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# A Dual-Sourcing Inventory Problem with Disruption and Preference between the Products

# Ehsan Mardan<sup>1</sup>, Mohsen Sadegh Amalnick<sup>2</sup>, Masoud Rabbani<sup>3</sup> and Fariborz Jolai<sup>4</sup>

<sup>1</sup>Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran. <sup>2</sup>Associate Professor, Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran. <sup>3,4</sup>Professor, Department of Industrial engineering, College of engineering, University of Tehran, Tehran, Iran. *Received: July24, 2015 Accepted: September 31, 2015* 

# ABSTRACT

This paper presents a newsvendor inventory problem with product preference and disruption. Two products are taken into consideration in whichthe first one is the main product and the second one is the substitute product. The supplier of the main product is prone to yield uncertainty. The demand is stochastic witha known distribution function. The products are ordered before perfect knowledge about the uncertain parameters. The first product is preferred to the second one and while there is a positive inventory from the first product, the arisen demand should be fulfilled by it; otherwise the demand can be fulfilled by the substitute product. The decision maker is risk-neutral who desires to maximize the net profit. The result shows the effectiveness of utilizing the substitute product supplier in improving the net profit.

KEYWORDS: Inventory Problem; Disruption; Random Yield; Preferable Product; Stochastic Demand.

# 1. INTRODUCTION

Recently in the newly organized competitive business world new business styles have appeared where organizations only concentrate on their main competitive capabilities. In these conditions, the non-core activities are outsourced. Due to highly related dependencies in such conditions, organizations have become extensively vulnerable against probable disruptions on their supply chains. Although the probability of disruptions is very low in the supply chains, they have the potential to bring about huge financial losses in the related organizations. This paper investigates the effect of considering substitutable products besides preference between the products to face disruption uncertainties.

In several recent instances, substitution of products has provided managers with additional flexibilities and prevented possible losses which could be imposed to the systems. For example, after the ten-minute fire ignited by lightening at Royal Philips, the main microchip supplier of Nokia and Ericsson, two well-known cell phone manufacturers, Nokia was able to leap huge financial loss by switching to other substitute microchips supplied from other manufacturers while Ericsson suffered 400 million dollars market loss due to lack of components [1]. In another example, the harsh winter in Northern provinces of china in 2010 and the consequent disorder in transportation of goods, the southern power plants substituted the imported coal supply instead of the previous coal supply from the northern provinces. At the same time, the northern grocery market substitute southern farm products instead of the previous local supply [2]. In both of the above instances a substitute product has emerged as a valuable option to prevent the destructive consequences of disruption on the system.

This paper presents a newsvendor inventory problem with uncertain demand. Two separate products are utilized to satisfy the arisen demand where the first one is called the main product and the second one is called the substitute product. The main product supply channel is considered to be uncertain. The associated uncertainty is modeled by yield uncertainty concepts where only a portion of the ordered quantity is delivered while the substitute product supply channel is perfectly reliable. The customer prefers the main product representing that while there is available inventory from the main product, the demand is fulfilled by it otherwise substitute product can be used to fulfill it. The orders are released once at the beginning of the horizon when complete information is not available about probable disruption. The additional inventories from both products are sold at a salvaged value lower than the procurement price at the end of the horizon which conforms to short life cycle inventory problems with rapid change of technology or perishable products. The contribution of this paper is concurrent consideration of product substitutability and product preference in uncertain environment prone to disruption.

The main difference of this model and the common dual sourcing models is that in dual sourcing problems no preference exists in the quality of the sources while in this paper the first product is preferred to the substitute product. In addition, in common dual sourcing models a similar selling price is considered for the products regardless of the supplier while in this model, it is considered that the unit profit margin of the substitute product is less than the unit profit margin of

Corresponding author: Mohsen SadeghAmalnik, Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran. Tel.: +98 21 88021067 - Fax: +98 21 88013102 Email: amalnick@ut.ac.ir

the main product which is justified according to lower customer willingness in taking the substitute product. In addition, this paper proposes an optimal ordering approach for the decision makers.

This paper is organized as follows. In section 2, the literature is reviewed. In section 3, the model and its properties are presented. In section 4, the numerical experiments are provided and the paper is concluded in section 5.

# 2. LITERATURE REVIEW

A rich literature exists for inventory models with uncertainty which is categorized by their main characteristics such as number of suppliers, number of products, source of uncertainty, etc. This paper is mostly related to the bodies of inventory models with dual-sourcing, yield uncertainty and substitutable products. Accordingly, the literature is reviewed separately with respect to these characters.

## 2.1. Dual Sourcing Models

Although it is easier for managers only to deal with a single supplier, multiple sourcing models provide much higher flexibilities for the decision makers by providing a set of ordering choices in uncertain environments. Multiple sourcing models desires to determine the order quantities to the available suppliers. Anupindi & Akella [3]presented a dual sourcing model with random lead-time in which it takes one or two periods where demand is uncertain. Yang et al. [4]studied a dual sourcing model with random yield. Tomlin & Wang [5]studied a dual sourcing model for a single period inventory problem and took into account two types of suppliers called cheap unreliable suppliers and expensive reliable (contingent) suppliers. Tomlin [6]extended the study of Tomlin & Wang [5] by considering capacity constraint and flexibility in order quantities. The study performed by Chopra et al. [7] is the extension of the study performed by Tomlin & Wang [5] by assuming a supplier prone to recurrent and disruption. Schmitt & Snyder [8] is the extension of the study of Chopra et al. [7] by considering a multi-period time structure. Qi [9]presented a dual sourcing problem where it is possible to wait for a while for the recovery of the main supplier. In the above mentioned models, similar products are investigated and there is no priority between the products while this paper contributes the priority between the products where each product has a different price.

# 2.2. Yield Uncertainty Models

Inventory models with yield uncertainty contribute the fact that only a portion of ordered quantities are delivered. A rich literature exists in vield uncertainty with inventory disruption. Dada et al. [10]presented a supplier selection ranking procedure for a single period inventory problem with several unreliable suppliers prone to yield uncertainty. Sloan [11] presented a production-inventory system where the yield of the machine depends on the age of machine and the model is formulated by Markov decision process. Gurnani et al. [12]presented a supplier diversification procedure for an inventory system prone to random yield. Wu et al. [13]presented a two-stage production concerning about multiple lot-sizing decisions and decided about multiple lot-sizing decisions. Grasman [14] studied an inventory system with several items in which the ordering process of each product is prone to random yield. Chen & Yang [15] concentrated on presenting an emergency backup ordering process for the final product where the delivery of the components are prone to yield uncertainty. Xanthopoulos et al. [16]studied a dual sourcing procedure where both suppliers are prone to yield uncertainty. Yeo & Yuan [17] considered a zero-lead time inventory system prone to random yield and proposed optimal replenishment policy for that. Lin & Hou [18] presented an inventory system where the yield variability of the suppliers could be reduced by investment on the system. Hsu et al. [19] studied a single-stage production system with uncertain production system prone to geometric yield and presented a multiple lot-sizing structure. Kutzner & Kiesmüller [20] investigated a system with stochastic demand and an uncertain production system where the output is modeled by random yield concepts. Chen et al. [21]studied concurrent pricing and ordering decisions where the suppliers are prone to yield uncertainty. Feng [22] and He [23] also studied pricing and lot sizing where the suppliers are prone to yield uncertainty. It is also possible to view comprehensive yield uncertainty of the literature in lot sizing problems in [24-27].

## 2.3. Substitutable Product Models

Despite the available rich literature about uncertain inventory models, only a small portion of the literature proposes product substitutability as an efficient way to oppose uncertainties on the models. Considering product substitution provide high flexibility to the models by the possibility of demand fulfillment by a set of substitutable products instead of a single product.

Drezner et al. [28]presented an Economic Order Quantity model with two substitutable product and compared the cases with 1- no substitution 2- full substitution 3- partial substitution. Birge et al. [29]studied a newsvendor inventory problem with two substitutable products and determined the optimal capacity and prices for each of the products. Zhao et al. [30]studied a system with two competing retailers and a single supplier (manufacturer) and presented a pricing framework when demand and manufacturing cost is prone to uncertainty. Hsieh & Wu [31] a system with two substitutable products where the demand is sensitive to the price of the products. Stavrulaki [32] considered a newsvendor inventory

problem with two substitutable products and inventory sensitive demand and model. Hsu et al. [19] presented a model with downward substitutable products where the arisen demand can be fulfilled by the downward substitutable products. Xia [33] studied supplier competition in a two-tier supply chain where two substitutable products can be offered to the customers. Suh & Aydin [34] developed pricing model for a two-product system with a finite selling season where the substitutable products are allowed. Bish & Suwandechochai [35] studied an inventory problem with a supplier and two substitutable products where supplier capacity is flexible and demand is related to the price. Li [36] studied an optimal pricing model where two perishable and substitutable products can fulfill the demand. Bassok et al. [37]studied an inventory system with several product class where the demand of each product can be fulfilled by products of that class.

#### 3. Proposed Model

# 3.1. AssumptionsAnd Notations

This paper presents a newsvendor (single period) inventory problem with two products where the main (first) product is preferred to the substitute (second) one. Such assumption indicates that while the first product is available, the demand should be fulfilled by it; otherwise the substitute product can be used to fulfill the arisen demand. The unit procurement prices of the products are denoted by  $g_i$  (i = 1, 2) while the additional inventories are salvaged at a lower price denoted by  $s_i$  (i = 1, 2) at the end of the horizon. It can be easily perceived that  $g_2 > g_1$  which correspond to the fact that the second product has higher quality standards, capacity, etc. Similarly, it is considered that  $S_2 > S_1$ . The selling price is denoted by  $r_i$  (i = 1, 2). According to the priority of the products, the selling price of the first product is higher ( $r_1 > r_2$ ). The unfulfilled demand is lost with unit penalty cost of  $\pi$  which corresponds to the goodwill loss. The main product supplier is unreliable while the second product supply channel is quite reliable. The first supplier unreliability is modeled by random yield in which with probability *p* the disruption happens and only a fraction of the ordered quantity will be delivered while in normal cases the ordered quantity is delivered perfectly. y indicates the yield coefficient and denotes the portion of the ordered quantities which is delivered.

The orders are released once before achieving perfect information about the yield of unreliable supplier. The demand is stochastic where demand X is a positive stochastic variable with a density function f(x) and cumulative distribution function F(x). The orders to the each supplier are shown by  $Q_1$  and  $Q_2$ .

## 3.2. Mathematical modeling

A risk-neutral decision maker desires to maximize the overall net profit regardless of the rate of demand-fulfillment rate. Accordingly in this case the net profit should be maximized. The associated profit function consists of two parts where the first part corresponds to the normal condition and the second part show the profit attained in the disruptive conditions. By probability p disruption occurs while it is not disrupted by probability (1 - p). In normal conditions where the supplier is not disrupted the profit function is represented by  $L_{NOR}(Q_1, Q_2)$  and is calculated as follows:

$$L_{NOR} \left( Q_{1}, Q_{2} \right) = \int_{0}^{Q_{1}} \left( \begin{matrix} r_{1}x - g_{1}Q_{1} - g_{2}Q_{2} \\ + s_{1} \left( Q_{1} - x \right) + s_{2}Q_{2} \end{matrix} \right) f(x) dx + \int_{Q_{1}}^{Q_{1} + Q_{2}} \left( \begin{matrix} r_{1}Q_{1} + r_{2} \left( x - Q_{1} \right) - g_{1}Q_{1} \\ - g_{2}Q_{2} + s_{2} \left( Q_{1} + Q_{2} - x \right) \end{matrix} \right) f(x) dx + \int_{Q_{1}+Q_{2}}^{\infty} \left( \begin{matrix} r_{1}Q_{1} + r_{2} \left( x - Q_{1} \right) - g_{1}Q_{1} \\ - g_{2}Q_{2} + s_{2} \left( Q_{1} + Q_{2} - x \right) \end{matrix} \right) f(x) dx$$

In disruptive conditions, the profit is shown by  $L_{DIS}(Q_1, Q_2)$ . In disruptive conditions the delivered quantity is  $yQ_1$ . The profit function in disruptive conditions is represented as follows:

$$L_{DIS} \left( Q_{1}, Q_{2} \right) = \int_{0}^{yQ_{1}} \left( r_{1}x - g_{1}Q_{1} - g_{2}Q_{2} + s_{2}Q_{2} \right) f(x) dx + \int_{yQ_{1}+Q_{2}}^{yQ_{1}+Q_{2}} \left( r_{1}yQ_{1} + r_{2}(x - yQ_{1}) - g_{1}Q_{1} - g_{2}Q_{2} + s_{2}(yQ_{1} + Q_{2} - x) \right) f(x) dx + \int_{yQ_{1}+Q_{2}}^{\infty} \left( r_{1}yQ_{1} + r_{2}Q_{2} - g_{1}Q_{1} - g_{2}Q_{2} - \pi \left( x - (yQ_{1} + Q_{2}) \right) \right) f(x) dx$$

The overall profit function is represented by  $L(Q_1, Q_2)$  and is calculated by

$$L(Q_1, Q_2) = (1 - p) \times L_{NOR}(Q_1, Q_2) + (p) \times L_{DIS}(Q_1, Q_2)$$
  
Proposition 1:

- a)  $L(Q_1, Q_2)$  is concave with respect to  $Q_1, Q_2$ .
- b) The maximum value of  $L(Q_1, Q_2)$  is obtained by solving equations (1)-(2):

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$$\begin{bmatrix} (-r_1 + r_2 + s_1 - s_2) \times \begin{pmatrix} (1 - p) F(Q_1) \\ + py F(yQ_1) \end{pmatrix} \\ + (-r_2 + s_2 - \pi) \times \begin{pmatrix} (1 - p) F(Q_1 + Q_2) \\ + py F(yQ_1 + Q_2) \end{pmatrix} \end{bmatrix} = (-r_1 - \pi) \times (1 - p + py) + g_1$$
(1)

$$(-r_{2} + s_{2} - \pi) \times \begin{pmatrix} (1-p)F(Q_{1} + Q_{2}) \\ +pF(yQ_{1} + Q_{2}) \end{pmatrix} = (-r_{2} + g_{2} - \pi)$$
(2)

Proof (a):

Construct the Hessian matrix of  $L(Q_1, Q_2)$  as follows.

$$H\left(L\left(\mathcal{Q}_{1},\mathcal{Q}_{2}\right)\right) = \begin{bmatrix} \frac{\partial^{2}L\left(\mathcal{Q}_{1},\mathcal{Q}_{2}\right)}{\partial\mathcal{Q}_{1}^{2}} & \frac{\partial^{2}L\left(\mathcal{Q}_{1},\mathcal{Q}_{2}\right)}{\partial\mathcal{Q}_{1}\partial\mathcal{Q}_{2}}\\ \frac{\partial^{2}L\left(\mathcal{Q}_{1},\mathcal{Q}_{2}\right)}{\partial\mathcal{Q}_{1}\partial\mathcal{Q}_{2}} & \frac{\partial^{2}L\left(\mathcal{Q}_{1},\mathcal{Q}_{2}\right)}{\partial\mathcal{Q}_{2}^{2}} \end{bmatrix}$$

where

$$\frac{\partial^{2} L\left(Q_{1},Q_{2}\right)}{\partial Q_{1}^{2}} = \begin{pmatrix} \left(-r_{1}+r_{2}+s_{1}-s_{2}\right) \times \begin{pmatrix} \left(1-p\right) f\left(Q_{1}\right) \\ +py^{2} f\left(yQ_{1}\right) \end{pmatrix} \\ +py^{2} f\left(yQ_{1}\right) \end{pmatrix} \\ +\left(-r_{2}+s_{2}-\pi\right) \times \begin{pmatrix} \left(1-p\right) f\left(Q_{1}+Q_{2}\right) \\ +py^{2} f\left(yQ_{1}+Q_{2}\right) \end{pmatrix} \end{pmatrix} < 0$$

$$\frac{\partial^{2} L\left(Q_{1},Q_{2}\right)}{\partial Q_{2}^{2}} = \left(-r_{2}+s_{2}-\pi\right) \times \begin{pmatrix} \left(1-p\right) f\left(Q_{1}+Q_{2}\right) \\ +pf\left(yQ_{1}+Q_{2}\right) \end{pmatrix} < 0$$

$$\frac{\partial^{2} L\left(Q_{1},Q_{2}\right)}{\partial Q_{1}\partial Q_{2}} = \left(-r_{2}+s_{2}-\pi\right) \times \begin{pmatrix} \left(1-p\right) f\left(Q_{1}+Q_{2}\right) \\ +pf\left(yQ_{1}+Q_{2}\right) \end{pmatrix} < 0$$

The first and second order determinant of the Hessian matrix of  $L(Q_1, Q_2)$  is calculated by

$$\begin{aligned} |D_1| &= \frac{\partial^2 L (Q_1, Q_2)}{\partial Q_1^2} < 0 \\ |D_2| &= \frac{\partial^2 L (Q_1, Q_2)}{\partial Q_1^2} \frac{\partial^2 L (Q_1, Q_2)}{\partial Q_2^2} - \left(\frac{\partial^2 L (Q_1, Q_2)}{\partial Q_1 \partial Q_2}\right)^2 \\ &= (-r_2 + s_2 - \pi) \times \begin{bmatrix} (-r_1 + r_2 + s_1 - s_2) \times \begin{bmatrix} (1 - p)^2 f (Q_1) f (Q_1 + Q_2) \\ + (1 - p) p f (Q_1) f (y Q_1 + Q_2) \\ + (1 - p) p y^2 f (y Q_1) f (Q_1 + Q_2) \\ + p^2 y^2 f (y Q_1) f (y Q_1 + Q_2) \end{bmatrix} \\ &+ (-r_2 + s_2 - \pi) \times \begin{bmatrix} p (1 - p) (1 - y)^2 f (Q_1 + Q_2) f (y Q_1 + Q_2) \end{bmatrix} \end{aligned} \right| > 0$$

As it can be seen, the first order determinant is negative while the second order determinant is positive indicating that  $L(Q_1, Q_2)$  is negative definite and thus  $L(Q_1, Q_2)$  is concave.

Proof (b):

The optimal order values can be obtained by the following equations which arises according to the concavity of  $L(Q_1, Q_2)$ .

$$\frac{\partial L(Q_1,Q_2)}{\partial Q_1} = 0 \Rightarrow (-r_1 + r_2 + s_1 - s_2) \times ((1 - p)F(Q_1) + pyF(yQ_1)) \\ + (-r_2 + s_2 - \pi) \times ((1 - p)F(Q_1 + Q_2) + pyF(yQ_1 + Q_2)) = (-r_1 + g_1 - \pi) \times (1 - p + py) \\ \frac{\partial L(Q_1,Q_2)}{\partial Q_2} = 0 \Rightarrow (-r_2 + s_2 - \pi) \times ((1 - p)F(Q_1 + Q_2) + pF(yQ_1 + Q_2)) = (-r_2 + g_2 - \pi)$$

## 4. Numerical Experiment

A variety of test problems have been generated to analyze the behavior of the above model which covers a gamut for all of the possible problems. The investigated problems are shown in Table 1. In this study, 12960 test problems are generated. The demand of the retailer is considered to have a gamma stochastic demand with alpha =20 and beta=10. The model is coded and solved in MATLAB 2008b with on a PC with 3 GB RAM and 2.26 GHz Core 2 Duo CPU. Solving each problem requires a processing time less than 1 second. Table 1 show the parameters used in this study.

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Table 1. Parameter Values in the Sample Problems										
Parameter	Value									
$r_1$	[1 4 0 ]									
$r_2$	[105,115,125,135]									
$g_1$	[65,75,85,95]									
${m g}_{2}$	[70,80,90,100]									
S <sub>1</sub>	[10,30,50]									
<i>s</i> <sub>2</sub>	[20, 40,60]									
π	[25,50,75,100,125,150]									
p	[0.05, 0.1, 0.15]									
У	[0.4,0.7,0.9]									

Figure 1 represents a typical behaviour of a risk-neutral decision maker for different values of  $Q_1, Q_2$ . The values of parameters in Figure 1 is  $r_1 = 140, r_2 = 105, g_1 = 65, g_2 = 70, s_1 = 10, s_2 = 60, \pi = 100, p = 0.1, y = 0.4$ . As it can be percieved from Figure 1, the objective function value change insignifacantly for high near optimal values of  $Q_1, Q_2$  indicating model robustness. In addition for very low or very high values of overall order quantities, the objective function decreases significantly which is due to salvage of products or shortage of products for customer satisfaction.



Figure 1. Shape of Profit Function for Near Optimal Solutions

Disruption severity on the investigated problem is determined by disruption probability or the yield of uncertain supplier. Figure 2 shows yield effect on the order quantities for а problem with  $r_1 = 140, r_2 = 105, g_1 = 65, g_2 = 70, s_1 = 10, s_2 = 60, \pi = 100, p = 0.1$ . In addition, Figure 3 depicts the effect of disruption probability on a problem with  $r_1 = 140, r_2 = 105, g_1 = 65, g_2 = 70, s_1 = 50, s_2 = 60, \pi = 100, y = 0.4$ .







Figure 3. Effect of disruption probability on the order quantity

As it can be seen from Figure 2, by the increase of the yield of the main supplier, the ordered quantity to this supplier increases while concurrently the order quantity to the substitute product decreases at a higher rate leading to the decrease of the overall order quantity. Such interpretation originates according to the fact that in cases when the main product supplier has higher reliability, the reliance on the substitute product decreases substantially. On the other hand, Figure 3 shows that with the increase of the disruption probability the reliance on the main product supplier decreases. Generally, it can be noted that with the increase of the disruption severity which is originated according to the decrease of the yield of suppliers or the increase of the disruption probability, the utilization of the substitute product increases but the value of objective function decreases.

On the other hand, the model shows a specific behavior against the change of other parameters including  $r_1, r_2, g_1, g_2, s_1, s_2, \pi$ . It is clear that  $o_i - c_i$  represents the profit margin attained by demand fulfillment by each of the products. For instance, when there is high profit margin for the main product the model significantly relies on it while when the profit margin of the products are relatively close reliance on the substitute product increases.

In addition, by the increase of the salvage value for each of the products, the order quantity to that special supplier increases. This means that by the increase of the salvage value of each product provides relative advantages for it. On the other hand, by the increase of the shortage penalty, the model relies on the substitute product supplier more. Several problems which certify the above discussion is shown in Table 2.

	$r_1$	$r_2$	$g_1$	$g_2$	$r_1 - g_1$	$r_2 - g_2$	<i>s</i> <sub>1</sub>	<i>s</i> <sub>2</sub>	$\pi$	р	У	$\mathcal{Q}_{l}^{*}$	$Q_2^*$
Effect of $r_1 - g_1$	140	105	65	100	75	5	10	60	100	0.15	0.4	217.15	28.9
	140	105	75	100	65	5	10	60	100	0.15	0.4	200.82	44.64
	140	105	85	100	55	5	10	60	100	0.15	0.4	185.94	58.72
	140	105	95	100	45	5	10	60	100	0.15	0.4	170.69	72.87
Effect of $r_2 - g_2$	140	135	65	70	75	65	10	60	100	0.15	0.4	109.88	186.29
	140	125	65	80	75	45	10	60	100	0.15	0.4	169.44	117.72
	140	115	65	90	75	25	10	60	100	0.15	0.4	193.85	73.81
	140	105	65	100	75	5	10	60	100	0.15	0.4	217.15	28.9
Effect of <i>p</i> , <i>y</i>	140	125	65	70	75	55	10	40	50	0.05	0.4	155.66	63.75
	140	125	65	70	75	55	10	40	50	0.05	0.7	165.56	53.42
	140	125	65	70	75	55	10	40	50	0.05	0.9	172.28	44.55
	140	125	65	70	75	55	10	40	50	0.1	0.4	121.36	103.19
	140	125	65	70	75	55	10	40	50	0.1	0.7	157.81	65.44
	140	125	65	70	75	55	10	40	50	0.1	0.9	172.05	46.72
	140	125	65	70	75	55	10	40	50	0.15	0.4	68.88	156.66
	140	125	65	70	75	55	10	40	50	0.15	0.7	149.62	77.86
	140	125	65	70	75	55	10	40	50	0.15	0.9	172	48.71
Effect of S <sub>i</sub>	140	115	65	70	75	45	10	60	50	0.15	0.4	171.46	127.48
	140	115	65	70	75	45	30	60	50	0.15	0.4	182.53	120.73
	140	115	65	70	75	45	50	60	50	0.15	0.4	204.89	107.86
	140	115	65	70	75	45	10	20	50	0.15	0.4	190.16	40.73
	140	115	65	70	75	45	10	40	50	0.15	0.4	274.64	77.4
	140	115	65	70	75	45	10	60	50	0.15	0.4	171.46	127.48
Effect of $\pi$	140	135	65	80	75	55	30	60	25	0.05	0.4	191.85	52.22
	140	135	65	80	75	55	30	60	50	0.05	0.4	189.9	63.58
	140	135	65	80	75	55	30	60	75	0.05	0.4	188.2	72.77
	140	135	65	80	75	55	30	60	100	0.05	0.4	186.72	80.46
	140	135	65	80	75	55	30	60	125	0.05	0.4	185.43	87.03
	140	135	65	80	75	55	30	60	150	0.05	0.4	184.31	92.73

#### Table 2. Effect of parameters on the order quantity

# 5. CONCLUSION AND REMARKS

The main contribution of this paper is the utilization of a substitute product for a newsvendor inventory problem. This study concentrates on presenting an optimal approach for an inventory problem with substitute product. Although the main product is preferred, the results show that using the substitute product can improve the model profitability. In addition, the model shows that in cases when the profit margin of the main product, disruption severity, salvage price of substitute product or shortage penalty increases, the substitute product is ordered more.

In summary, it can be mentioned that although using a single supplier provide several advantages such as decreasing the fixed ordering expenses or using discount advantages, in cases when the supplier is not perfectly reliable using a substitute product can provide higher flexibility and accordingly increases the net profit. This paper depicts that using a substitute product can improve the quality of the solutions as well as the net profit. Managers who are willing to use such models should balance the ordered quantities based on the proposed model to improve the quality of solutions.

# REFERENCES

- 1. Latour, A., 2001. Trial by fire: A blaze in Albuquerque sets off major crisis for cell-phone giants. Wall Street Journal, 1(29)
- 2. Babich, V., 2006. Vulnerable options in supply chains: Effects of supplier competition. Naval Research Logistics (NRL), 53(7): 656-673.
- 3. Anupindi, R. and R. Akella, 1993. Diversification under supply uncertainty. Management science, 39(8): 944-963.
- 4. Yang, S., J. Yang and L. Abdel-Malek, 2007. Sourcing with random yields and stochastic demand: A newsvendor approach. Computers & Operations Research, 34(12): 3682-3690.
- 5. 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.
- 6. Tomlin, B., 2006. On the value of mitigation and contingency strategies for managing supply chain disruption risks. Management science, 52(5): 639-657.
- 7. 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.
- 8. 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.

- 9. Qi, L., 2012. A continuous-review inventory model with random disruptions at the primary supplier. European Journal of operational research, 225(1): 59-74.
- 10. Dada, M., N.C. Petruzzi and L.B. Schwarz, 2007. A newsvendor's procurement problem when suppliers are unreliable. Manufacturing & Service Operations Management, 9(1): 9-32.
- 11. Sloan, T., 2004. A periodic review production and maintenance model with random demand, deteriorating equipment, and binomial yield. Journal of the Operational Research Society, 55(6): 647-656.
- 12. Gurnani, H., R. Akella and J. Lehoczky, 2000. Supply management in assembly systems with random yield and random demand. IIE transactions, 32(8): 701-714.
- Wu, H.H., C.H. Wu and J.T. Lin, 2011. Dynamic selling of quality-graded products under demand uncertainties. Computers & Industrial Engineering, 61(1): 141-149.
- 14. Grasman, S.E., 2009. Multiple item capacitated random yield systems. Computers & Industrial Engineering, 57(1): 196-200.
- 15. 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.
- Xanthopoulos, A., D. Vlachos and E. Iakovou, 2012. Optimal newsvendor policies for dual-sourcing supply chains: A disruption risk management framework. Computers & Operations Research, 39(2): 350-357.
- 17. Yeo, W.M. and X.M. Yuan, 2011. Optimal inventory policy with supply uncertainty and demand cancellation. European Journal of operational research, 211(1):26-34.
- Lin, L. and K. Hou, 2005. An inventory system with investment to reduce yield variability and set-up cost. Journal of the Operational Research Society, 56(1): 67-74.
- 19. Hsu, H.M., T.S. Su, M.C. Wu and L.C. Huang, 2009. Multiple lot-sizing decisions with an interrupted geometric yield and variable production time. Computers & Industrial Engineering, 57(3): 699-706.
- 20. Kutzner, S.C. and G.P. Kiesmüller, 2013. Optimal control of an inventory-production system with state-dependent random yield. European Journal of operational research, 227(3): 444-452.
- 21. Chen, W., Q. Feng and S. Seshadri, 2013. Sourcing from suppliers with random yield for price-dependent demand. Annals of Operations Research, 208(1): 557-579.
- 22. Feng, Q., 2010. Integrating dynamic pricing and replenishment decisions under supply capacity uncertainty. Management science, 56(12): 2154-2172.
- 23. He, Y., 2013. Sequential price and quantity decisions under supply and demand risks. International Journal of Production Economics, 141(2): 541-551.
- 24. Yano, C.A. and H.L. Lee, 1995. Lot sizing with random yields: A review. Operations research, 43(2): 311-334.
- 25. Khouja, M., 1999. The single-period (news-vendor) problem: literature review and suggestions for future research. Omega, 27(5): 537-553.
- Minner, S., 2003. Multiple-supplier inventory models in supply chain management: A review. International Journal of Production Economics, 81: 265-279.
- 27. Tang, C.S., 2006. Perspectives in supply chain risk management. International Journal of Production Economics, 103(2): 451-488.
- Drezner, Z., H. Gurnani and B.A. Pasternack, 1995. An EOQ model with substitutions between products. Journal of the Operational Research Society, 46: 887-891.
- 29. Birge, J.R., J. Drogosz and I. Duenyas, 1998. Setting single-period optimal capacity levels and prices for substitutable products. International Journal of Flexible Manufacturing Systems, 10(4): 407-430.
- 30. Zhao, J., W. Tang and J. Wei, 2012. Pricing decision for substitutable products with retail competition in a fuzzy environment. International Journal of Production Economics, 135(1): 144-153.
- 31. Hsieh, C.C. and C.H. Wu, 2009. Coordinated decisions for substitutable products in a common retailer supply chain. European Journal of operational research, 196(1): 273-288.
- Stavrulaki, E., 2011. Inventory decisions for substitutable products with stock-dependent demand. International Journal of Production Economics, 129(1): 65-78.
- 33. Xia, Y., 2011. Competitive strategies and market segmentation for suppliers with substitutable products. European Journal of operational research, 210(2): 194-203.
- 34. Suh, M. and G. Aydin, 2011. Dynamic pricing of substitutable products with limited inventories under logit demand. IIE transactions, 43(5): 323-331.
- 35. Bish, E.K. and R. Suwandechochai, 2010. Optimal capacity for substitutable products under operational postponement. European Journal of operational research, 207(2): 775-783.
- Li, F., 2003. Optimal dynamic pricing for two perishable and substitutable products., Virginia Polytechnic Institute and State University.
- 37. Bassok, Y., R. Anupindi and R. Akella, 1999. Single-period multiproduct inventory models with substitution. Operations research, 47(4): 632-642.