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An Emergency Ordering Model for Multi-Item Multi-Product Environment

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ABSTRACT

This paper presents a multi-item, multi-product inventory problem with disruption in the supply of items. Items can be procured from two separate channels called cheap unreliable suppliers and expensive reliable suppliers called emergency supplier. Although taking advantage of cheap suppliers can decrease ordering expenses, it can lead to huge backorder charges in case of disruption. A two-stage decision making process is proposed in which in the first stage the orders are released to the cheap suppliers and in the second stage when new information about the yield of unreliable suppliers are revealed, orders can be released to the reliable emergency supplier. In order to overcome the complexities of the two-stage stochastic model, a Sample Average Approximation method is applied in the model which provide high quality solutions for the proposed model.
KEYWORDS: Supply Disruption, Emergency Ordering, Multi-Product Inventory Problem, Random Yield, Inventory Problem.

1. INTRODUCTION

Recently, implementing lean production practices has improved operational and financial performance of industrial organizations by employing bare bone inventory strategies, cooperating with the least number of qualified suppliers or using the highest capacity of equipments. Although using such practices can improve the attained net profit in a problem-free environment, they leave huge losses on the system in case of disruption.Despite the potential losses which might be incured due to disruption, only a small portion of studies consider disruption in their assumptions. This paper address the effectiveness of emergency ordering to manage the effect of disruption on the supply chain.

In order to confront the effect of such uncertainties on the system, Inventory Mitigation and Sourcing Mitigation Strategies are utilized in practice. Inventory Mitigation strategy suggest to keep extra inventory to protect the system against backorders according to the unpredictable events. Although the increase of the inventory level reduces the stock out expenses, it charges higher inventory holding expenses tothe system. Accordingly a trade-off between stock out costs and inventory holding costs should be achievedwhen Inventory Mitigation Policy is utilized.On the other hand, a proper Sourcing Mitigation Strategy indicates that several suppliers should be utilized.

In several contemprery instances availability of emergency supplier has emerged as a god-sent for managers. After a fire at Aisin Seiki Co. , the main valve supplier of Toyota, Toyota was able to use Somic as its temporary supply source [1]. Although using an emergency supplier may increase the incured charges, it can decrease huge financial loses in case of disruption. In many environments products are made of several items and lack of any item leads to inability in the production of the related final products. Such assumptions are applicaple in a variety of industries such as pharmaceutical, chemical or assembly lines.

In this paper, in order to overcome the uncertainties in suppliy of items, an emergency ordering approach embeded in a two-stage decision process is utilized in which in the first stage the orders are initially released to the cheap unreliable suppliers and in the second stage when uncertainties are cleared orders to the expensive reliable suppliers(emergency suppliers) are released. It could be intuitively percieved that in such problems using Inventory Mitigation strategy loss its effectiveness due to the variety of items and it is only possible to rely on Sourcing Mitigation strategies.

The rest of this paper is organized as follows. In section 2 the literature is reviewed. In section 3, the mathematical model is proposed. In section 4, Sample Average Approximation Method is proposed to solve the problem. The computational experiments and sensitivity analysis is presented in section 5. This paper is concluded in section 6.

2. LITERATURE REVIEW

In this section, a review of the most relevant literature of inventory management models with disruption is presented. Inventory Mitigation and Sourcing Mitigation strategies form the majority of Inventory models with uncertainty. Inventory Mitigation tactics attempts to decrease the effect of disruption by keeping higher inventory level

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while Sourcing Mitigation tactics take into account several suppliers to distribute the risk between them. Despite advantages of using a single supplier such as lower supplier management expenses or the possibility of taking discount offers from the supplier, reliance on only a single supplier makes the system more vulnerable against probable uncertainties.

Ferrer[2]concentrates on a implementing a single supplierin a single period time structure.Xiao and Qi[3]present a single supplier dealing with two competing retailers. Keren [4]investigates a sole supplier environment where the supplier is prone to supply yield uncertainty.Zeynep Sargut and Qi[5]consider a single unreliable supplier and a single retailer. Not considering a plan B when the supplier is disrupted other than keeping higher inventory in the above papers, they only rely on Inventory Mitigation tactics to manage disruptions.

On the other hand, Sourcing Mitigation tactics are considered as the main strategy in the other portion of the related literature. Two differentclass of sourcing mitigation models are presented by the researchers where inthe first type the order quantities are released at a moment before exact realization about uncertain parameters. In such strategies no recourse action is allowed after achieving new data about uncertainties. While in the second type, called contingency/emergency ordering models, the decisions about the orders are determined in a consecutive decision process in which initially the orders are released to the cheap unreliable supplier and later when uncertain parameters are revealed, emergency orders are placed to the reliable expensive supplier. Parlar and Perry[6] considers two identical-price suppliers where the suppliers are randomly and independently disrupted where two exponential distributions are adapted for the repair and failure process. Dada, Petruzzi, and Schwarz[7]study a single period inventory problem with multiple unreliable suppliers and different prices and reliabilities.Tomlin and Wang [8] compares single and dual sourcing policy for a supply chain with multiple products with two dissimilar dual sources.Babich, Burnetas, and Ritchken [9] investigates several competing suppliers with dissimilar suppliers where the proposed model attempts to procure form the cheapest suppliers and taking advantage of supply diversification. Wang, Gilland and Tomlin [10]presents the process improvement strategy to improve the reliability of unreliable suppliers and considered a dual sourcing model with both identical and non-identical situations. Emergency sourcing literature is ordered as follows.Babich[11]studied a dual sourcing model where the supplier with lower lead time is considered as the emergency source. Tomlin [12]presented a contingent sourcing strategy with a capacitated emergency supplier where the procurement cost for the quantities ordered over the regular capacity is higher. Chopra, Reinhardt, and Mohan [13]presented an emergency sourcing scheme for a newsvendor inventory problem. Schmitt and Snyder [14]considered a sourcing assumption similar to the work of Chopra, Reinhardt, and Mohan [13] and extended their study by considering a multi period time structure. Babich [11], Tomlin [15], Chopra, Reinhardt, and Mohan [13], Schmitt and Snyder [14] considered that exactly after it is realized that the unreliable supplier is disrupted, the decision maker will reroute to the reliable supplier, while Qi[16]assumes that it is possible to wait for a while for the recovery of the unreliable supplier and during this waiting time, safety stock is used[16]. In addition, Dong and Tomlin[17] compares emergency ordering and insurance against interruption in their problem. Chen and Yang [18]studied a supply chain where a buyer purchases finished items from a contracting supplier to satisfy a stochastic market demand and the supplier's production is subject to random yield and it is possible to satisfy the demand by emergency supplier.

Several types of flexible contracts including backup contracts, quantity flexibility contracts, revenue sharing contracts, etc., has proposed to coordinatesupply chain with emergency sourcing options. Eppen and Iyer[19]proposed a backup agreement where the buyer commits an order quantity and a part of this order should be delivered initially and the other portion may be proqured at a later time where the buyer is incured to pay a penalty for the committed units not purchased. In another type of contracts called quantity-flexibility contracts, a forecast of future orders is initially provided and later the decision maker place the actual order which is within the pre-specified limits of the original forecasts. Bassok et al.[20],Tsay and Lovejoy [21]are performed by considering such assumption.In agreements called pay-to-delay capacity reservation, the supplier gives a fixed payment and the buyer could then place orders and offersthe payment for the actual procurement costs [22].

Although several papers have been performed in a multi-product, multi-source scheme, the number of papers which considers emergency ordering too is limited. In a nutshell, it can be mentioned that this paper is performed to fill the literature gapwith multi-product multi-item environments with emergency ordering where in order to produce a unit of final product, several items should be delivered.

3. Proposed Model

3.1. Problem descriptionand assumptions

This paper presents a multi-item, multi-product environment where each final product consists of different ingredients/parts. Not availability of any item leads to inability in the production of the final product in which makes the ordering process items more interrelated. Orders are released in a two stage decision process in which in the first stage the orders are released to the cheap unreliable suppliers and later when new information about uncertain parameters becomes available, the orders to the expensive reliable suppliers are released. The cheap unreliable suppliers are prone to yield uncertainty while emergency suppliers are perfectly reliable and can supply the system with a higher unit procurement price. Cheap suppliers are prone to yield uncertainty where only a portion of the ordered quantity is delivered. At least one reliable and one unreliable supplier are considered for any item. The purpose of the model is to determine the optimal order quantities to take advantage of both cheap prices of unreliable source and reliability of unreliable suppliers. In addition this model tries to establish the proper relationship between the ordering and production planning decision. the additional quantities are salvaged at the end of the planning horizon. The lead times are considered to be zero. The model is developed for the operational level of supply chain. Figure 1 depicts the sequence of decision making in the proposed model.

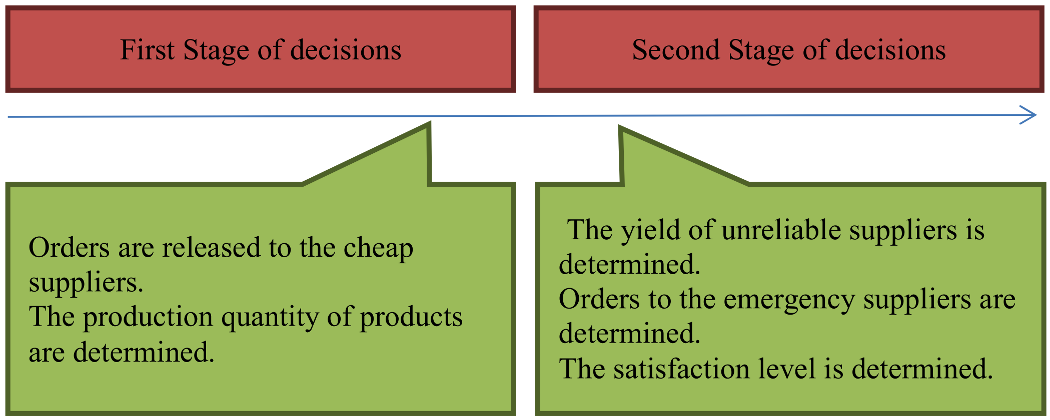

Figure 1. Decision Sequence in the proposed model

3.2. Model Development
3.2.1. Notations

Indices

i	Item/ingredient i=1,…,I
p	Product p =1,…,P
u	Unreliable supplier
r	Reliable supplier
t	Time period t=1,…,T
s	Scenario $s = 1,...,S$

Parameters

u_i	Unreliable supplier set that can supply item i
r_i	Reliable (emergency) supplier that can supply item i
$D_{p,t}$	Demand of product p in period t for scenario s
$Y_{i,u,t,s}$	Yield of item i in period t from supplier u for scenario s
$\overline{Y}_{i,u,t}$	The average yield for item i from unreliable supplier u that are capable to supply that product
$BO_{i,p}$	Bill of material of item i in product p
PRB_s	Probability of Scenario s
W	Warehouse Space
SI_i	Space required for a unit of Item i
SP_p	Space required for a unit of Product p
$PU_{i,u,t}$	unit Procurement price of the Item i from Unreliable supplier u in period t
$PR_{i,r,t}$	unit Procurement price of the Item i from Reliable supplier r in period t
$BC_{p,t}$	unit Backorder Penalty of product p for period t

$LC_{p,t}$	unit Lost sale Penalty of product p at the end of the horizon
SI_i	salvage or Book value of Item i at the end of the planning period
SP_p	salvage or Book value of Product p at the end of the planning period
$PRC_{p,t}$	Production Cost for unit of product p in period t
HI_i	Holding Cost of Item i in period t
HP_p	Holding Cost of Product p in period t
$EA_{p,t}$	Unit selling price of product p in period t
SVI_i	Salvage value of Item i at the end of the planning period
SVP_p	Salvage value of Product p at the end of the planning period
$CAP_{i,r}$	Capacity of supplier r for item i

Variables

$II_{i,t,s}$	Inventory level of Item i in period t with scenario s
$IP_{p,t,s}$	Inventory level of Product p in period t with scenario s
$OU_{i,u,t}$	Order quantity of item i to Unreliable supplier u to be received in period t
$OR_{i,r,t,s}$	Order quantity of item i to Reliable supplier r in period t with scenario s
$C_{i,t,s}$	Consumed amount of item i in period t with scenario s
$FD_{p,t,s}$	Fulfilled Demand of product p in period t with scenario s
$PRO_{p,t}$	Production plan of product p for period t
$B_{p,t,s}$	Backorder of product p in period t with scenario s

3.3. Model Formulation

The related model is formulated as follows.

$$\max\left\{\begin{array}{l} -\sum_{i=1}^{I}\sum_{u=1}^{u_i}\sum_{t=1}^{T}\left(PU_{i,u,t}\times\bar{Y}_{i,u,t}\times OU_{i,u,t}\right)-\sum_{p=1}^{P}\sum_{t=1}^{T}\left(PRC_{p,t}\times PRO_{p,t}\right) \\ +\sum_{s=1}^{S}PRB_s\times\left(\begin{array}{l}\sum_{p=1}^{P}\sum_{t=1}^{T}\left(EA_{p,t}\times FD_{p,t,s}\right)-\sum_{i=1}^{I}\sum_{t=1}^{T}\left(HI_i\times II_{i,t,s}\right)-\sum_{p=1}^{P}\sum_{t=1}^{T}\left(HP_p\times IP_{p,t,s}\right) \\ -\sum_{i=1}^{I}\sum_{r=1}^{r_i}\sum_{t=1}^{T}\left(PR_{i,r,t}\times OR_{i,r,t,s}\right)-\sum_{p=1}^{P}\sum_{t=1}^{T}\left(BC_{p,t}\times B_{p,t,s}\right) \\ -\sum_{p=1}^{P}\left(LC_{p,t}\times B_{p,T,s}\right)+\sum_{i=1}^{I}SVI_i\times II_{i,T,s}+\sum_{p=1}^{P}SVP_p\times IP_{p,T,s}\end{array}\right)\end{array}\right\} \quad (1)$$

$$\left\{\begin{array}{ll} \sum_{u=1}^{u_i}Y_{i,u,t,s}\times OU_{i,u,t}+\sum_{r=1}^{r_i}OR_{i,r,t,s}=II_{i,t,s}+C_{i,t,s} & \forall i,s,t=1 \\ II_{i,t-1,s}+\sum_{u=1}^{u_i}Y_{i,u,t,s}\times OU_{i,u,t}+\sum_{r=1}^{r_i}OR_{i,r,t,s}=II_{i,t,s}+C_{i,t,s} & \forall i,s,t=2,\ldots,T \end{array}\right. \quad (2)$$

$$\begin{cases} PRO_{p,t} = IP_{p,t,s} + FD_{p,t,s} & \forall p,s,t=1 \\ IP_{p,t-1,s} + PRO_{p,t} - B_{p,t-1,s} = IP_{p,t,s} + FD_{p,t,s} & \forall p,s,t=2,\dots,T \end{cases} \tag{3}$$

$$FD_{p,t,s} = D_{p,t} - B_{p,t,s} \quad \forall p,s,t \tag{4}$$

$$\sum_{i=1}^{I} SI_i \times II_{i,t,s} + \sum_{p=1}^{P} SP_p \times IP_{p,t,s} \le W \quad \forall s,t \tag{5}$$

$$\sum_{p=1}^{P} BO_{i,p} \times PRO_{p,t} = C_{i,t,s} \quad \forall i,s,t \tag{6}$$

$$OR_{i,r,t,s} \le CAP_{i,r} \;, \forall i,r,s,t \tag{7}$$

$$II_{i,t,s}, IP_{p,t,s}, OU_{i,u,t}, OR_{i,r,t,s}, C_{i,t,s}, FD_{p,t,s}, PRO_{p,t}, B_{p,t,s} \ge 0 \tag{8}$$

Equation (1) is the profit objective function which consists of the first and second stage parts. Equation (2) balances the inventory level for items. Equation (3) balances the inventory level of products.Equation (4) determines that the demand of each product can be fulfilled or backordered. Equation (5) considers the warehouse capacity for products and items.Equation (6) determines the required quantity of items to produce the final products. Equation (7) restricts the order quantities to the emergency supplier capacity. Equation (8) is the non-negativity of variables.

4. SOLUTION METHODOLOGY

In order to solve the two-stage stochastic optimization problem, several methods are proposed. In this paper, Sample Average Approximation method is utilized to solve the problem. This approach is presented in the next section.

4.1. Sample Average Approximation (SAA)

Sample Average Approximation method attempts to estimate the value of the objective function by solving the problem with smaller size. The major steps of this algorithm are presented as follows:

Initialization: Generate M sample problems $(m = 1, \dots M)$ in which each of them include N_m independently and identically distributed (i.i.d.) scenarios. Consider a bigger scenario set with N' scenarios called reference set $\left(N' >> N\right)$. x_m is considered as the first stage decision variables.

Step 1: Solve each of the sample problems and represent the value of the objective function by v_N^m.

Step 2: Calculate the average and variance attained in the previous section as follows.

$$\bar{v}_{N,M} = \frac{1}{M}\sum_{m=1}^{M} v_N^m \tag{9}$$

$$\sigma^2_{\bar{v}_{N,M}} = \frac{1}{M \times (M-1)} \times \sum_{m=1}^{M}\left(v_N^m - \bar{v}_{N,M}\right)^2 \tag{10}$$

Step 3: Substitute the first stage values in the problem with the reference scenario set to attain a better approximation of the objective function and call it $f_{N'}\left(\bar{x}\right)$. This value is the lower bound of the original problem. Calculate the variance of $f_{N'}\left(\bar{x}\right)$ for different scenarios and call it $\sigma^2_{N'}\left(\bar{x}\right)$.

Step 4: calculate the optimality gap and variance of the estimators

$$GAP = \bar{v}_{N,M} - f_{N'}\left(\bar{x}\right) \tag{11}$$

$$\sigma^2_{\text{gap}} = \sigma^2_{\bar{v}_{N,M}} + \sigma^2_{N'}\left(\bar{x}\right) \tag{12}$$

The optimality gap confidence interval is calculated as follows.

$$\tilde{f}_{N'}\left(\bar{x}\right) - \bar{v}_{N,M} + z_\alpha \times \sigma_{gap} \tag{13}$$

It should be considered that in the above equation $F(z)$ is cumulative distribution function of the standard normal distribution and $z_\alpha = F^{-1}(1-\alpha)$.

5. Case Study

The proposed model is implemented in an assembly line of car switches located in Iran. The unreliable suppliers are considered to be the manufacturers of the components in which the unreliability of these suppliers arise due to production uncertainty which is modelled by yield uncertainty concepts.

In this study 8 products which is constituted from 4 to 7 components are investigated. Each of the components has at most 3 unreliable supplies and a single reliable supplier. The models are run by in the SAA method. Table 1 shows the lower bound and confidence interval of the model.

Table 1. Confidence Degree of the model.

	$M = 100, N = 100, N' = 1000$	$M = 100, N = 200, N' = 2000$	$M = 100, N = 300, N' = 3000$
Lower Bound	6374.62	6383.81	6392.76
Confidence Interval	141.93	105.72	80.20

Figure 2 depicts the optimality gap and the required CPU time for different values of M.

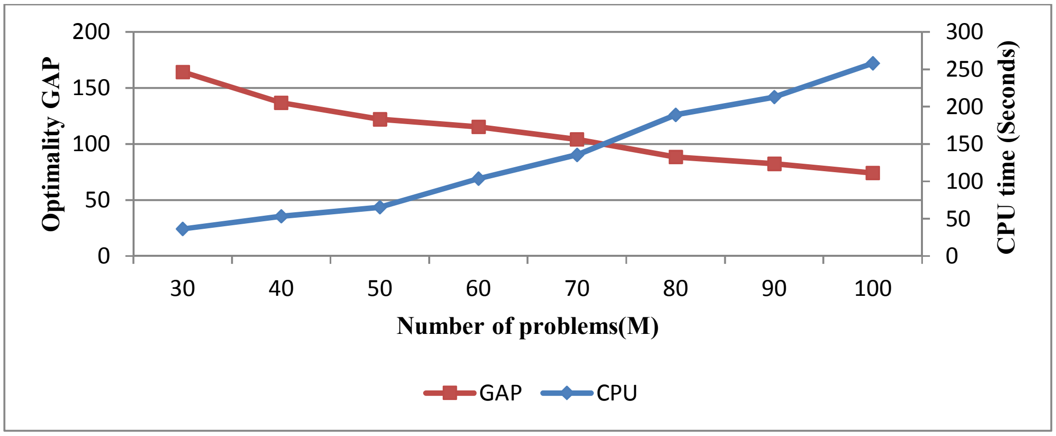

Figure 2. Optimality Gap and the required CPU time

The model is modeled in GAMS and solved by CPLEX 11 on a 2.26 GHz Core 2 Duo PC with 3GB RAM. The following experiment is performed by $M = 100, N = 300, N' = 3000$. The Value of Stochastic Solution (VSS) is calculated as follows.

$$VSS = \overset{=}{f}_N\left(\overline{X}\right) - \overset{=}{f}_N\left(X^{Mean-value}\right)$$

Where $\overset{=}{f}_N\left(\overline{X}\right)$ is the value of the objective function for SAA and $\overset{=}{f}_N\left(X^{Mean-value}\right)$ is the value of objective function for the value of the average of the uncertain parameters. The value of VSS is indicated as follows.

Table 2. Value of Stochastic Solution

	$X^{Mean-value}$	$\overline{x}(N = 100, N' = 2000)$	$\overline{x}(N = 200, N' = 4000)$
Objective function	5921.75	6473.78	6421.11
VSS	-	552.03	499.36

5.1. Sensitivity Analysis

The main purpose of this study is to address the effectiveness of using the emergency suppliers. Accordingly two types of parameters including the price and capacity of emergency supplier are considered to show sensitivity of the model against the emergency supplier. Accordingly, two types of coefficients called 1- Coefficient of Emergency supplier Price (CEP) 2- Coefficient of Emergency supplier Capacity (CEC) are utilized. These coefficients are multiplied in the original data to generate new test problems. In order to measure the effectiveness of emergency sourcing the value of Objective Function and Utilization of Unreliable suppliers are considered as the main indexes. Figure 3 shows the effect of emergency supplier prices on the value of Objective Function and Utilization of Unreliable Supplier.

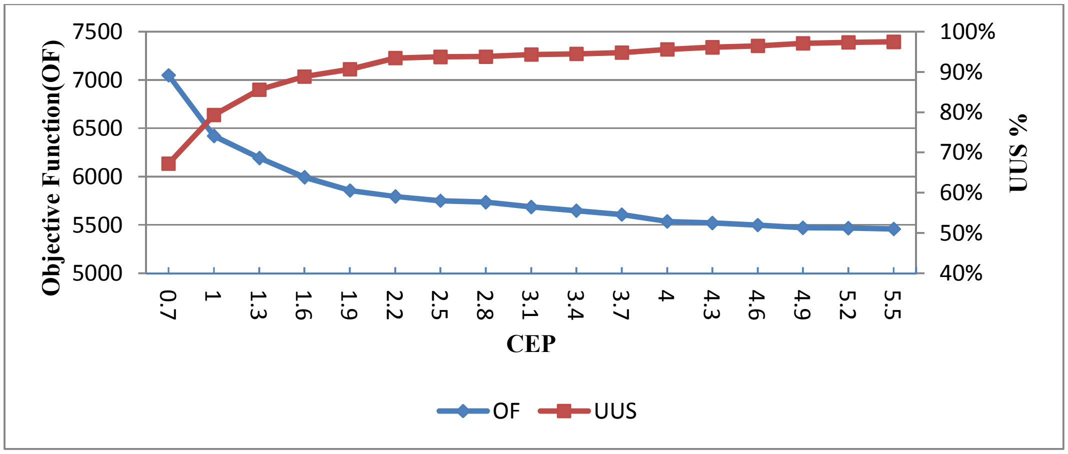

Figure 3. Effect of Price of emergency supplier on the problem

It can be perceived from the above figure that the change of the model for high values of CEP is not significant. Accordingly the Value of Emergency Ordering (VEO) can be calculated as follows.

$$VEO = OF_{CEP=1} - OF_{CEP=5.5} = 963.94$$

The ratio of $\frac{VEO}{OF_{CEP=1}} = 0.1501$ indicates that around 15 percent of the profit is attained by using the emergency supplier. In the other words, in case of ignoring the emergency supplier around 15 percent of the net profit is lost. In addition, the above figure shows that by the increase of the emergency supplier price, the unreliable supplier is utilized much higher.

On the other hand, by considering CEC as the coefficient of the emergency supplier capacity the effect of emergency supplier capacity can be measured on the model. Figure 4 depicts the results for different values of CEC. As it can be viewed from the above model the increase of the emergency supplier capacity improves the value of the Objective Function and decrease the Utilization of Unreliable supplier.

$$VEO = OF_{CEP=1} - OF_{CEP=0}$$

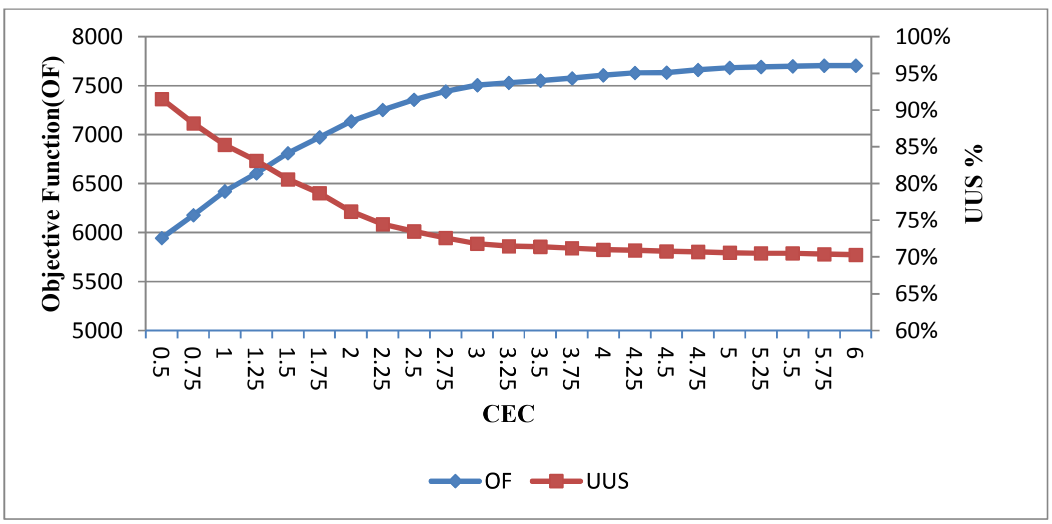

Figure 4. Effect of emergency supplier on the model

In a nutshell it can be mentioned that utilizing emergency supplier can substantially improve the quality of the inventory system.

6. CONCLUSION

In this paper a multi-item, multi-product environment is presented in which in order to produce the final product a few items should be procured. Decisions are made in a two-stage decision process in which during the first stage, the orders to the unreliable suppliers are released and in the second stage the orders are released to the reliable supplier. Unreliable suppliers have a lower selling price in relation to the reliable supplier. The results show that concurrent utilization of both types of suppliers will improve the quality of solutions. Although the proposed two-stage model will increase the computational complexities of the models, by implementing a SAA method the quality of the solutions can be guaranteed.

REFERENCES

1. Reitman, V., 1997. Toyota Motor shows its mettle after fire destroys parts plant. Wall Street Journal, 8: A-1.
2. Ferrer, G., 2003. Yield information and supplier responsiveness in remanufacturing operations. European Journal of operational research, 149(3): 540-556.
3. Xiao, T. and X. Qi, 2008. Price competition, cost and demand disruptions and coordination of a supply chain with one manufacturer and two competing retailers. Omega, 36(5): 741-753.
4. Keren, B., 2009. The single-period inventory problem: extension to random yield from the perspective of the supply chain. Omega, 37(4): 801-810.
5. Zeynep Sargut, F. and L. Qi, 2012. Analysis of a two-party supply chain with random disruptions. Operations Research Letters, 40(2): 114-122.
6. Parlar, M. and D. Perry, 1996. Inventory models of future supply uncertainty with single and multiple suppliers. Naval Research Logistics (NRL), 43(2): 191-210.
7. Dada, M., N.C. Petruzzi, and L.B. Schwarz, 2003. A newsvendor model with unreliable suppliers.: University of Illinois at Urbana-Champaign.
8. Tomlin, B. and Y. Wang, 2005. On the value of mix flexibility and dual sourcing in unreliable newsvendor networks. Manufacturing & Service Operations Management, 7(1): 37-57.
9. Babich, V., A.N. Burnetas, and P.H. Ritchken, 2007. Competition and diversification effects in supply chains with supplier default risk. Manufacturing & Service Operations Management, 9(2): 123-146.
10. Wang, Y., W. Gilland, and B. Tomlin, 2010. Mitigating supply risk: Dual sourcing or process improvement? Manufacturing & Service Operations Management, 12(3): 489-510.
11. Babich, V., 2006. Vulnerable options in supply chains: Effects of supplier competition. Naval Research Logistics (NRL), 53(7): 656-673.
12. Tomlin, B., 2006. On the value of mitigation and contingency strategies for managing supply chain disruption risks. Management science, 52(5): 639-657.
13. Chopra, S., G. Reinhardt, and U. Mohan, 2007. The importance of decoupling recurrent and disruption risks in a supply chain. Naval Research Logistics (NRL), 54(5): 544-555.
14. Schmitt, A.J. and L.V. Snyder, 2012. Infinite-horizon models for inventory control under yield uncertainty and disruptions. Computers & Operations Research, 39(4): 850-862.
15. Tomlin, B., 2009. Disruption-management strategies for short life-cycle products. Naval Research Logistics (NRL), 56(4): 318-347.
16. Qi, L., 2012. A continuous-review inventory model with random disruptions at the primary supplier. European Journal of operational research, 225(1): 59-74.
17. Dong, L. and B. Tomlin, 2012. Managing disruption risk: The interplay between operations and insurance. Management science, 58(10): 1898-1915.
18. Chen, K. and L. Yang, 2014. Random yield and coordination mechanisms of a supply chain with emergency backup sourcing. International Journal of Production Research, 52(16): 4747-4767.
19. Eppen, G.D. and A.V. Iyer, 1997. Backup agreements in fashion buying—the value of upstream flexibility. Management science, 43(11): 1469-1484.
20. Bassok, Y., A. Bixby, and R. Srinivasan, 1997. Design of component-supply contract with commitment-revision flexibility. IBM Journal of Research and Development, 41(6): 693-703.
21. Tsay, A.A. and W.S. Lovejoy, 1999. Quantity flexibility contracts and supply chain performance. Manufacturing & Service Operations Management, 1(2): 89-111.
22. Brown, A. and H.L. Lee, 1997. Optimal pay-to-delay capacity reservation with application to the semiconductor industry. Department of Industrial Engineering and Engineering Management Working Paper, Stanford University, Stanford, CA,.