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(R, s, S) INVENTORY CONTROL POLICY AND SUPPLIER SELECTION IN A TWO-ECHELON SUPPLY CHAIN: AN OPTIMIZATION VIA SIMULATION APPROACH

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ABSTRACT

Existing literature proves that Optimization via Simulation (OvS) is relatively easy to develop regardless of the complexity of the problem and provide a much more realistic solution methodology without assumption. Hence, we used OvS to determine optimal (R, s, S) policy for Distribution Center (DC)s and suppliers and to properly select the suppliers for DCs under stochastic environmental condition and lost sales system. Determining the optimal parameters, especially determining reorder point and order-up-to level, are major challenges for (R, s, S) policy and hence, their optimal values are determined by means of OvS. Also, initial inventories of DCs and suppliers are considered because the initial conditions of a simulation are crucial aspects of simulation modeling. The proposed OvS model can be helpful for managers to understand better the scope of both the problem at hand and opportunities associated with inventory management.

1 INTRODUCTION

Inventory management is considered as one of the most important factor in Supply Chain Management since the cost of inventories approximately comprises 30% of the value of the product when entire supply chain is taken into account. Therefore, inventory must be kept at the optimal level in entire supply chain to minimize total supply chain cost. In this respect, inventory control of each echelon plays a key role in inventory management. However, due to today's dynamic marketplace, inventory control includes high level of supply and demand uncertainty, contradictory objectives, information ambiguity, and a great number of decision variables and constraints (Arisha and Hamad 2010). Due to this complexity, most inventory management models are created with rather restrictive assumptions and simplifications but their solutions differ fundamentally from the actual conditions. In this case, simulation seems to be a remarkable recourse to model and analyze performances for real world problems. Simulation has an ability to capture specific features of the real object and to incorporate a greater level of detail (Paul and Chanev 1998). However, simulation models do not provide the capability of finding the optimum set of decision variables in terms of predefined objective function(s). This is made by optimization models that allow decision makers to find the best possible alternatives. Therefore, integrating simulation and optimization into supply chain framework provides practitioners with a comprehensive solution toolbox (Omar, Mustaffa, and Othman 2012). OvS along with modern computing power is an answer to modeling complex supply chain problem and addressing aforementioned criticisms. OvS could solve any real stochastic complex optimization problem (Kabirian 2009). There is no restriction on the relationship of the components of the system, relations between the system and beyond the boundaries of the system. However, defining system characteristics and problem specific variables such as demand, replenishment parameters are critical in OvS. For example, it is rather difficult to analyze and solve inventory control problems by considering lost sales system due to the changing competitive environment where customers are unwilling to wait anymore. In addition, different replenishment policies are necessary to describe lost sales inventory systems (Bijvank and Vis 2011). Bijvank and Vis (2012) considered the optimal replenishment policies and (R, s, S) policies to develop a service model for a periodic review inventory system with lost sales. Donselaar and Broekmeulen (2013) identified two constructs of variables that have a large impact on the performance of lost sales systems. Modeling any one of the supply chain problem is very complicated because it involves a series of analysis and optimization tasks. Selecting the right suppliers has key importance on this modeling process and stands for a major opportunity for companies to overcome challenging objective. In literature, various models and techniques have been used to deal with selecting suppliers but some of them consider inventory management of the items purchased (Boer, Labro, and Morlacchi 2001). For example, Haq and Kannan (2006) integrated supplier selection and multi echelon distribution inventory control model in supply chain environment using fuzzy analytical hierarchy process and genetic algorithm (GA). In the study, deterministic demand and unlimited supplier capacity are taken into account. Keskin, Melouk, and Meyer (2010) developed OvS approach to improve the performance of the supply chain where inventory position is continuously reviewed and vendor can only be able to satisfy an order from its related plant if its capacity level is greater than or equal to order quantity.

In this study, we present (R, s, S) policy and supplier selection simultaneously in a two echelon supply chain under stochastic environment and lost sales system. It seems intuitive that OvS should provide a significant opportunity to find optimum inventory control parameters because OvS has ability of capturing the advantages of both simulation and optimization based methods simultaneously. Also, OvS is not constrained by analytical assumptions and simplifications. OvS can give reasonable solutions for evaluating different configurations of inventory control system and supplier selection while minimizing the total supply chain cost including distribution and inventory related cost.

2 PROBLEM DEFINITION

DCs and suppliers provide a single product in a stochastic environment which includes varieties of complex factors such as stochastic lead time, and stochastic lost sales cost, etc. The distribution of the customer order quantity at the DCs has a Poisson distribution with a rate parameter of 50. Also, we assumed that average customer arrival at each DC is 1 per day. Inventory levels of each DC and each supplier, having initial value, are all inspected at every R time units where R is a fixed constant and assumed to be 5 days. It should be noted that only this value is considered to be constant and assumed to be the same for all suppliers and DCs placed in the supply chain. Thus, each DC and each supplier has their own initial inventory, reorder point and order-up-to level values separately. The replenishment lead time is assumed to be probabilistic and inventory level continues to decrease over the duration of the lead time since the order placed at a review period will not be received until the end of the lead time. DCs can take many number of customer orders within a review period. If customer order quantity is lower than the inventory level of DC, demand is fully satisfied from the DC's available stock. If order quantity is higher than its available stock, possible order fulfillment takes place. Unmet customer order quantity at each DC is lost. At the beginning of each review period, the inventory level of each DC is fulfilled until the order up to level (S) whenever it decreases to a value smaller than or equal to the reorder level (s). To satisfy the demand at each DC, the firm should select the most suitable supplier. Each DC's inventory is replenished only from its predetermined supplier. The DC's replenishment orders are fully satisfied if the existing inventory level at the supplier is greater than or equal to the DC's replenishment order quantity. If supplier does not have enough inventories to fulfill order, possible order fulfillment takes place depending upon inventory level. Thus, excess DC's replenishment order quantity is lost. Note that DC's replenishment order quantity may vary depending on the customer order quantity between successive orders and the resulting inventory at the time of ordering. At the beginning of each review period, each supplier inventory is replenished from unlimited sources until the order-up-to level whenever it decreases to a value smaller than or equal to the reorder level. If supplier's inventory level is higher than the reorder point, we do not place any order for supplier. The general structure of the considered supply chain is given in Figure 1.

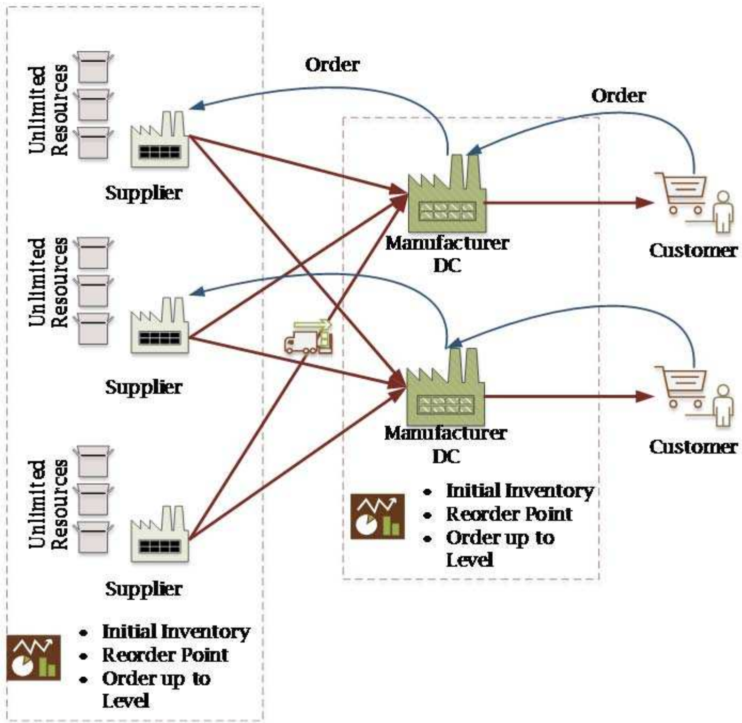


Figure 1: General structure of the considered supply chain.

It is seen that two different sources of customers place orders on DCs. The two chain DCs can utilize three different suppliers for a particular item. The lower and upper bound value of the initial inventory is considered to be 800 and 2000 for each DC and each supplier, respectively. The lower and upper bound value of the reorder point is considered to be 50 and 200 for each DC and each supplier, respectively. The lower and upper bound value of the order-up-to level is considered to be 200 and 750 for each DC and each supplier, respectively. In this system, it is assumed that suppliers have a perfect raw material (i.e., raw material is assumed to be always available). Processing time is required to prepare products (i.e., the processing of the product into the stores and on the shelves) for serving DCs/customers. Both suppliers and DCs receive orders and need order processing time to process them. The order processing time is the length of time between the time when an order for a particular item is placed and when it actually becomes ready to satisfy the demand. In this respect, order processing time should be thought as the time spent processing customer order and/or DC replenishment order before it is filled. Transportation time is the length of time that is needed to transport between two locations (i.e., supplier to DC). Thus, replenishment lead time includes processing time, order processing time, and transportation time (Table 1). It should be noted that there is always enough time for receiving a replenishment order before the next review period because replenishment lead time is shorter than the review period. To estimate the performance of a given system design, fixed and variable ordering cost, average holding cost, lost sales cost, order holding cost rate, fixed and unit transportation cost which are given in Table 1 together with their corresponding values are considered. Each DC_i (i denotes DC in the system, i= 1 or 2) incurs a fixed ordering cost U_i for each replenishment order. Any non-negative inventory level is charged average holding cost proportional to the remaining inventory quantity, $h_i\ X_{in}^{+}$, where n denotes the set of periods where an order is placed, h_i represents average holding cost per unit product per unit time at DC_i and X_{in}^{+} represent physical average holding unit at DC_i over period n.

Table 1: The parameter values related with replenishment lead time and cost.

Suppliers	**DCs**
Lost Sales Cost: Uniform (80,100)	Lost Sales Cost: Uniform (80,100)
Order Holding Cost Rate: Uniform (5,10)	Order Holding Cost Rate: Uniform (5,10)
Fixed Ordering Cost: Uniform (100,150)	Fixed Ordering Cost: Uniform (10,20)
Variable Ordering Cost: Uniform (50,75)	Variable Ordering Cost: Uniform (5,10)
Average Holding Cost: Uniform (2,5)	Average Holding Cost: Uniform (2,5)
Unit Transportation Cost: Uniform (0.75, 3.00)	-
Fixed Transportation Cost: Uniform (250,275)	-
Processing Time: Triangular (3,5,7)	Processing Time: Triangular (1,2,3)
Order Processing Time: Uniform (2,5)	Order Processing Time: Uniform (2,5)
Transportation Time: Uniform (1.25,3)	-

A shortage cost $k_i X_{in}^{-}$ is charged proportional to the shortage level, where X_{in}^{-} and k_i represent unmet customer order quantity at DC_i over period n and lost sales cost per unit short at DC_i, respectively. Order holding cost rate O_i, is the cost per unit time charged, or accrued, to the cost of any order while waited in related DC. It should be noted that, o_{im} represents order processing time of m^{th}(m=1,..,total number of orders over n periods) order at DC_i. Thus, we formulated total supply chain cost for each DC ($TSCC_{in}$) as follows:

$$TSCC_{in} = h_i X_{in}^{+} + I\{X_{in} \leq s_i\}\big(U_i \ + c_i(S_i - X_{in})\big) + k_i X_{in}^{-} + o_{im} O_i, \tag{1}$$

where X_{in} and c_i represent existing inventory level at DC_i at the beginning of period n, variable ordering cost per unit order at DC_i, respectively. Also, I$\{.\}$ specify indicator function of the set. Similarly, total supply chain cost for each supplier, $TSCC_{jn}$ (j denotes number of suppliers in the system, j=1, 2, and 3), is calculated. Each replenishment order of the supplier incurs fixed ordering cost U_j. Any non-negative inventory level in supplier is charged average holding cost proportional to the remaining inventory quantity, $h_j X_{jn}^{+}$, where h_j represents average holding cost per unit product per unit time at supplier j and X_{jn}^{+} represents physical average holding unit at supplier j over period n. A shortage cost $k_j X_{jn}^{-}$ is charged proportional to the shortage level, where k_j and X_{jn}^{-} represents lost sales cost per unit short at supplier j and unmet DC replenishment order quantity at supplier j over period n, respectively. In addition, transportation cost $T_j Y_{jn}$ is charged proportional to the satisfied DC replenishment order quantity, where Y_{jn} and T_j represent satisfied order quantity at supplier j over period n and transportation cost per unit at supplier j, respectively. The fixed transportation cost per each shipment at supplier j is A_{jT}. Order holding cost rate O_j is the cost per unit time charged, or accrued, to the cost of any order while waited in related supplier. It should be noted that, o_{ik} represents order processing time of k^{th} (k=1,..,total number of orders over n periods) order at Supplier j. Thus, we formulated $TSCC_{jn}$ as follows:

$$TSCC_{jn} = h_j X_{jn}^{+} + \ I\{X_{jn} \leq s_j\}\Big(U_j \ + c_j\big(S_j - X_{jn}\big)\Big) + k_j X_{jn}^{-} + T_j Y_{jn} + A_{jT} + o_{jk} O_j, \tag{2}$$

where X_{jn} and c_j represent existing inventory level at supplier j at the beginning of period n and variable ordering cost per unit order at supplier j, respectively. Finally, total cost of each DC and each supplier are summed up to calculate total supply chain cost ($TSCC_n$) as follows:

$$TSCC_n = \sum_{i=1}^{2} TSCC_{in} + \sum_{j=1}^{3} TSCC_{jn} \tag{3}$$

Considering our cost function and stochastic parameters, neither simple procedures nor algorithms are available to give the optimal values of reorder point and order-up-to level in (R, s, S) inventory control system. Hence, OvS model provides significant opportunity to find optimum inventory control parameters and to select best suppliers for DCs.

3 OPTIMIZATION VIA SIMULATION

Dynamic nature of the inventory is the major obstacle for inventory control practitioners and makes most analytical models either over simplistic or computationally intractable. To overcome the limitation of existing analytical models, OvS can be used because of its capability for handling variability (Ding, Benyoucef, and Xie 2005). In this study, general OvS methodology is explained with two fundamental phases: (1) An optimization phase where GA is used to optimize the control parameters of the (R, s, S) policy except from review period since it is taken as a predetermined value and also the most suitable supplier for each DC, (2) A simulation phase that evaluates performances of candidate solutions. In this system, the simulation output is used by the optimization phase to provide feedback while searching for the optimal solution.

3.1 Optimization Phase: GA

GA is a global optimization method and makes no assumptions about the functions to be optimized. Therefore, GA can be easily adapted to the inventory control problem. Adaptation is made with respect to GA parameters and operators such as chromosome representation, population initialization, selection, crossover, and mutation (Daniel and Rajendran 2005). GA randomly generates an initial population of chromosomes. In GA, potential solution of the problem is represented as a set of parameters. These parameters are joined together to form a chromosome. The chromosome structure of this research is illustrated in Figure 2. First part of the chromosome represents supplier selection for DC1 and DC2. The second part of the chromosome represents determination of the initial inventory, reorder point, and order-up-to level of each DC and each supplier. It is worth remembering that we used two DCs and three suppliers in supply chain system.

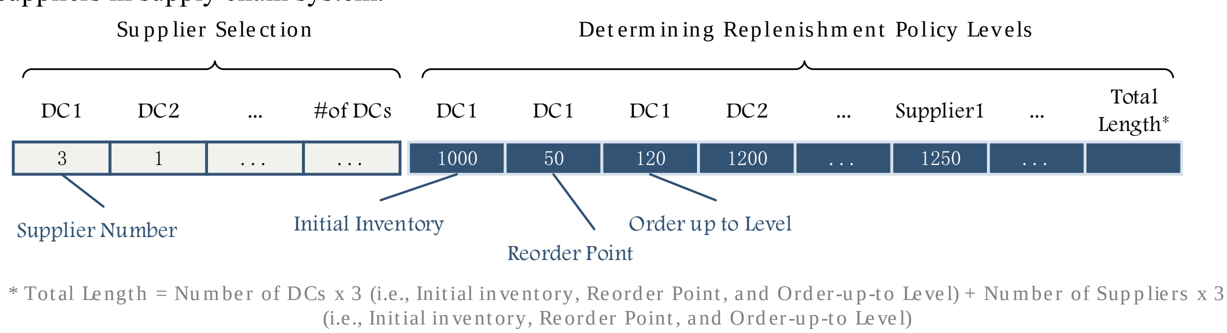


Figure 2: Chromosome structure of GA.

The fitness value of each alternative solution is automatically taken from simulation model to form a new generation in GA. The fitness evaluation operation of GA calculates the fitness value of each individual according to the objective function that minimizes $TSCC_n$. Fitness value f_k is computed for chromosome k by using the objective function value as given in (4):

$$f_k = \frac{1}{TSCC_k} \tag{4}$$

Here $TSCC_k$ is the objective function value of the kth chromosome. After calculating fitness value, the plan for selecting chromosomes to create the next generation is displayed by selection strategy. Selection operator leads GA to select chromosomes from the population as parents to use in crossover. The tournament selection is used in this study as it is simpler and produces reasonably good results. It randomly picks two chromosomes from the population and selects higher fitness value as a parent. In crossover operator, two individuals are taken and their chromosome strings are randomly cut to produce two “head" segments and two “tail" segments. Then, the tail segments are swapped over to create two new full length chromosomes. This is also known as single point crossover (Figure 3). It should be noted that crossover is generally not applied for all pairs of individuals selected for mating. In literature, crossover rate is typically applied between 0.6 and 1.0 and it is taken as 0.8 in this study.

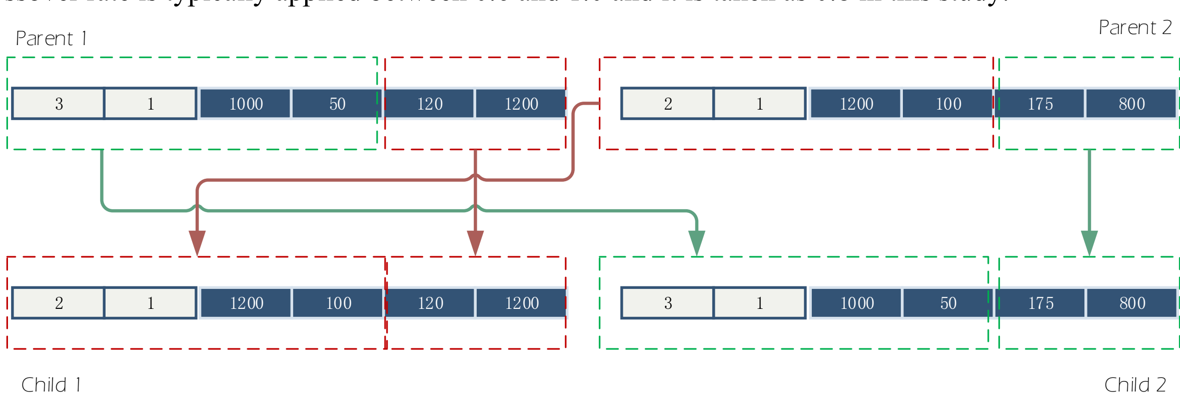


Figure 3: Crossover Operator of GA.

After applying crossover, mutation is randomly performed to each child individually with a small probability. In this study, mutation applied to convert chromosome’s 0 to 1, or 1 to 0 and we set mutation rate as 0.05. In this way, a small amount of random search is provided. The best chromosome is extracted at the end of the each iteration and used for the evolution of the next iteration. This is repeated until desired generation is reached (Beasley, Bull, and Martin 1993).

3.2 Simulation Phase

Simulation modeling is an effective tool for evaluating different configurations of inventory control system in stochastic environments. It enables practitioners to understand the consequences and effects of each system without having to experiment on the real system (Rosen, Harmonosky, and Traband 2008). In simulation phase, defining control parameters is very important because it directly affect system performance. In this study, DCs and suppliers adopt the (R, s, S) inventory policy and simulation starts with different levels of initial inventories at DCs and suppliers because the initial conditions of a simulation are crucial aspects of simulation modeling. In review period, the inventory level of each DC and each supplier is replenished if its inventory level is smaller than or equal to the reorder level. The chances of lost sales are directly proportional to the value of the inventory control parameters. The higher inventory level in supply chain, the lower chance of lost sales. On the other hand, customer order quantity can be lower than inventory level in specified review period and hence excess holding cost can be incurred. Managers should decide how inventory level should be built up to meet not only the customer demand, but also other factors in order to minimize $\mathrm{TSCC_n}$. In this respect, simulation provides illustrative insight into complex stochastic problem where the actual environment is difficult to observe within acceptable time. Note that computer model of a single product two echelon supply chain environment is modeled by using SIMIO 6.105.11267 Enterprise Edition.

The assumptions of the simulation model are given as follows:

1. Single product flows through each DC and each supplier.
2. DCs and suppliers operate under the (R, s, S) policy where R is fixed (i.e., 5 days).
3. Inventory order policy parameters that are initial inventories, order-up-to level, reorder point for a given DC and supplier remain the same across the entire finite time horizon.
4. Poisson demand process and stochastic lead time are used.
5. Each customer order is supplied only by single DC and each DC replenishment order is supplied only by single supplier.
6. If the order amount exceeds the existing inventory level, possible order fulfillment takes place and unmet demand is lost.
7. There is always enough time for receiving an order before the next review period because replenishment lead time is shorter than the review period.
8. Inventory levels are not allowed to be negative.
9. Each of the supplier's vehicles performs at most one route. Each vehicle has enough capacity and there is no limit on the number of vehicles available.
10. Simulation model is run for one year.

4 RESULTS AND DISCUSSION

In today's competitive environment, the main goal of the supply chain management is that customer orders should be handled in the best possible manner. Therefore, the appropriate levels of inventory at the various stages involved in a supply chain must be determined. In general, high inventory levels are hold to increase the responsiveness of the supply chain. However, excess inventory affects financial performance and incurs additional problems. Thus, excess inventory decreases its cost efficiency because of the inventory holding cost. In this case, determining the proper values of reorder point and order-up-to level in the inventory control system are major challenges for decision makers. We used OvS to find the optimal values of the inventory control parameters. Thus, initial inventory, reorder point, and order-up-to level values are simultaneously determined for each DC and each supplier (Table 2).

Table 2: The optimal value of the initial inventory, reorder point and order-up-to level.

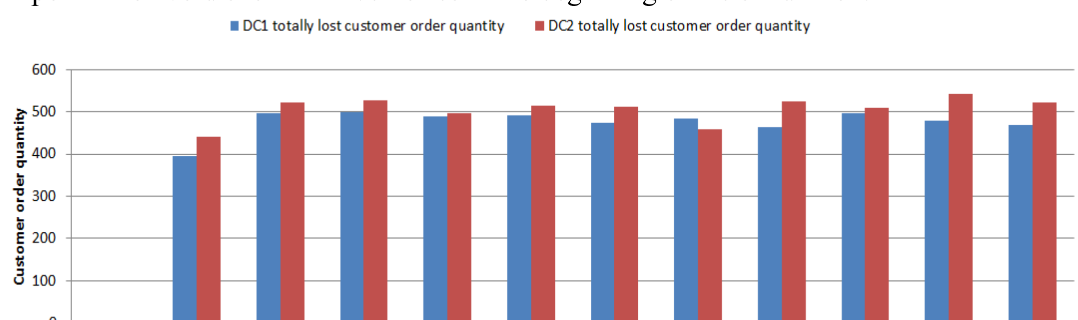
	Initial inventory	**Reorder Point (s)**	**Order-up-to level (S)**
DC1	1733	62	425
DC2	1733	62	425
Supplier 1	909	171	443
Supplier 2	846	62	425
Supplier 3	846	62	425

In (R, s, S) policy, the reorder point provides sufficient stock to satisfy demand until the next order's arrival. The determination of the order-up-to level allows us to see the maximum inventory level in system. Also, it should be noted that the effects of two decision variables, review period and order-up-to level, are not independent in most situations, that is the best value of review period depends on the order-up-to level value and vice versa. However, it is quite reasonable for practical purposes when dealing with B item to assume that review period has been predetermined without knowledge of the order-up-to level value (Silver, Pyke, and Peterson 1998). Note that B item is one of the class in ABC classification where items are divided into 3 classes, namely, A (very important), B (moderately), and C (least important). Hence, the value of review period is assumed to be predetermined in this study. Besides considering inventory control parameters, the most suitable supplier is determined for each DC. In this system, supplier 1 and supplier 3 are selected to satisfy DC's replenishment order; however, supplier 2 is not selected for any DC. It is noticeable that the optimal initial inventory, reorder point, and order-up-to-level values of Supplier 1 are larger than those of Supplier 3. The source of these variations may be due to stochastic order processing times, stochastic transportation times, or other stochastic parameters. The strongest candidate among these is stochastic customer order quantity. After displaying the critical inventory control parameters and suppliers, we give a detailed analysis about number of the partially lost (possible order fulfillment takes place depending on the inventory level of the DCs and unmet customer order quantity lost), number of the totally lost (customer order is fully lost) and number of the totally met (If customer order quantity is lower than the inventory level of DC, demand is fully satisfied from the DC's available stock) by taking into account customer order in each period while displaying customer order quantities for each case as seen in Figure 4-6.

Period	1	2	3	4	5	6	7	8	9	10	11	12
DC2-Totally met order	30	19	18	17	18	18	18	19	17	18	17	18
DC1-Totally met order	30	20	18	18	17	18	18	18	18	18	18	19

Figure 4: The analysis of the totally met in DC1 and DC2.

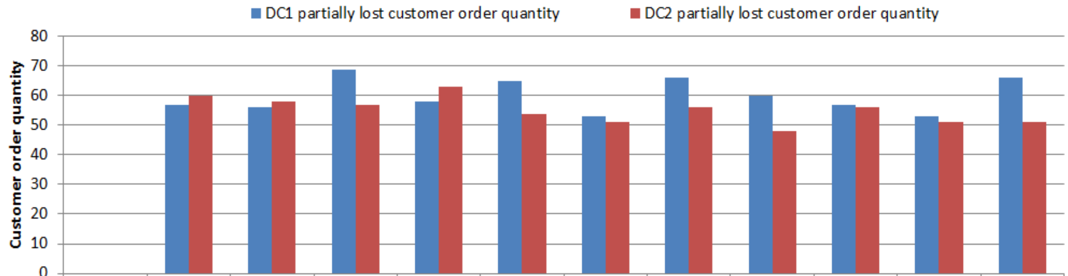
It is noticeable that except for the first period customer order quantity uniformly distributed across the periods with DC1 and DC2. Also, number of totally met customer order and totally met customer order quantity in DC1 and DC2 have slightly differ in all period because determined value of the initial inventory, reorder point, and order-up-to level are same for each DC. Note that, at period 1 all incoming orders are totally met. The reason for period 1's being an exception is DCs' all having adequate levels of initial inventories at that period. It should be noted that DCs' and suppliers' initial inventories are extremely important to avoid shortfall inventories at the beginning of the simulation.



Period	1	2	3	4	5	6	7	8	9	10	11	12
DC2-Totally lost order	0	9	10	11	10	10	10	9	10	10	11	10
DC1-Totally lost order	0	8	10	10	10	10	10	10	9	10	10	9

Figure 5: The analysis of the totally lost in DC1 and DC2.

From Figure 5, it is seen that first period is completely different from other periods and totally lost customer order quantity sharply increases at second period. Also, DC2 has higher totally lost customer order quantity except from period 8. The main reason for this situation should be the stochastic nature of the environment. For example, replenishment lead time for DC2 can be higher than DC1. Similar conclusions can be drawn related to partially lost customer order quantity. Although DC1 and DC2 have same inventory control parameters, other parameters affect the partially lost customer order quantity.



Period	1	2	3	4	5	6	7	8	9	10	11	12
DC2-Partially lost order	0	3	2	2	2	3	2	2	2	2	2	2
DC1-Partially lost order	0	2	2	2	2	2	2	2	2	2	2	2

Figure 6: The analysis of the partially lost in DC1 and DC2.

All DC replenishment orders are fully met by supplier 1 in each period. Thus, the existing inventory level at the supplier 1 is always greater than or equal to the DC's replenishment order quantity. However, some of the DC's replenishment order is partially satisfied by supplier 3 despite being quite a few. The main reason for this behavior is inventory control parameters. The optimal value of the initial inventory, reorder point, and order-up-to level with supplier 1 is higher than that of supplier 3. The replenishment orders are transported from suppliers to DCs by vehicles. We observed that transportation from suppliers to DCs takes place either two or three times in each period. To calculate $TSCC_n$, fixed and variable ordering cost, average holding cost, lost sales cost, order holding cost rate, fixed and unit transportation cost are considered and obtained results are given in Table 3 together with average service level of each DC and each supplier where average service level specifies the probability of the satisfied order from inventory.

Table 3: The results obtained from proposed OvS.

DC1 average service level	0,672134
DC2 average service level	0,656617
Supplier 1 average service level	1
Supplier 2 average service level	NA
Supplier 3 average service level	0,996562
$TSCC_n$	$3{,}3283\times 10^6$

The success of DCs and suppliers can be evaluated based on total supply chain cost and average service level. The higher average service level with lower total supply chain cost is needed to achieve significant savings. From Table 3, it is seen that the average service level for DC1 is close to average service level for DC2. Similarly, Supplier 1's average service level is very close to Supplier 3's average service level. Thus, each echelon member has similar cost and average service level value.

5 CONCLUSION

Thus far, many researchers have restricted their attention to analytical model in inventory control system. However, finding the optimal inventory control policy and characterizing its structural properties are analytically solvable only under simplifying assumptions and approximations. In this case, OvS undoubtedly play an important role due to OvS's capability and adaptability in supply chain analysis. In this study, OvS is used to determine the optimal inventory policy that coordinates stock levels in DCs and suppliers, and to select the best possible suppliers for DCs simultaneously. Proposed system involves the inventory control of a single product in two-echelon (R, s, S) inventory control system under stochastic environment and lost sales system. Specifically, we showed that the structure of the optimal inventory control policy is directly related with initial inventory, reorder point, and order-up-to-level and there is close relationship between inventory control parameters and lost sales. Briefly, we have provided an answer to the question of how OvS model is applied with lost sales inventory systems while considering total supply chain cost.

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