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FUZZY INVENTORY MODELING OF CRUDE PALM OIL IN THE PORT BULK TANK

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Abstract: This paper aims to develop a model for inventory optimization of crude palm oil by applying the economic order quantity (EOQ) and the fuzzy theory. The used defuzzification method is the signed distance method. Model development was conducted by, first, re-formulating the EOQ basic model. The model development was implemented in terms of decision support systems with the inventory optimization and sales forecast of crude palm oil as the model basis, whereas the parameters of cost, demand bias and past sales data as the data basis. Defuzzification was used as the knowledge basis. The study showed that the optimal quantity measurement of the fuzzy EOQ was always less than crisp EOQ model. The produced decision support system can support the decision-makers in planning and control the supply operational to the port.

Keywords: inventory, EOQ, fuzzy, decision support system, crude palm oil

INTRODUCTION

In the Agroindustrial supply chain system of crude palm oil (CPO), inventory policy is one of the major concerns. Inventory is not only beneficial for maintaining the service level, but also for providing consequences to the total cost of supplies. Problem of crude palm oil inventory, that is quite important, is determining level of inventory in the port bulk tank. The factory unit that processes the fresh fruit bunches into crude palm oil will send the supplies to the port based on demand.

The arisen complexity of inventory problems is triggered by demand fluctuation, product availability in the processing unit and harvest season in the palm field unit. Specifically, the right perspective should be placed to improve the effectiveness of supply chain management. Inventory management in the bulk tank should not ignore the fuzzy condition in the decision-making process.

Business environment that is very competitive and fluctuating has to be considered correctly by the decision-makers. Demand forecast can not much longer be defined in the form of crisp values in the business situation with fluctuating and competitive demand. Fuzzy form of demand is represented in normal demand number, high or low. Fuzzy state will trigger the loss of sales and revenue risk so that requires an appropriate approach to handle. One of the solutions is by applying the fuzzy techniques.

This study aimed to develop a mathematical model and to design a decision support system for crude palm oil inventory control by applying the economic order quantity (EOQ) with fuzzy demand conditions. EOQ model is proven to be quite effective in its implementation for inventory control in various fields. Implementation is carried out through the re-formulation of the EOQ basic model. Model development is implemented in the form of...
decision support systems. System approach in the decision-making, which is known as decision support systems, is intended to describe system elements in detail so that system can support managers in decision-making process (Eriyatno 2003).

Scope of supply chain system which is discussed in this study is interaction between factory plant and port bulk tank. Inventory control policy of crude palm oil is focused in port bulk tank to obtain optimal order quantity. Real situation is modeled as mathematical model. The benefit of this study is the software that will help the decision-makers such as plant managers and district general managers in coordinating to maintain the optimal inventory levels.

LITERATURE REVIEW

Inventory models that apply fuzzy theory have been mathematically developed. Lee and Yao (1998) discussed economic production quantity (EPQ) model with fuzzy demand and fuzzy production using triangular membership function. The discussion substance was the computation scheme by applying centroid defuzzification method.

Lee and Yao (1999) also discussed the EOQ model with fuzzy ordering quantity and fuzzy total inventory cost using centroid defuzzification method. The similarity between these two models was the application of centroid defuzzification method and triangle membership functions, while the difference was the applied inventory model.

Chen and Hsieh (2000) developed a principal functions defuzzification method that could be applied to trapezoidal and triangle membership functions. The discussion was still focused on the mathematical explanation that was intended to produce computing scheme only. The application of the model development was the inventory EOQ model.

Syed and Aziz (2007) applied the signed distance method to the EOQ model with ordering cost and storage cost of fuzzy conditions. The comparison result showed that the ordering quantity of the fuzzy model was larger than the crisp model.

Yao and Chiang (2003) compared the centroid defuzzification and signed distance methods on the EOQ model with fuzzy total inventory cost and fuzzy storing cost. The comparison results showed that the signed distance method gives better result.

The direction of further model development was to consider various conditions in inventory policy with fuzzy conditions. Kao and Hsu (2002) considered the stock-out cost with fuzzy conditions demand. Defuzzification using Yager method for ranking fuzzy numbers thus it was obtained the smallest total inventory cost.

Chiang et al. (2005) developed a model that considered the stock out cost with all fuzzy conditions inventory parameters. The used membership function was the triangular with defuzzification using the signed distance method. The focus of the discussion was only on the computational scheme to improve the accuracy of the calculation results.

Chen et al. (2007) developed an EPQ inventory model by considering that there were inferior products and fuzzy conditions on demand, the cost of storage and preparation costs. The used defuzzification method was the principal function with the trapezoidal membership function.

The completion techniques for inventory model which is containing the fuzzy condition on model component were also developed. Gao and Feng (2006) developed an inventory model with fuzzy condition on demand and considering the product sales price discount rate. A very complex mathematical formulation was solved by assigning a framework that consists of hybrid intelligent algorithm and dynamic program. Kumari and Raju (2008) developed an inventory model that considered the stock out cost and product damage. The model was formulated with two objectives, those were revenue maximization and minimization of waste product cost. The developed model solution techniques were the weighted non-linear fuzzy programming, fuzzy additive goal programming and the integration of those two techniques. The discussion was aimed to compare those solving techniques without concluding which completion technique was better. Taleizadeh et al (2009) developed the inventory model with fuzzy conditions on demand. The model solving technique uses particle swarm optimization. This solving technique was also used by Xiaobin et al. (2007) for inventory model with fuzzy conditions preparation cost and storage cost.
Inventory model development in paper industries can be found in the paper discussed by Björk (2008). The developed EPQ model aimed to get the optimum supply cycle time. Fuzzy condition was defined in the inventory cycle time with triangular membership function. Model finishing was carried on analytically.

Not so many inventory models that were developed based on real conditions of an industry, including the crude palm oil agroindustry. Model development that is described mathematically will complicate its application in practical. Inventory mathematical model loading into the model base in a decision support system will provide specific appropriate values for managers or decision makers.

RESULT AND DISCUSSION
Model Development

The elements of the inventory system of crude palm oil in the port bulk tank consists of crude palm oil demand ($d$) from the port, that is an effort to meet the sales plan or shipment, and ordering quantity ($q$), that is the amount of economic supply to the port. High and low number of request is defined as fuzzy query ($\tilde{d}$) with triangular membership function. The involved cost components are ordering cost ($k$), storage cost ($h$) of product in the bulk tank, and transportation cost per kilogram ($c$) of crude palm oil from the factory plant to the port. Total inventory cost or $TC(q)$ is the sum of all associated costs, as follows:

$$TC(q) = \left(c \odot \tilde{d}\right) + \left(\frac{k \odot \tilde{d}}{q}\right) \oplus \frac{hq}{2}$$  \hspace{1cm} (1)

Equation (1) is basic equation of EOQ model that show the inventory total cost (Chien and Shieh 2000, Chiang et al. 2005) and it is modified with demand query ($\tilde{d}$) in fuzzy number. Demand value that is not firmly expressed is represented in the form of fuzzy numbers. If the demand is symbolized by $\tilde{d}$ in the form of triangular fuzzy numbers, then there will be a difference of D that is determined by decision makers based on their knowledge and experience. The D values will contribute to the demand value difference of $d$, where $d$ is a known number from the previous forecast. Fuzzy value of $d$ can be written as follows:

$$\tilde{d} = (d - \Delta_1, d, d + \Delta_2)$$  \hspace{1cm} (2)

Total inventory cost will be in the form of fuzzy where $TC(q)$ is in condition where and . The values of $H_1, H_2, H_3$ can be formulated:

$$H_1 = TC(q) - c\Delta_1 - \frac{k\Delta_1}{q}$$  \hspace{1cm} (3)

$$H_2 = cd + \frac{k\Delta_1}{q} + \frac{hq}{2}$$  \hspace{1cm} (4)

$$H_3 = TC(q) + c\Delta_2 + \frac{k\Delta_2}{q}$$  \hspace{1cm} (5)
Defuzzification can be done using signed distance method in accordance with the basic formula (Yao and Chiang 2003) with the following results:

\[
d(TC(p),0) = cd + \frac{kd}{q} + \frac{hq}{2} + \frac{1}{4}\left[c(\Delta_2 - \Delta_1) + \frac{k(\Delta_2 - \Delta_1)}{q}\right]
\]

(6)

Optimal value of ordering quantity \( q^* \) is obtained by getting the first derivative of Equation 6. Conditions that need attention are and:

\[
k\{4d + (\Delta_2 - \Delta_1)\} = \frac{h}{2}
\]

(7)

\[
q^* = \frac{\sqrt{k(4d + \Delta_2 - \Delta_1)}}{2h}
\]

In the case of demand in firmly form or in exact number then the elements of difference \( D_1 \) and \( D_2 \) are equal to zero or \( D_1 = D_2 = 0 \). Equation 7 for condition \( D_1 = D_2 = 0 \) will be the equation from the firm EOQ basic model. The total inventory cost by considering fuzzy condition demand is represented as follows:

\[
TC(q^*) = cd + \frac{kd}{q^*} + \frac{hq^*}{2} + \frac{1}{4}\left[c(\Delta_2 - \Delta_1) + \frac{k(\Delta_2 - \Delta_1)}{q^*}\right]
\]

(8)

\[
TC(q^*) = cd + \frac{1}{4}c(\Delta_2 - \Delta_1) + \frac{1}{2}\sqrt{2kh(4d + \Delta_2 - \Delta_1)}
\]

If the equation of fuzzy total inventory cost is compared to the total inventory cost of firm EOQ model, it is differentiated by elements \( \Delta_1 \) and \( \Delta_2 \). If \( \Delta_1 = \Delta_2 = 0 \), then it will go back into firm EOQ.

Optimal point which has been obtained can be proven by examining the second derivative of the total inventory cost function.

\[
\frac{d^2TC(q)}{dq^2} = \frac{k\{4d + (\Delta_2 - \Delta_1)\}}{8q^3}
\]

(9)

\[
\frac{d^2TC(q)}{dq^2} > 0 \text{ or always be positive as proof that } q^* \text{ is the optimal value, so that it will produce the minimum total inventory cost. Fuzzy value of } d \text{ for the total inventory cost function will give a positive value with the following explanation:}
\]

\[
4d + \Delta_2 - \Delta_1 = 3d + \Delta_2 + (d - \Delta_1)
\]

(10)

Procedure to determine the value of supply to the port bulk tank consists of two basic steps, those are: setting the bias value of sales, and setting the value of \( D_1 \) and \( D_2 \) based on the opinions of decision makers among the authorities of bulk tank management at the port. Then, preparing the data that is associated with shipping cost \( c \), ordering cost \( k \), the storage cost \( h \) and sales forecast \( d \).

Value of sales bias will be the database while the cost parameter will be the input in the interface. After these two kinds of data are available, the calculation of economic supply value and the total inventory costs can be carried out based on the formula that has been formulated.

A decision support system of crude palm oil inventory in the port bulk tank consists of the model base and database. The model base consists of optimization of inventory, total cost of inventory and defuzzification technique. The database is the parameters of cost, demand bias and sales or demand forecasting data that can be updated as circumstances change in the company. Decision support system is designed to plan the amount of supplies to the port during one year in monthly basis. Configuration of model can be seen in Figure 1.

Verification was conducted by tracing the running program first. If the entire line of program code was successfully executed according to the logic then program would be considered successful. Next examination was the examination of result or output of the computer program. A good model would produce solution that met to the model requirements. If the completion of the program indicated any error and did not work according to the defined logic, then it would be repaired. Verification process had been carried out and model was able to work in accordance with the assumed logic and conditions.
Validation aimed to obtain a match that the model already contained all of the elements, events and relations of the real system. The applied Face validity technique was formulating the fundamental questions regarding the usefulness and accuracy of model prediction that involved the participation of practitioners and academics separately. The model was considered as valid because it represented the basic elements of the crude palm oil inventory system and was able to predict well the overall key system operation.

**A Case Study**

Determination of inventory can be determined based on the sales forecast. Forecast made for the next 12 months. The goal was to know the sales forecast every month that would be the input in determining the quantity of the economic supply each month. Table 1 contains the results of crude palm oil sales forecasting (d).

Other inputs that are required are parameters of cost and demand interval limit. Data of inventory cost for \( k = \text{IDR 14,466,684} \), \( c = \text{Rp 54,000} \) per ton and \( h = \text{IDR 9,070} \) per ton per month. The limits of demand value that are accommodated by fuzzy parameter are obtained based on the opinion of the decision makers, those are \( \Delta_1 = 0.1d \) and \( \Delta_2 = 0.05d \). Parameter values are inputted to the software interface as shown in Figure 2.

The result of inventory optimization by determining the quantity of the economic supply from factory plant to the port that was produced by the software can be seen in Table 1.

Results from the model showed that the amount of the economic supply quantity and demand forecast are almost equal. Supply cycle time approached one period. A supply planning period
in this study was one month. This could mean that delivery to the port was carried out one times only.  

The amount of the supply quantity will be influenced by the value of $\Delta_1$ and $\Delta_2$, as a parameter determining the demand interval length. Value of supply quantity will be different if $\Delta_1$ and $\Delta_2$ are modified. The existence of the software can be utilized by decision makers to analyze several scenarios of inventory policies. Scenarios can be defined in three categories, namely optimistic, moderate and pessimistic.

Table 1. Economic Supply Quantity (ton)

<table>
<thead>
<tr>
<th>Period</th>
<th>Supply Low</th>
<th>Supply Normal</th>
<th>Supply High</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>3,271</td>
<td>3,227</td>
<td>3,396</td>
</tr>
<tr>
<td>February</td>
<td>3,359</td>
<td>3,403</td>
<td>3,582</td>
</tr>
<tr>
<td>March</td>
<td>3,075</td>
<td>2,852</td>
<td>3,002</td>
</tr>
<tr>
<td>April</td>
<td>3,182</td>
<td>3,055</td>
<td>3,215</td>
</tr>
<tr>
<td>May</td>
<td>3,129</td>
<td>2,952</td>
<td>3,108</td>
</tr>
<tr>
<td>June</td>
<td>3,110</td>
<td>2,918</td>
<td>3,072</td>
</tr>
<tr>
<td>July</td>
<td>2,834</td>
<td>2,422</td>
<td>2,550</td>
</tr>
<tr>
<td>August</td>
<td>2,816</td>
<td>2,391</td>
<td>2,517</td>
</tr>
<tr>
<td>September</td>
<td>2,811</td>
<td>2,384</td>
<td>2,509</td>
</tr>
<tr>
<td>October</td>
<td>3,036</td>
<td>2,780</td>
<td>2,926</td>
</tr>
<tr>
<td>November</td>
<td>2,765</td>
<td>2,307</td>
<td>2,428</td>
</tr>
<tr>
<td>December</td>
<td>3,122</td>
<td>2,940</td>
<td>3,094</td>
</tr>
</tbody>
</table>

Optimistic scenario is the tendency that demand will be greater than expected. The value of parameter $D_1$ will be greater than $D_2$. Pessimistic scenario is the tendency that demand will be less than normal demand. The value of parameter $D_1$ will be greater than $D_2$. The normal scenario is the condition considered by decision makers that demand more or less in the same in intervals. The value of parameter $D_1$ is equal to $D_2$. The result of analysis on those three scenarios can be seen in Figure 3.

Simulation on the influence of the demand interval in the three scenarios on the value of $q^*$ indicates a real difference. The value of $q^*$ will increase if decision makers getting optimistic regarding the demand forecast. This condition is in accordance with the equation 7, where $q^*$ is directly proportional to the magnitude of the difference $\Delta_1$ and $\Delta_2$. The greater the difference of $\Delta$, the greater the value of $q^*$.

Analysis of inventory in supply chain management of crude palm oil is an effort to integrate the economies scale and the fulfillment of sales plans. Auction system in crude palm oil sales by joint marketing office will be effective if supported by supply economic quantity information. This inventory information is also very useful in scheduling transportation from factory plant to port.

Optimal $q^*$ value that exceeds or less than sales forecast ($d$) can be interpreted as economical amounts to be auctioned by the marketing unit. EOQ concept that is applied in the inventory control of crude palm oil is reflecting the economic quantity for sales. If the forecast value becomes the sales quantity reference, then the potential for high stock in the end of the month will occur. This condition is seen clearly in the case where $q^*$ is greater than $d$. In the real condition, stock at the end of the year will be in a big amount. Integration between sales plan and the quantity of supply will enhance the effectiveness of inventory management.

Product availability in the factory bulk tank will determine the fulfillment ability of the port demand. The decision of the decision makers when selecting port demand fulfillment with the economic constraints needs to be analyzed furthermore by the supply chain optimization. More comprehensive analysis is needed so that economic scale can be achieved without sacrificing the factory utilization. This approach makes the completion of the real situation like this more easier.

Inventory control in the bulk tank is part of the quality risk management to achieve a superior value. This is based on the period of product stockpiling in port bulk tank that has to be maintained so it should not be too long to reduce the
risk of quality degradation. The quantity of the supply as the basis for sales planning needs to be trade-off with the sales forecasts to ensure the period of stockpiling in the bulk tank does not exceed the one month period. In heuristic, the trade-off can be determined by the following rules:

\[ q^{adj} = \min \{ q^s, d \} \]  

This policy is based on the efforts to maintain minimum inventory at the end of the period. This is not separated from the efforts of quality degradation risk management in the port bulk tank to keep the period of stockpiling does not exceed the one month period. If the best supply quantity \( q^{adj} \) is applied, then the cycle time \( t_c \) will be obtained as follows:

Table 2. Inventory policy \( q^{adj} \)

<table>
<thead>
<tr>
<th>( q^{adj} ) (ton)</th>
<th>( t_c ) (month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.271</td>
<td>1</td>
</tr>
<tr>
<td>3.359</td>
<td>1</td>
</tr>
<tr>
<td>3.002</td>
<td>1</td>
</tr>
<tr>
<td>3.182</td>
<td>1</td>
</tr>
<tr>
<td>3.108</td>
<td>1</td>
</tr>
<tr>
<td>3.072</td>
<td>1</td>
</tr>
<tr>
<td>2.550</td>
<td>1</td>
</tr>
<tr>
<td>2.517</td>
<td>1</td>
</tr>
<tr>
<td>2.509</td>
<td>1</td>
</tr>
<tr>
<td>2.926</td>
<td>1</td>
</tr>
<tr>
<td>2.428</td>
<td>1</td>
</tr>
<tr>
<td>3.094</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ Q^{fuzzy} = Q^{crisp} \sqrt{1 + \frac{(\Delta_2 - \Delta_1)}{4d}} \]  

(12)

Fluctuations in demand with bias value of \( \Delta \) has been anticipated in the model, so it produces smaller EOQ if not to consider the fluctuations in demand. Total inventory cost EOQ-fuzzy is smaller than the EOQ-crisp. The model that was developed in conventional EOQ model.

This study was able to control the inventory with demand in the certain value interval. Low, medium and high demand conditions can be aggregated into an economic supply value with a minimum total inventory cost. The existence of this model is very useful for decision makers in analyzing the economic inventory level at the port in various scenarios.

The inventory control of crude palm oil is related to the quality risk because the greater volume of stored products and the longer period in stockpiling will trigger the oil quality change reactions such as contamination, enzymes actions, microbial actions and other chemical reactions. Stockpiling function should be begun as a synchronization effort of delivery schedule and is not only stockpiling. Inventory optimization is a supply chain management efforts that consider the risk of quality degradation. The result of inventory optimization will be the input in the optimization of the entire supply chain system.
CONCLUSION
This study has resulted mathematic model for inventory control of crude palm oil and a decision support system to assist decision maker in analyzing inventory policy in port bulk tank. The model of fuzzy EOQ that has been developed in this study is intended to accommodate the fuzzy demand. Result of the study shows that the optimal quantity of fuzzy EOQ is influenced by the value of $\Delta$ and $\Delta_2$. From the analysis of the three scenarios, it is known that the value of $q^*$ will be increase if the decision-makers getting more optimistic regarding the upper limit of the sales forecast implementation.

Decision support system which is resulted can help the decision-makers in the operational planning and control of the supply to the port. Model is accommodating decision maker preference to anticipate demand in fuzzy environment.

The direction of further model development is to consider the risks of demand and stockpiling period in the bulk tank against the total inventory cost. Fuzzy conditions can be included in the model both on demand and product storage costs. Further model development can be carried out by developing a decision support system which is more comprehensive than the supply chain management of crude palm oil.

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