Abstract—Inventory is carrying high risk and high benefit as a supply chain management system. A shortage or lack of supplying sufficient inventory can disrupt manufacturing plan. Inventory management plays an important role to avoid shortage or ending up with overstock. The most important task of inventory management is making trade-off between the minimization of the total cost and maximization of the customer satisfaction. The goal of this study is to introduce a model that can maximize the availability rate of accessories and reduce the total inventory costs in conversion services. To overcome this problem, the Fuzzy Logic Approach was used. Fuzzy logic was used to control uncertainties in demand and supply. Fuzzy logic control is now being the effective methodology in many applications under uncertainty. In the proposed Fuzzy Inventory System (FIS), both demand and lead time are described in linguistic terms. Then, the developed fuzzy rules were used to extract the fuzzy order quantity. The fuzzy model reduced the total inventory cost almost by 26%. In addition, no shortage was allowed in these models.

Keywords—Supply Chain; Inventory Management; Fuzzy Logic; Uncertain Demand; Uncertain Supply

I. INTRODUCTION

In every organization, supply chain management plays an important role for keeping the business running. Therefore, continuous improvement on the different aspects in the supply chain should be taken into consideration. The term supply chain management refers to cooperative management of materials and information flows between supply chain partners, to reach goals that cannot be achieved acting individually [1]. Therefore, sharing demand information with suppliers has a great effect on making the business running smoothly. On the other hand, sharing supply information with the customer (company) will also improve the management of inventory. Uncertainty and risk exist in every supply chain; customer demand variable, lead times will never be certain, and machines and vehicles will break down. Accessory's demand in Automobile industry is highly affected with both lead time and demand uncertainties, which is affecting the availability rates of accessories and as a result increasing the overall inventory cost. Accessories (sensors, fog lamp, Audio etc.) are installed in all types of vehicles sold by the local automobile trader. Supply chain department is taking care of the demand planning and ordering of all required accessories. Over 120 accessories are supplied by overseas suppliers. Therefore, in order to achieve a high fulfillment rate in the vehicles accessory, all items must be available on time. This study will focus on developing a model using fuzzy logic that can consider the factor of uncertainties, in order to end up with a lower inventory cost and better satisfaction of customers.

Each month supply chain department gets demand data of vehicles from the marketing team, which is the input of the inventory model. Then vehicles are converted to accessories in order to know the requirements of that month. The current ordering model is based on Max-Max Concept (Max Max Concept determines a maximum level of inventory that can be stocked). However, it has some disadvantages:

- Neglecting all operating costs (procurement and holding cost)
- Cannot adopt to high fluctuations in demand.
- It assumes that demand is constant for the next five months.

II. LITERATURE REVIEW

The classical inventory model, EOQ, discussed in inventory control system assumes that demand and lead time are constant and known. In real life, demands are never constant [2]. Customer Service Level and safety stock is one of the available methods of solving the inventory problem under uncertain supply and demand. The purpose of the safety stock is to cover the random variations in demand and lead time. Safety stock is not intended to eliminate the occurrence of shortages but it can cover the variations in demand and lead time based on the predetermined service level. In this study, customer service level is defined to be 98%. In 2006, Nick T. Thomopoulos [3] gives a comparison between two fundamental methods of determining the size...
of safety stock, which are the availability method and the service level method.

Fuzzy inventory model with both uncertain parameters and fuzzy variables have been discussed recently. In 2008, Chien-Chang Chou [4] proposed a Fuzzy Economic Order Quantity (FEOQ) inventory model, in which costs and quantities were expressed in trapezoidal fuzzy numbers. The purpose was to provide a defuzzification technique for the FEOQ inventory model using the Function Principle, the Graded Mean Integration Representation method and the Kuhn-Tucker conditions.

In 2010, Achmad Riadi [5] investigated the effectiveness of fuzzy inventory control system for controlling the inventory, especially with the presence of demand uncertainty.

In 2011, Malay Niraj et al. [6] developed a fuzzy expert decision system for solving the supplier selection problem with multiple objectives. Three factors were considered in developing the model which are: price, quality and service.

Christoph H. Glock et al. [7] develops an economic order quantity model with fuzzy demand and learning fuzziness. It was shown that learning in fuzziness reduce uncertainty by improving the information base for future orders.

Hindriyanto D. Purnomo et al. [8] proposed a fuzzy economic order quantity model with partial back order. It was found that the optimal fuzzy economic order quantity is higher than the economic order quantity in crisp value due to lack of information.

Thanthatemee et al. [9] proposed a fuzzy inventory control system for a single item continuous control system. The model can deal with both uncertain demand and availability of supply. The developed fuzzy model was used to determine the order quantity and the reorder point.

D. Dutta and Pavan Kuma [10] proposed a fuzzy inventory model (without shortage) to determine the optimal total cost and the optimal order quantity. The defuzzification process to extract the EOQ was carried out using the signed distance method.

III. Fuzzy Inventory Control Model

A. The Fuzzy Model

The proposed fuzzy model will be used for the calculation of the safety stock and will consider both uncertainties in supply and demand. Fuzzy logic control is now an effective methodology in many applications under uncertainty. Therefore, a fuzzy logic approach for solving the problem of inventory control under uncertainty is proposed. In the proposed Fuzzy Inventory System (FIS), both demand and supply (lead time) are described in linguistic terms. These linguistic terms were decided by expert managers, who have been worked in the supply chain department for more than 10 years. Then, the developed fuzzy rules were used to extract the fuzzy order quantity.

In the proposed Fuzzy model, there are three components; fuzzy inputs, fuzzy outputs and fuzzy rules. Fuzzy logic toolbox of MATLAB is used to construct the model for calculating order quantities. Each element of the model is shown in fuzzy inference system editor. (Fig.1)

![Fig.1 The Fuzzy Model of Controlling Uncertain Supply & Demand](image)

B. The Fuzzy Inputs

Two fuzzy input variables are defined: demand and supply and one output variable is defined as order quantity. These variables are represented by linguistic variables. Trapezoidal and triangular functions are used to fuzzify the crisp input and output variables.

Fuzzy inputs in the fuzzy model are demand and supply which are described by membership functions \(\mu_D\) and \(\mu_S\), respectively. Fuzzy demand and fuzzy supply were determined based on observation and test using normal distributions of historical data. Both demand and supply are assumed to be represented by 3 linguistic values; low, medium and high, and normal, late and very late respectively as shown in Fig. 2 and 3.
The universe of discourse of the demand input space is designed from the real data within the interval \([0, \max(D)]\), where \(\max(D)\) is the maximum demand that had been ordered. Supply is designed based on real data within the interval \([0, \max(S)]\), where \(\max(S)\) is maximum lead time of supply from the current suppliers of determined planning horizon.

Conventional inventory models use fixed value of order quantity. However, in real situation of uncertain demand and supply, fixed values of order quantity are not appropriate because materials may not be available when they are most needed. Moreover, the situation of supply may tend to decrease. Safety of shortage should be carefully determined.

C. The Fuzzy Output

In the proposed model, one fuzzy output is constructed. It is fuzzy order quantity and is described by membership functions \(\mu Q\). Fuzzy order quantity is assumed to be represented by 4 linguistic values; low, medium, high, very high as shown in Fig. 4.

Fuzzy inference type of the proposed system is Mandani. The relationship among demand \((x_1)\), lead time \((x_2)\) and order quantity \((y_1)\) is described by the following rules and is also shown in Table I:

- **R1:** IF \((x_1 \text{ is ‘Low’}) \text{ AND } (x_2 \text{ is ‘Normal’})\) THEN \((y_1 \text{ is ‘Low’})\) ELSE
- **R2:** IF \((x_1 \text{ is ‘Low’}) \text{ AND } (x_2 \text{ is ‘Late’})\) THEN \((y_1 \text{ is ‘Medium’})\) ELSE
- **R3:** IF \((x_1 \text{ is ‘Low’}) \text{ AND } (x_2 \text{ is ‘Very Late’})\) THEN \((y_1 \text{ is ‘High’})\) ELSE
- **R4:** IF \((x_1 \text{ is ‘Medium’}) \text{ AND } (x_2 \text{ is ‘Normal’})\) THEN \((y_1 \text{ is ‘Medium’})\) ELSE
- **R5:** IF \((x_1 \text{ is ‘Medium’}) \text{ AND } (x_2 \text{ is ‘Late’})\) THEN \((y_1 \text{ is ‘High’})\) ELSE
- **R6:** IF \((x_1 \text{ is ‘Medium’}) \text{ AND } (x_3 \text{ is ‘Very Late’})\) THEN \((y_1 \text{ is ‘High’})\) ELSE
- **R7:** IF \((x_1 \text{ is ‘High’}) \text{ AND } (x_2 \text{ is ‘Normal’})\) THEN \((y_1 \text{ is ‘High’})\) ELSE
- **R8:** IF \((x_1 \text{ is ‘High’}) \text{ AND } (x_2 \text{ is ‘Late’})\) THEN \((y_1 \text{ is ‘Very High’})\) ELSE
- **R9:** IF \((x_1 \text{ is ‘High’}) \text{ AND } (x_2 \text{ is ‘Very High’})\) THEN \((y_1 \text{ is ‘Very High’})\)
With the help of fuzzy tool box of MATLAB, fuzzy output is translated into linguistic form as shown in Fig. 5.

By taking the max-min compositional operation, the fuzzy reasoning of these rules yields a fuzzy output of fuzzy reasoning. These outputs can be expressed as in equations (1) [9]:

$$\mu_{Di} \left( y_i \right) = \left( \mu_{Di} \left( \chi_1 \right) \wedge \mu_{Di} \left( \chi_2 \right) \right) \vee \ldots \left( \mu_{Di} \left( \chi_1 \right) \wedge \mu_{Di} \left( \chi_n \right) \right)$$  \hspace{1cm} (1)

Where \( \wedge \) is the minimum operation and \( \vee \) is the maximum operation. Di, Si, and Ri are fuzzy subsets defined by the corresponding membership functions.

Finally, a defuzzification method, called the center-of-gravity method, is adopted here to transform the fuzzy inference output into a non-fuzzy value order quantity \( y_0 \).

IV. RESULTS AND FINDINGS

In order to validate the reliability of the proposed fuzzy model, historical data was used and compared to the results of the actual situation.

The results of the Fuzzy Control of Uncertain Supply and Demand Model shows that no shortage will occur during the year. Figure 6 shows graphically the demand and stock situation.

Moving to the financial results, it was found that the average holding cost is $18,877, average ordering cost is $296 and the average inventory cost is $18,854.

Determining the best ordering model depends on many factors and may vary from one organization to another. Many organizations prefer not to face shortage at all in order not to lose sales and customer loyalty. Therefore, these kinds of organizations would rather accept taking the risk of ending up with overstock than facing a shortage. Other organizations can accept having shortage up to a certain level.

Table II shows a comparison between the current ordering model and the proposed fuzzy model. It was conducted on the basis of important inventory factors.

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>COMPARISON BETWEEN CURRENT MODEL AND THE PROPOSED MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Name</td>
<td>Avg. Holding Cost</td>
</tr>
<tr>
<td>Current Model</td>
<td>25,865</td>
</tr>
<tr>
<td>Fuzzy Model</td>
<td>18,590</td>
</tr>
</tbody>
</table>

Based on the above summary, there are significant differences between the inventory performance factors of the current model compared to the fuzzy one. The average stock month is much lower in the fuzzy model than in the current model, which, as a result, leads to lower holding cost. Shortage never occurred in the study period when applying the fuzzy model, but it happened twice when using the current model for the same study period. Almost 1000 pieces were short compared to 100% availability rate using the fuzzy model.
The effectiveness of the proposed fuzzy model as compared to stochastic approaches is that fuzzy model is more flexible in case of any adjustment or improvement of supplying goods.

Although the current model shows a huge inventory cost, shortage still exists. This is because the model is built based on wrong assumption that demand will remain constant for the next 5.5 months. Accordingly, whenever a fluctuation happens, it will be late to order.

In fact, using the right ordering model does not only prevent/reduce the occurrence of shortage but can also reduce total inventory cost by at least 26%. For future work, it is recommended to use statistical approaches to model uncertainties in demand and lead time as well. A comparison should be done in order to end up with the most suitable model that can meet the goal of the organization.

V. CONCLUSION

In this work, fuzzy logic was utilized along with the economic order quantity to model demand and supply uncertainties in automobile industry. MATLAB was used to develop the fuzzy model. Two inputs were considered: demand and supply. Order quantity was considered as the output of the model. Linguistic values were used to represent both inputs and output. Fuzzy rules were set based on the experience of a group of supply chain members. Results show a huge reduction in the total inventory cost, compared to the current model. In addition, no shortage occurred in the proposed fuzzy model. This will lead to more customer satisfaction and as a result will increase customer loyalty.

REFERENCES