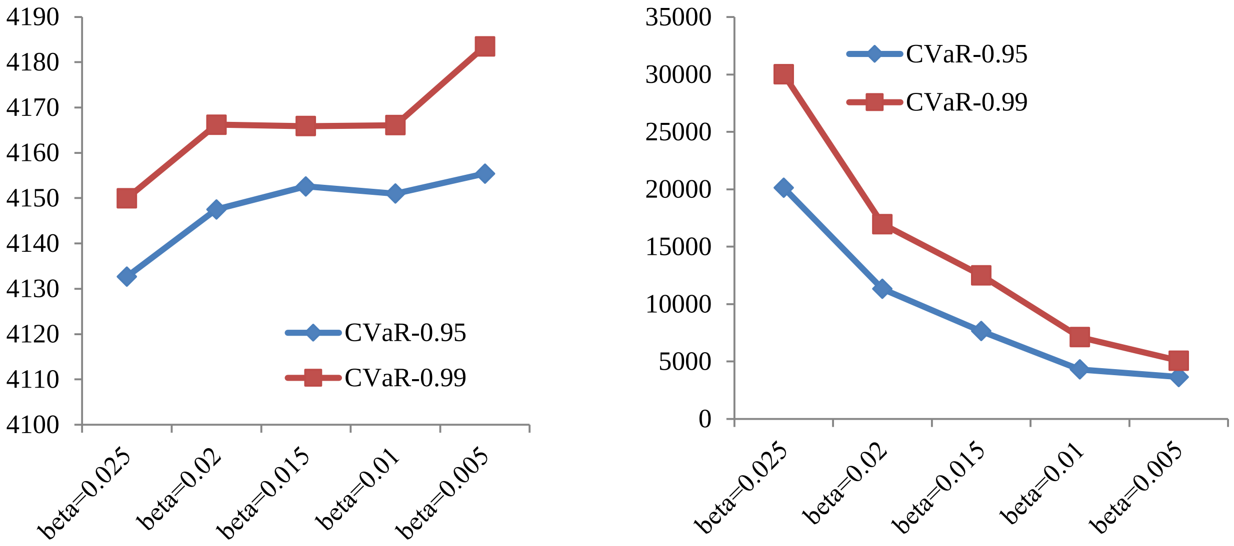

Figure 9. $CVaR_{0.95}$ and $CVaR_{0.99}$ for the cost of orders (left) and total stockouts (right)

As shown in the above figure, by decreasing β, risk index (CVaR) related to the cost of orders will increase. Instead, risk index related to the stockouts will decrease by decreasing the value of β.

6. Conclusions

In this paper, risk assessment of the global supply chain is surveyed using monte carlo simulation. Simulation of the uncertainties in the supply chain was performed using @risk software. The main global aspects of the considered supply chain are: 1- currency exchange rate (exchange rate of US dollar and Euro), 2- extended leadtimes (supplying from the foreign supplier will result in the larger leadtimes), 3- considering disruption of the region in addition to the local disruption of suppliers. In this paper, we examined different conditions of these global aspects on the cost of orders and stockouts. As mentioned by Manuj and Mentzer (2008-a), global risk assessment consists of 5 steps which the second step is: "risk assessment and evaluation". The focus of this paper was on the quantifying the risk in the supply chain. Also based on Tang and Musa (2011), quantifying the risk of supply chains is a challenge. According to the literature review, two popular methods of risk assessment are: Value at Risk (VaR) and Conditional Value at Risk (CVaR). In this paper, these methods were used in a simulation framework to assess the risks of loss and stuckout in a two echelon supply chain with supplier disruption uncertainties (consist of two suppliers and two manufacturers in two different currency zones). The results showed that in the case of risk aversion (risk behaviors defined by β), the cost of the orders in the supply chain will increase and stockouts will decrease. Extending supply chain layers and evaluating the effect of the uncertainties in each layer can be considered as the future works.

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