Using Simulation to Explore the Impact of Inventory Policies on Supply Chain Performance

Siri-on Setamanit
Faculty of Commerce and Accountancy, Chulalongkorn University, Bangkok, Thailand

Abstract--**To survive in today competitive environment, companies need to improve customer service while reducing costs. One way to address this challenge is to effectively and efficiently managing inventory. Companies carry inventory to ensure the level of customer service and avoid lost sales. However, holding inventory comes with costs such as inventory carrying cost and opportunity cost. There are several inventory policies proposed in the literature which aim to manage the difficult trade-off between minimizing the costs of holding inventory and satisfying customer demand. Unfortunately, these policies tend to be generic and work well under assumptions. Some assumptions may be contradicted to real-world practice, for example, stable and deterministic customer demand. In addition, certain policy that works well in one industry may not be appropriate for other industry under different environment. As a result, there is a need to develop a simulation model to determine a suitable inventory policy and explore the effect of inventory policy on supply chain performance, including cost and service level (fill rate) for a particular company or supply chain. In this paper, a case study of a beverage distribution center was used to illustrate the use of simulation to identify the most suitable inventory policy. Simulation model and simulation optimization can serve as a guiding tool to develop appropriate inventory policy. Furthermore, experimenting with the simulation model can also help manager to understand the effect of change in environment/condition on the effectiveness of the inventory policy.**

I. INTRODUCTION

The importance of inventory management has been evident for a long time. Generally, inventory is one of the important investments in all firms, ranging from a merchandise distributor to a manufacturer. Each of these firms needs to hold inventory in order to satisfy its customers or production requirements, while attempting to minimize total inventory cost, including holding cost, ordering cost, and shortage cost (stockout cost). Therefore, it is vital for a firm to find way to manage its inventory to maximize customer service, minimize total investment, and maintaining operation efficiency. Unfortunately, these three objectives are frequently in conflict with each other. Manager needs to make trade-off decision when trying to improve one of these objectives. For example, to achieve high customer service level, a relatively high investment in inventory is needed. In general, manager needs to find an inventory policy that specifies 1) when an order for additional items should be placed and 2) how many items should be ordered each time [6, 10].

There are many different types of inventory control model being developed to help determine the appropriate inventory policy. However, most of these models often based on restrictive assumptions, for example, demand is stable or constant. This, however, makes it difficult to apply to the real world situations. Through computer simulation, such assumptions can be avoided [2, 4, 5, 7]. Thus, a simulation model can provide a highly realistic representation of the real world system and allows manager to explore the effect of changes in related decision variables on system performance measures. This helps managers identify the most appropriate inventory policy for a particular company or supply chain under certain circumstance. There are many studies that use computer simulation to study and analyze inventory control systems [3, 8, 11, 12]. Most of them were use to evaluate different configurations and attempt to identify the most suitable configuration for the inventory system by answering "what if" questions.

However, to identify the optimal or most suitable configuration, one has to manually vary decision variables, run simulation, obtain performance result, and redo the process again until one is satisfied. This process is more or less similar to trial and error and requires extensive time and effort, and may not yield optimal result. Recently, simulation optimization is used to determine the best values for the decision variables of the system that maximize or minimize a single or multiple performance measures. It is a process of searching for the best decision variable values from among all possibilities without performing a complete evaluation search [1]. Furthermore, several optimization procedures have been incorporated into commercial simulation package. This makes it easier and quicker for researchers and practitioners to identify the optimal inventory policy under different conditions/circumstances.

In this paper, a simulation model of a case study company was developed by using ARENA simulation package together with OptQuest in order to evaluate the effect of inventory policy and identify the optimal one. Then, an experiment with a simulation model is performed to evaluate the impact of the variability in demand, the lead time, and the order interval period on the performance of the inventory policy in terms of cost and service level.

The rest of this paper is organized as follow: Section 2 describes a background of a case study company and a simulation model developed. Section 3 shows the use of simulation optimization to identify the most appropriate inventory policy and reports the results on the performance of the suggested inventory policy. Section 4 discusses the model experimentation and the results. Conclusions are provided in Section 5.

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II. CASE STUDY BACKGROUND

A case study company is a beverage manufacturer. It produces and sells more than 40 products under 10 different brands all over Thailand. There are 6 products that are distributed via company owned distribution center (DC), which represents more than 90% of the company sale revenue. In general, the DC orders products from the factory, stores them at its facility, and waits for customers (agents or retailers), who then sell the products to consumers, to pick them up. The distribution system of the case study company is shown in Fig 1.

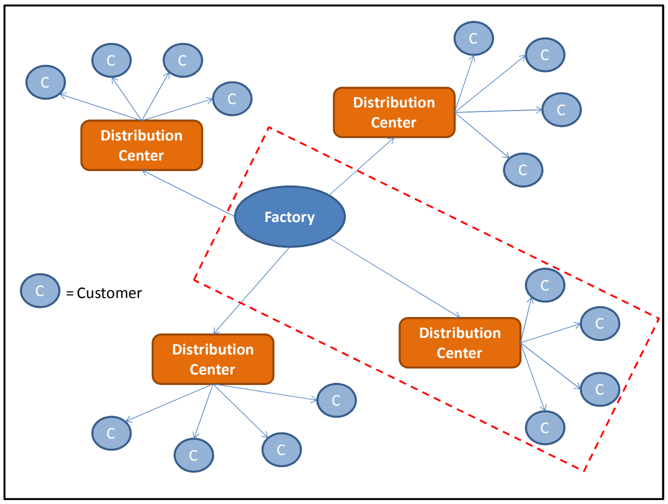

Figure 1: The distribution system of a case study company

Since all DC facilities are rented, the rental fee and other expenses are relatively high. Therefore, it is important for the DC to have effective inventory management policy in order to minimize the amount inventory and keeping the costs down while attempting to maximize customer service level. This case study will focus on finding the appropriate inventory policy for one of the company's DC that generates highest sale revenue. There are 6 items that are distributed via this DC. Based on the ABC analysis, there is 1 item that represents 75% of the annual sale value. Therefore, this study will focus on managing inventory for this item.

Currently the inventory system is fixed order interval system. At the beginning of each week, the manager of the DC reviews weekly sale forecast together with the space available in the DC, and decides on the quantity to order by using his/her own experience. Most of the managers tend to maintain high level of inventory to prevent stockout problem. After the manager places order at the manufacturer, it usually takes about 1.5 to 2 weeks for the manufacturer to deliver the products to the DC. The manager would like to find way to better manage inventory especially the appropriate level of inventory to keep and how many items to order each time. Note that the author will continue to use fixed order interval system since it is easier to understand and implement. This study will concentrate on identifying appropriate values for decision variables such as target inventory (order-up-to-level), reorder point, and order interval period.

A. A Simulation Model

The discrete-event simulation software package, ARENA, is used to construct the simulation model for DC inventory management system. The DC will place an order using (s, S) policy by evaluating its own inventory level only. Note that the s and S values will be determined by using OptQuest (optimization tool).

The operations process for this inventory management model can be summarized as follows:

- The DC receivers the delivery from the factory, which was ordered L periods ago (the lead time is L periods). The lead time in this case ranges from 1.5 to 2 weeks.
- The DC updates its inventory level.
- The DC reviews the order placed by its customers. For simplification, we assume that the orders from the all customers arrive at the same time each week.
- The DC fulfills its customer's order (plus backorders if there are any) by its available inventory. If there are not enough inventories, the unfulfilled quantity will be backordered. Note that the customers will wait until the DC can fulfill the order.
- The DC reviews its inventory level and decides on how many units to order from the factory. In this case, the quantity order will be equal to the difference between S (order-up-to level) and the current inventory level. If the current inventory level is more than s (reorder point), no order will be placed.

This cycle continues until the end of the specified simulated time. For this study, simulation model will be run for 52 weeks (about a year). Fig. 2 shows the overview of a simulation model.

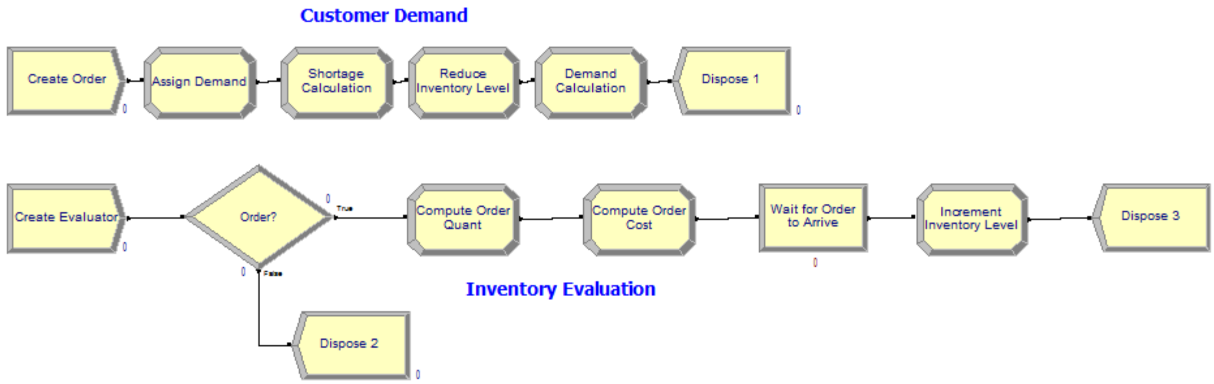

Figure 2: Overview of a simulation model

B. Data Collection

Weekly customer demand was collected for 2 years (104 data points). The weekly demand is found to fit the normal distribution with a mean of 157,812 units and a standard deviation of 38,566 with a 95% confidence level. Based on the interview and data collected, the lead time is uniformly distributed with a minimum of 1.5 weeks and a maximum of 2 weeks. For cost information, the ordering cost and the inventory carrying cost were calculated using information from the company annual performance report. On the other hand, shortage cost was derived from the interview with the manager. Note that the customer demand and the lead time are the source of randomness in this inventory simulation model.

C. Performance Measure and Cost Structure

The average total cost per week and the fill rate will be calculated to represent the performance of the inventory policy. The better and more effective inventory policy will result in lower average total cost per week and higher fill rate.

The average total cost per week consists of three major costs as follow:

- Average ordering cost per week
  The DC will incur a cost of 766 Baht every time it places an order regardless of the quantity ordered. If no order is placed, the ordering cost will be zero. The average ordering cost per week is calculated by dividing the sum of the total ordering cost by the number of simulated week (52 in this case).
- Average inventory carrying cost per week
  When inventory level is more than zero ($I(t) > 0$), there will be an inventory carrying cost of 0.47% of the unit cost (or 1.65 Baht) per unit per week. Therefore, the total inventory carrying cost for the whole simulated time will be:
  $$\int_0^{52} 1.65 \times \max(I(t), 0)\, dt \qquad (1)$$
  The average inventory carrying cost per week will be equal to the total inventory carrying cost divided by the number of simulated week (52 in this case).
- Average stockout cost per week
  When the quantity that the customer ordered is higher than the available on-hand inventory, stockout will occurs. The unfulfilled order will be backordered and the inventory level will be less than zero ($I(t) < 0$). This stockout costs 5 Baht per unit per week. The total sotckout cost will be:
  $$\int_0^{52} 5 \times \max(-I(t), 0)\, dt \qquad (2)$$
  The average stockout cost per week will be equal to the total stockout cost divided by the number of simulated week (52 in this case).

The other performance measure is fill rate which is a fraction of the demand that can be satisfied from on-hand inventory. This measure represents the ability to satisfy customer. The higher the fill rate, the better the customer service level. In this study, we will focus on the unit fill rate which is calculated as follow:

$$\text{Unit Fill Rate} = \frac{\text{Total Unit Shipped}}{\text{Total Unit Ordered}} \qquad (3)$$

For each simulation run, the model will automatically calculate the average total cost per week and the fill rate. This will make it easier for performance comparison of different inventory policy.

D. Model Verification and Validation

Several verification techniques suggested by [9] including structure walkthrough, running the model under simplify assumptions and under a variety of the input parameter, and output traces were used to verify the model. Animation was not considered relevant due to the nature of the problem.

For model validation, face validity was evaluated. In addition, the author also compares the results of the model against reference behavior pattern (real world performance). It was found that the model result is consistent with the real world data.

III. CASE STUDY RESULTS

The objective of this study is to identify the most suitable inventory policy for the DC. The customer demand follows normal distribution with an average of 157,812 units per week and the standard deviation is 38,566, which means that the coefficient of demand variation is approximately 0.25. If the value from demand distribution is below zero, the demand is assumed to be zero. The order interval is 1 week which means that the DC manager will review inventory at the beginning of each week and place the order if the inventory level is lower than reorder point (s).

The replication length is 52 weeks which is approximately equal to one year. The number of replications was set to 30 replications. OptQuest was used to find the best inventory policy that will minimize the average total cost while maintaining 90% service level. Therefore, the objective of the optimization problem is to minimize the average total cost. The constraint is that the fill rate should be equal to or more than 0.9. The control variables are the reorder point (s) and the order-up-to level (S). It was found that the reorder point (s) of 251,446 and the order-up-to level (S) of 251,472 yield the lowest average total cost (499,160 Baht per week) and the fill rate of 90%. It is interesting to note that the values of s and S are relatively close, and the difference is a lot smaller than average weekly demand. This implies that the order will be placed every time the inventory is reviewed. This agrees with the current DC practice since the inventory holding cost is relatively high comparing to the ordering cost. Thus, it is more economical to order frequently at smaller quantity. The model result of this inventory policy is shown in Table 1 (Simulation Optimization 1 policy).

TABLE 1: RESULT COMPARISON OF SIMULATION POLICY AND ANALYTICAL POLICY

Policy	Reorder Point	Order-Up-To Level	Average Total Cost per Week (Baht)	Unit Fill Rate
Analytical	405,616	417,740	499,160	99.94%
Simulation Optimization 1	251,446	251,472	304,320	90.14%
% Difference*			-39.03%	-9.81%
Simulation Optimization 2	348,842	348,842	393,800	99.04%
% Difference*			-34.62%	-1.00%
*** Compared to Analytical Policy**				

To further illustrate the benefits of simulation optimization, we also calculate (s, S) using analytical model. The reorder point (s) is equal to demand during lead time plus safety stock, which equals to 405,616. The order-up-to level (S) is equal to the order quantity (from the Economic Lot Size Model - EOQ) plus the reorder point, which equal to 417,740. With analytical policy, the average total cost is equal to 499,160 Baht and a fill rate of almost 100%. One can see that if manager are willing to reduce the fill rate to about 90%, he/she can save almost 40% of the average total cost per week.

Nevertheless, if the manager still prefers to maintain a fill rate of about 99%, he/she can run simulation optimization with a constraint that a fill rate is equal or more than 99% to find the appropriate s and S value that will yield the lowest cost. The result is shown in Table 1 (Simulation Optimization 2 policy). It was found that the reorder point (s) and the order-up-to level (S) equal to 348,482 yield the lowest average total cost of 393,800 Baht per week (35% lower than the average cost from analytical policy).

One can see that simulation optimization helps identify the optimal inventory policy that will be resulted in the lowest total cost at the predetermined customer service level (fill rate). In addition, it allows practitioner to find optimal policy at different conditions or constraints which will be beneficial in decision making process. For example, manager can make a trade-off decision whether to decrease the fill rate in order to reduce costs.

IV. MODEL EXPERIMENTATION

To further gain insight into the effect of the variability in demand, the lead time, and the order interval period on the cost and service level performance of the inventory system, we conducted an experimental study as shown in the following sub sections.

A. Effect of Variability in Demand

The first experimentation is to explore the effect of demand variability on the performance of the inventory system. The weekly customer demand in this case was assumed to follow normal distribution with an average of 157,812 units per week and the standard deviation is 15,781, which means that the coefficient of demand variation is approximately 0.1 (the original is 0.25). First, the simulation optimization is conducted to identify the optimal s and S parameters for the new situation (less demand variability). Then, the author compares the performance result of the new situation against the current one. The result comparison is shown in Table 2.

TABLE 2: EFFECT OF VARIABILITY IN DEMAND

Coefficient of Variation	Reorder Point (s)	Order-Up-To Level (S)	Average Total Cost per Week (Baht)	Unit Fill Rate
0.25	251,446	251,472	304,320	90.14%
0.1	234,940	237,720	273,210	90.01%
% Difference			-10.22%	-0.15%

As the variability in demand decrease, the inventory level tends to decrease due to the reduction in safety stock (required to cover uncertainty). In this case, one can see that the reorder point (s) decreases by 16,506 units when coefficient of demand variation reduces from 0.25 to 0.1. In addition, the average total cost decreased by 10% while the unit fill rate (customer service level) remains the same.

Furthermore, the author also evaluates the effect of the reduction in demand variability on the average total cost and fill rate in the situation that the inventory policy remains the same (same reorder point (s) and order-up-to level (S) as in current situation). It was found that the average total cost reduces to 278,400 (9% reduction) while the fill rate increase to 92% (2% increase). This is as expected since when one holds the same inventory level, one should be able to fulfill more order, which result in lower shortage cost.

Therefore, if DC manager can reduce variability in demand by coordinate and collaborate more with the customer, he/she can reduce the inventory level hold, the total costs, and probably the space required for DC facility. However, if he/she decides to keep the inventory at the same level, the service level will be improved. One can see that simulation model provides useful information for manager to make a trade-off decision and find the best inventory policy that best suit the company objective.

B. *Effect of Lead Time*

For this experimentation, the lead time between the factory and the distributor increase from 1.5-2 weeks to 3-4 week, however, the type of the distribution remains the same (uniform). Again, the simulation optimization is conducted to identify the optimal s and S parameters for the new situation (longer lead time). Then, we compare the performance result of the new situation against the current one. The result comparison is shown in Table 3.

TABLE 3: EFFECT OF LEAD TIME

Lead Time	Reorder Point (s)	Order-Up-To Level (S)	Average Total Cost per Week (Baht)	Unit Fill Rate
UNIF (1.5,2)	251,446	251,472	304,320	90.14%
UNIF (3,4)	478,891	478,903	1,300,300	89.87%
% Difference			327.28%	-0.30%

One can see that the effect of the increase in lead time is relatively strong on the average total cost (given that we want to keep the same service level). The average total cost per week increases by 327%. With this information on hand, the DC manager has to pay attention on the lead time. He/she should discuss with the factory to keep the lead time at current level.

The author also conducts further experiment to determine the effect of the increase in lead time on the average total cost and fill rate in the situation that the inventory policy remains the same (same reorder point (s) and order-up-to level (S) as in current situation). It was found that the average total cost per week is 1,201,900 Baht and the fill rate is 75%. This is interesting since the average total cost per week is lower than the optimal policy (1,300,300 Baht), but the fill rate decreases significantly from 90% to 75%. This shows that when the lead time increases, company will incur more costs in order to keep the same service level. However, if a certain degree of reduction in service level is acceptable, company may be able to save more on total cost. The manager can experiment further with the model to find the acceptable combination of cost and service level.

C. *Effect of Order Interval Period*

The third experimentation is to explore the effect of order interval period on the performance of the inventory system. The order interval period is set to 2 weeks instead of every week in the current situation. Again, the simulation optimization is conducted to identify the optimal s and S parameters for the new situation (order every 2 weeks). Then, the author compares the performance result of the new situation against the current one. The result comparison is shown in Table 4.

TABLE 4: EFFECT OF ORDER INTERVAL PERIOD

Order Interval	Reorder Point (s)	Order-Up-To Level (S)	Average Total Cost per Week (Baht)	Unit Fill Rate
Every week	251,446	251,472	304,320	90.14%
Every 2 weeks	408,508	463,736	267,710	89.99%
% Difference			-12.03%	-0.17%

As expected, the reorder point (s) and the order-up-to level (S) is higher when the order interval period increase from 1 week to 2 weeks since we need to hold more inventory to cover the longer period. What interesting is that the average total cost per week decreases to 267,710 Baht (12% reduction) when the order is placed every 2 weeks. By further examining model output, it was found that the average inventory level in both cases is not much different. However, the ordering cost is a significantly lower in the new situation (number of order reduces by half). In addition, the shortage cost in the new situation is also lower. This may look counterintuitive since the fill rate for both cases is relatively the same. The reason is that fill rate doesn't account for the time customer has to wait for the order to be filled. But the shortage cost increases every week until the order is filled. For example, if there is an order for 100 units and 90 units are available. The fill rate will be 90% and the shortage cost will be 50 Baht (5*10) for the first week. If these 10 units cannot be fulfilled in the second week, there will be shortage cost of 50 Baht for the second week. The shortage cost keep increasing every week until these 10 units are delivered. On the other hand, the fill rate is calculated only once at the beginning.

The author also test the effect of the increase in lead time on the average total cost and fill rate in the situation that the inventory policy remains the same (same reorder point (s) and order-up-to level (S) as in current situation). As expected, the values of s and S are not appropriate when the order interval period increase from 1 week to 2 weeks since more inventories are definitely needed to cover the longer period. It was found that the average total cost increases to 593,640 Baht and the fill rate drop significantly to 32%. This finding illustrates the importance of having the right decision variables (s and S) that match with the order interval period. Again, simulation model can help one see the impact of the mismatch policy and allows one to experiment with the model to identify the suitable policy.

V. CONCLUSION

This paper shows how simulation model and simulation optimization can be used to determine the most suitable inventory policy under different circumstance. In addition, one can explore the effect of several important factors such as variation in demand, lead time, and order interval period on the performance of inventory policy both in terms of cost and service level. In this paper, a case study of a beverage distribution center was used to illustrate the benefit of the simulation model. First, the simulation optimization can be used to determine the most appropriate inventory policy (reorder point and order-up-to level) for certain objectives (in this case, total cost and service level). Then, simulation was used to examine the impact of demand variability on the inventory policy performance. It was found that the average total cost and average inventory level is generally lower when demand variability is lower. For lead time, it has strong impact on cost performance. The increase in lead time is resulted in higher total cost and lower fill rate. If lead time increase and the manager fail to adjust inventory policy, the fill rate will be reduced significantly which can cause customer dissatisfaction. Lastly, the simulation model was used to explore the effect of increasing the order interval period. The increase in order interval period generally required higher inventory (higher order-up-to level) in order to maintain the same service level. In addition, it is very importance adjust reorder point (s) and order-up-to level (S) to match the order interval period. Otherwise, the firm will incur higher cost and the service level will drop significantly.

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