DEVELOPMENT OF PROBABILISTIC LEAD TIME MODEL BASED ON FUZZY SYSTEM TO SOLVE INTEGRATED INVENTORY PROBLEM

A THESIS

Submitted to International Program
Faculty of Industrial Technology in Partial Fulfillment of
The Requirements to obtain the Bachelor Degree at
Universitas Islam Indonesia

By:
YULIA PURNAMASARI
Student Number: 07 522 171

INTERNATIONAL PROGRAM
DEPARTMENT OF INDUSTRIAL ENGINEERING
FACULTY OF INDUSTRIAL TECHNOLOGY
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THESIS APPROVAL OF SUPERVISOR

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THESIS

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Yogyakarta, November 2011

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Fakultas / Jurusan : Teknologi Industri / Teknik Industri

Akademi / Universitas: Universitas Islam Indonesia

Benar – benar telah mencari data di " DEVA " , untuk keperluan penyusunan skripsi dengan judul :

" Development of Integrated Inventory Model
with Stochastic Demand and Lead Time "

Demikian surat keterangan ini kami buat , agar dipergunakan sebagaimana mestinya.

Yogyakarta , 26 Oktober 2011

Administrasi dan Keuangan " DEVA "

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Barikhah Yulianti

This Thesis is dedicated to:

My Super Mom: Huzaimah Zubir
Dad; Abdullah Fikri
My Sisters; Eka Marta Fitria
Rizka Apriani Putri
Yunita Anggraini
Mon Cher; Metamagfirul Djadir

MOTTO

"…. Allah will exalt in degree those who of you believe, and those who have been granted knowledge; and Allah is Well-Acquainted with what you do" – Q.S Al-Mujadila: 11

"O My Sons! Go you and enquire about Yusuf and his brother, and never give up hope of Allah's Mercy. Certainly no one despairs of Allah's Mercy, except the people who disbelieve" – Q.S Yusuf: 87

"I do the very best I know how - the very best I can; and I mean to keep on doing so until the end." – Abraham Lincoln

"To exist is to change, to change is to mature, to mature is to go on creating oneself endlessly." – Henri Bergson

"To achieve the IMPOSSIBLE is believe it is POSSIBLE" – Walt Disney

"Life is like riding a bicycle. To keep your balance, you must keep moving" – Albert Einstein

"Semua keberhasilan yang kau impikan itu, berada di balik semua hal yang kau takuti." – Mario Teguh

"Menua itu pasti, menjadi kuat adalah sebuah ketegasan" – Mario Teguh

"Life is very interesting! In the end, some of your greatest pains become your greatest strengths." – Drew Barrymore

"When you keep living in the comfort zone, you don't get the meaning of life" – Anonymous

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May Allah's mercy and blessing be upon on you

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Yogyakarta, November 2011

Yulia Purnamasari

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ABSTRACT

Supply activity is one of activities involved in manufacturing system in order to achieve customer satisfaction by supplying parts or products to all organizations level in supply chain. Coordination of managing inventory system among the organizations is one of the motivation for developing integrated inventory model. The final aim of this research are to minimize the total cost caused by holding inventory in warehouse and maintain long term relationship among the organizations. Common problems occur in integrated inventory are demand and lead time uncertainty. This research proposes the development of integrated inventory model by adding delay ratio caused by non productive time in vendor production process, whereas delay times is the part of lead time that consist of moving, waiting, and queuing time. This proposed model uses fuzzy logic to model delay ratio and identify the effect of delay changing to total cost. The result of initial fuzzy logic model gives MSE and PME value is 2.41E-5 and 22.513% respectively. Fuzzy logic model optimization is conducted using branch and bound technique by optimizing weight of fuzzy rule consequent. The MSE and PME after optimization are reduced into 8.96E-8 and 1.170% respectively. Optimal total cost of integrated inventory is obtained by applying solution procedures. The optimum result of total cost is Rp. 857,326.25, while quantity (Q) is 1147, and shipment frequency (n) is 7 at delay 0.0096. Delay prediction calculation is conducted to check fuzzy logic model validation and the result shows the MSE and PME value 2.41E-7 and 2.20% respectively. The development of integrated inventory model is useful to respond lead time uncertainty particularly uncertainty due to internal production process.

Keywords: Lead time, Non productive time, Delay, Fuzzy Logic, and Integrated Inventory model

CHAPTER I

INTRODUCTION

1.1 Background

Supply chain management is one of production system activities focused on material supply, inventory planning, and maintain long-term relationships with suppliers. Supply chain management has significant effect to production or manufacturing process in an industry. Several activities involved in supply chain management in manufacturing industry are product development, procurement, planning and control, production, and distribution (Pujawan, 2005).

Currently, the activities were done by coordinating with the parties involved in supply chain activities. The focus of these activities is to develop strong coordination and cooperation in a supply chain, and gathering the benefit from the components involved in order to increase efficiency in inventory management (Ben Daya and Hariga, 2004). Some coordination's that have been conducted are the information technology utilization, replenishment, material management, and distribution configuration. Perona and Saccani (2002) mentioned that internal efficiency of industry could be increased by conducting integration with supplier in operational area. Coordination and integration in operational area includes a coordination of lean replenishment, material management, operation planning and control, distribution configuration, and distribution management.

Integrated inventory management has a good dealing to increase the efficiency among the parties involved in supply chain (Ouyang, et al., 2003). Ben Daya and Hariga (2004) proposed an integrated model focused on supplier and buyer. The model assumed that lead time and lot size has linear relationship, and the demand is deterministic. It is assumed that the lead time relationship is proportional to the lot size and added by constant delay, which is caused by transportation or nonproductive time. The total cost of integrated inventory shows that there is reduction in cost due to integration.

In a dynamic environment, particularly supply chain, common problem that usually occurs are uncertainty in delivery lead time. One of the strategies to reduce inventory cost and customer service time is contracting the supplier with shortest lead time (Hennet and Arda, 2006). However, the lead time that affected by constant delay contradicts to the dynamic environment.

This research proposed an integrated inventory model for probabilistic lead time. The integrated inventory model used is Ben Daya and Hariga (2004)'s model, since it is considered delay in lead time. The objective is to determine the total cost of integrated production inventory if delay is uncertain. Delay will be affected by non productive time in production process. The functions to be used are waiting time, moving time, and queuing time. Delay prediction calculation will be carried based on fuzzy inference technique. The result of delay prediction that has high error percentage will be optimized using branch and bound method to minimize the error and obtain more accurate fuzzy logic model. The parameter to be optimized is rule weight on fuzzy logic model.

1.2 Problem Formulation

Based on the explanation on background, the problem formulations are:

1. How to develop fuzzy logic model for probabilistic delay of lead time?
2. How is the effect of probabilistic delay toward total cost of integrated inventory model?
3. How to optimize fuzzy logic and total cost of integrated inventory model using Branch and Bound technique?

1.3 Research Limitation

In order to achieve the objectives of the research, the research needs to be limited in certain aspect. The focuses of the research are defined by the boundaries as follow:

1. The object of research is UMKM Phia Deva as vendor and Koperasi Purosani as buyer
2. This research is limited to single vendor and single buyer
3. This research involves long term relationship between supplier and buyer
4. Cost data has been determined and are not changed during observation period

1.4 Research Objectives

The purposes of research are:

1. Developing fuzzy logic model for probabilistic delay of lead time
2. Identifying the effect of probabilistic delay toward total cost of integrated inventory model

3. Optimizing fuzzy logic model and total cost of integrated inventory using Branch Bound technique

1.5 Research Benefits

The benefits of this research are:

1. Enrich knowledge about supply chain management, especially in integrated inventory management, the conditions occurred and its impact to the industrial activity
2. Enrich knowledge about artificial intelligence, especially its implementation in inventory management and its effect to the industry
3. Maintain the long-term relationship among parties involved in the network, and increase the efficiency and effectiveness in supply activity

1.6 Research Outlines

The rest of research systematic outlines are written as follow:

CHAPTER II LITERATURE REVIEW

This chapter gives brief information about previous research done by other researchers. This chapter also describes theoretical background and related concepts supporting the research.

CHAPTER III RESEARCH METHODOLOGY

This chapter provides information about the research object, model development, and the workflow of the research itself.

CHAPTER IV **DATA PROCESSING AND RESEARCH RESULT**

This chapter contains the data collected that will be used to solve the problem. This chapter also describes how the problem solving will be done.

CHAPTER V **DISCUSSION**

This chapter discusses about the result of data processing done in previous chapter. Analysis toward the result will be done to measure how far the research has solved the problem that has been formulated in problem formulation.

CHAPTER VI **CONCLUSION AND RECOMMENDATION**

This chapter provides the final result of the research, answering the problem formulation. Several possibilities of next improvement will also be recommended as the base of next research.

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CHAPTER II

LITERATURE REVIEW

2.1 Previous Research

Several research concerning integrated production inventory gathered more attention in recent years. It is motivated by growing focus on supply chain management. Coordination and cooperation among organizations in supply chain could create benefits and maintain efficiency of inventory management (Ben Daya and Hariga, 2004). The objectives of managing inventory are minimizing cost, providing high service level and keeping continuous production (Hennet and Arda, 2006). Several ways to achieve the objectives are keeping the low level inventory stock or keeping the high level stock. The motives of holding an inventory are economic scale and uncertainty. The economic scale is related to the industry objective to reduce the costs by doing continues production or ordering a large lot of material. The uncertainty motives are related to the system, such as demand uncertainty, or demand supply. Coordination among the parties involved is needed to achieve the objectives.

Saccani and Perona (2004) conducted a research concerning on the integration techniques. The research was focused on the tactical and operational practices to support the relationship among suppliers and buyers. It is shown that the integration in operational and tactical practices could increase the efficiency by analyzing the employee's sales and effectiveness by analyzing the growth rate in an industry. The integrative coordination of supplier and buyer could identify whether the supplier and buyer are prefer to participate in e-market instead of traditional market. The role of supply chain contract in e-market offered indicates that the coordination of supplier and buyer could increase benefit (Wang and Benaroch, 2004). Furthermore, the studies are conducted concerning in integration inventory models as one of the strategy to achieve the effectiveness and efficiency in the supply chain parties.

Lead time becomes an important issue in integrated inventory management and it might create benefit to supplier and buyer. Tersine (1982) mentioned that lead time reduction consists of several components, namely: order preparation, order transit, supplier lead time, and delivery lead time. An industry can reduce investment in inventory, loss caused by stock out, improve customer service level, and increase the competitiveness, as the consequences of shortening lead time (Ouyang and Wu, 1997). Liao and Shyu (1991) presented a continuous review model to reduce lead time. This model assumed that order quantity is predetermined and lead time is the decision variable. Ben Daya and Raouf (1994) presented a model by extending the Liao and Shyu (1991) continuous review model. The model allowed lead time and order quantity to be a decision variable. Later, Ben Daya and Raouf (1994) model was extended by Ouyang et.al. (1996). The model proposed by Ouyang et. al generalized' Ben Daya and Raouf's model, which is allowing shortages with mixture of backorders and lost sales. Pan and Yang (2004) mentioned that lead time is an important element in inventory management system. However, several literatures gave assumption that lead time is constant (Kim and Park, 1985; Ravichandram, 1995) or stochastic variable (Foote et.al., 1988). Moreover, lead time assumed as a parameter in stochastic continuous review model. Kim and Benton (1995) presented an integrated inventory model by establishing a linear relationship between lead time and lot size, and incorporating the relationship into classical stochastic continuous review model. Hariga (1999) presented a model by extending Kim and Benton's (1995) model. The model rectified the annual back order cost and proposed another relation for revised lot size. Ben Daya and Hariga (2004) proposed a model by giving the assumption that demand is deterministic and the lead time has linear relationship to the lot size. The considered the non productive time in the lead time expression. Ouyang et al., (2004) conducted research in integrated inventory management assuming the long term relationship between buyer and supplier has been built. The model assumed that the lead time demand is normally distributed, and the probability has known and finite. Hoque and Goyal (2006) proposed a model by assuming the lead time is controllable, the batches size is changing, stock are restricted to desired limit. Pan and Hsiao (2005) proposed an integrated inventory model by assuming the lead time is controllable, and considering the backorder discount. Ben Daya and Hariga (2004) proposed a model by giving the assumption that demand is deterministic and the lead time has linear relationship to the lot size. This research also considered the non productive time in the lead time.

The uncertainty in supply chain is a common problem in industry. The uncertainty in demand is the most significant in most of systems. In addition to it, the uncertainty in delivery lead time also becomes the common problem in supply process. Most buyers will rather to sign the contract to the supplier which provide the shortest delivery lead time.

Given the uncertainty situation either in demand or lead time in supplies activity, this research will present an integrated inventory model to determine the expected total cost by considering deterministic demand and probabilistic lead time.

The integrated inventory model used in this research is model presented by Ben Daya and Hariga (2004). The model considered the constant value of non productive time in the lead time expression later called as delay. This research will change the constant delay value into probabilistic based on fuzzy inference technique.

2.2 Theoretical Background

2.2.1 Supply Chain Management

Supply chain is the entire stages of integration process to fulfill customer request, which includes the manufacturers, suppliers, transportations, warehouses, retailers, customers as the organization, and product development, marketing, operations, distribution, finance, and customer service as a function. Supply Chain Management is a strategic method to manage the integration process that included products flow, information, and cost incurred by the organizations involved. The objective is to represent organizations network involved supply chain, through linkages in material, information and financial flows, in the different activities and processes to produce value in form of products or services (Christopher, 1998).

Pujawan (2005) described the supply chain management activities scope if it refers to manufacturing system industry. The main supply chain management activities involved are:

1. Product Development

   The activities are; conducting market research, designing product development, coordinating with suppliers in designing product

2. Procurement

The activities are; selecting supplier, evaluating supplier performance, purchasing materials and components, monitoring supply risk, and maintaining supplier relation

3. Planning and Control

   The activities are; conducting demand planning, forecasting demand, capacity planning, production and inventory planning

4. Operation or Production

   The activities are; executing the production process and controlling quality

5. Shipping or Distribution

   The activities are; planning distribution, scheduling distribution, searching and maintaining relation with service industry, monitoring service level in each distribution center.

2.2.2 Inventory Management

Inventory is total materials found in integrated manufacturing and distribution that are used to achieve customer satisfaction. Inventory in supply chain is the result of inflow and outflow processes, which is included transport and production. Raw material, Work in Process, and finished product inventory are spread throughout the supply chains that hold by supplier, manufacturer, distributor, and retailer (Chopra and Meindl, 2001). Holding inventory will cause additional cost and has high effect to responsiveness. However, it can provide benefits if it is managed properly (Gopal and Cypress, 1993). According to motives of holding inventory, inventory decomposes into several components:

Table 2.1 Stock components, determinants, and benefits

Stock Component	Determinants	Benefit
Production lot-sizing stock	setup frequency	setup cost and time reduction
Transportation lot-sizing stock	shipment quantity	transportation cost reduction
Inventory in transit	transportation time	transportation cost reduction
Seasonal stock	demand peaks, tight capacity	investment and overtime cost reduction
Work-in-Process	lead time, production planning and control	increase utilization, reduced investments in additional capacity
Safety stock	demand and lead time uncertainty, process uncertainty	increased service level, reduced cost for emergency shipments and lost sales

Source: Christopher Gopal and Harold Cypress. 1993. *Integrated Distribution Management: computing on Customer Service, Time and Cost*. Richard D. Irwin Inc. Illinois

Cycle inventory or Production lot-sizing is held in order to take the economical benefit and reduce cost in supply chain. Its existence is because the purchasing in large size of batch allows the economical scale to be exploiting and causing the lower cost. Cycle inventory defined as the average inventory increased because the supply chain stage. The costs considered in cycle inventory on supply chain are; material cost, fixed ordering cost, and holding cost

2.2.3 Lead Time

Lead time is a span of time required to perform an activity. Lead time can be interpreted depends on its activity which is individual or collective items or operations. Production cycle time is the total time purchasing materials and components, processing, testing, and packaging the product. The total manufacturing time of individual lead time to perform operations from the earliest operation to the last operation (finishing) is manufacturing cycle time. Tersine (1994) mentioned that manufacturing lead time consists of five elements:

1. Setup time; is time required to prepare material, machine, or work center to conduct an operation
2. Process time; is time required to perform an operation
3. Wait time; is time required by material to move to next work station
4. Move time; is time required to move the material from storage, to storage, or between work station
5. Queue time; is time required by material caused by order is being processed at work center

Setup time, wait time, and queue time are inactive period within manufacturing cycle time due to delay. Tersine (1994) mentioned several typical reasons of delay are:

1. Waiting time for work center availability
2. Waiting time for move to next work center
3. Waiting time for inspection
4. Receiving of priority job
5. Tools, Material, or Information shortages
6. Machine breakdown
7. Absenteeism

2.2.4 Ordering/Setup Cost

Ordering/ Setup cost is total cost of issuing purchase order, or internal production. The assumption is varying based on the order quantity or setup placed, and not all with the size of order (Tersine, 1994).

Ordering cost is cost incurred based on all activities required in issuing production order. The cost included in preparation cost are writing order, preparing specifications, order recording, order follow up, invoice, and payment (Fogarty et.al., 1991). Order cost includes the incremental costs which associated with the receiving or placing activity (Chopra and Meindl, 2001). It is incurred each time an inventory replenishment order is placed (Vollman et al., 2005).

Setup cost is total cost associated with setup activity occurred in production process. Setup cost is incurred based on manufacturing process activity as an opposed to purchase item. Setup cost includes the preparation costs for production, which are the activities include obtaining tools, mounting fixtures, receiving instructions, adjusting machine setting, checking items (Fogarty et al.,1991). The components of setup cost are machine cost and labor cost.

2.2.5 Holding Cost

Holding Cost is the cost incurred because of storing one unit material or goods at inventory in specified period. It is generally estimated by summarize its major components. Chopra and Meindl (2001) described the components of holding cost:

1. Capital Cost is the cost determined by evaluating the weighted average capital cost
2. Obsolescence Cost is the cost determined by estimating value rate at the value of product is crashed either because of its market value or quality deterioration.
3. Handling Cost is the cost which including the receiving and storage cost
4. Occupancy Cost is the cost reflected by the change in space cost because of the cycle inventory changing.

5. Miscellaneous Cost is the cost incurred by the small number of cost, which is includes incurrence, tax, security, damage, or other cost that possibly incurred.

2.2.6 Mathematical Model

Model is designed as a representation of real system. Model could be represented by developing mathematical model or computer program, which is operated by entering the numerical values or parameters. Model is designed to support decision making about the current system (Buzacott and Shanthikumar, 1993). Several motives are encouraging the model development, which are:

1. *Understanding*, model development is used by user to answer the questions "why" and "how".
2. *Learning*, model development is designed based on the real system, so that model provides the parameters that affect the systems performance. However, it could be ignored several attributes of the system itself.
3. *Improvement*, in developing model, it is permitted to change the parameters, rules, or factor in order to achieve the performance target, because model development is used to improve the system.
4. *Optimization model*, some models are developed to optimize the current models by combining the model parameters.
5. *Decision making*, a model has to support the decision, either in operation or design of the system.

The reasons of model development will determine which is the model is suitable to represent the system and its problem. In discrete manufacturing, three types of model that generally used are:

1. Physical model; is represent by developing another system which is dimensionally smaller than the real system.
2. Simulation model; is represent by computer program in common which provides several events that probably occur in a real system in a sequences. Simulation model explains the logical relationships for the events in detail.
3. Analytical model; is represent by developing mathematical formula or symbols. Then, the formulas are used to define an algorithm, or computational procedure which is possibly to calculate the performance measure.

2.2.7 Fuzzy Logic

Fuzzy logic is a branch of artificial intelligence that represents expert knowledge that used vague and ambiguous terms. It is a set of mathematical principles to represent a knowledge based on degrees of membership, which describes vagueness. Unlike Boolean logic, Fuzzy logic adds range of logical values between 0 (completely false) and 1 (completely true) to Boolean logic. It accepts several things that could be included in true and false in the same time.

1. Fuzzy Set

Crisp set theory is mathematical logic that only uses one of two values (0 and 1). However, this theory is unable to represent vague concepts. Fuzzy set basic idea is an element that belongs to a fuzzy set in a certain degree of membership, which is could be part of true or false.

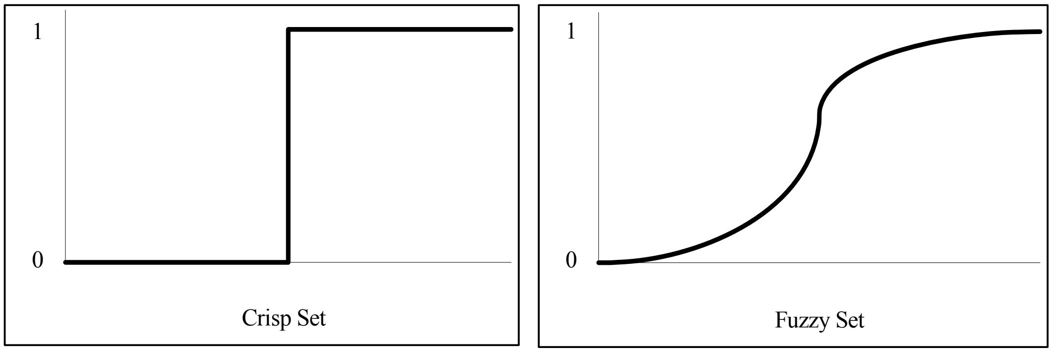

Figure 2.1 Crisp Set and Fuzzy Set

Source: Michael Negnevitsky, "Artificial Intelligence". 2002. England: Pearson Education Limited

Fuzzy set is a set of fuzzy boundaries that capable to provide transitions across a boundary.

2. Linguistic Variables and Hedges

Linguistic variable is fuzzy variable. Linguistic variable is a branch of fuzzy set theories. These variables are used as fuzzy rules. The range values of linguistic variable represent the universe of discourse of variable. A variable may contain several subsets that represent a linguistic value correspondence to variable. As an example; variable speed has range between 0 and 220 km per hour. The variable contains fuzzy subsets such as slow, medium, and fast.

Hedges are linguistic variables that could change the shape of fuzzy sets. It includes adverb such as very, somewhat, quite, more or less, and slightly. Hedges are used as:

a. All-purposes modifiers, such as very, quite, or extremely
b. Truth-values, such as quite true or mostly false
c. Probabilities, such as likely or not very likely
d. Quantifiers, such as most, several, or view

e. Possibilities; such as almost impossible or quite possible

3. Fuzzy Rules

Fuzzy rule is a conditional statement that contains linguistic variables and linguistic values, where linguistic variables are determined by fuzzy sets on the universe of discourses respectively. The conditional statement could be written as:

IF x is A

THEN y is B,

Where x and y are linguistic variables; A and B are linguistic values. Here, linguistic variable x and y have the range, but the range includes fuzzy set, such as small, medium, and large.

4. Sugeno Fuzzy Inference

Fuzzy Inference is a mapping process from giving input to an output using theory of fuzzy sets. Sugeno-style fuzzy inference uses singleton, a fuzzy set with a membership function that is unity as a single particular point on the universe of discourse and zero everywhere else.

Sugeno-style fuzzy inference changes rule consequent. It uses mathematical function of the input variable instead of fuzzy set. Sugeno-style fuzzy rule can be written as follow:

IF x is A

AND y is B

THEN z is $f(x,y)$

Where *x*, *y*, and *z* are linguistic variables; *A* and *B* are fuzzy sets on universe of discourses *X* and *Y*; and *f(x,y)* is a mathematical function. There are two types of Sugeno inference system:

a. Zero order Sugeno Fuzzy Model

The fuzzy rules are commonly written as follow:

IF *x* is *A*

AND *y* is *B*

THEN *z* is *k;* where *k* is constant.

The output of fuzzy rules is determined to be constant.

b. Single order Sugeno Fuzzy Model

The fuzzy rules are commonly written as follow:

IF *x* is *A*

AND *y* is *B*

THEN *z* is *f(x,y),* where *f(x,y)* is a mathematical function

The mapping processes in Sugeno-style fuzzy are:

a. *Fuzzification*. The first step is taking crisp inputs x_1 and y_1, and determining the degree for each variable. The crisp input is a numerical value limited to the universe of discourse. The inputs could be measured directly or expert estimation.

b. *Rule Evaluation.* By taking the fuzzified inputs and apply them to the antecedents of the fuzzy rules. The fuzzy operator (AND or OR) is generally used to obtain single number if fuzzy rule has multiple antecedents.

c. *Aggregation of the rule outputs* is the process unification of the rules outputs. The input of aggregation is membership functions of rule consequents and combine then into single fuzzy set

d. *Defuzzification* is a process to transform the output of fuzzy system into crisp number. The input of defuzzification process is aggregate output of fuzzy set. Common defuzzification method used is Centroid Technique. The formula is:

$$COG = \sum_{x=a}^{b} \mu A(x)x \Bigg/ \sum_{x=a}^{b} \mu A(x) \qquad (2.1)$$

2.2.8 Branch and Bound Technique

Integer programming is a linear programming that has additional restriction which is variables must have integer value. It is based on the practical problems that several decision variables require integer value. Integer programming which relax assumptions that only some variables requiring integer value called as mixed integer programming.

Branch and bound technique is one of enumeration procedure to find optimal solution for integer programming. The basic concept of this technique is dividing the problem into sub problems which are divided into smaller subsets. Each subset contains feasible solution for integer programming. The subset that has optimal solution is bounded, while the subset that does not has optimal solution will be discarded (Hiller and Lieberman, 2005)

Hiller and Lieberman (2005) mentioned Branch and Bound has three basic steps, there are:

1. *Branching*; is process to partitioning the set of feasible solution into subset by fixing the value into each subset based on the sub problem.
2. *Bounding*; is applying simplex method to linear programming to obtain optimal solution for each sub problem.
3. *Fathoming*; is the process to store feasible solution as the incumbent, then perform fathoming test.

CHAPTER III

RESEARCH METHODOLOGY

This chapter explains the research methodology which is consists of research object, mathematical model, data requirement, data collecting method, and research flowchart. The detail steps are arranged in sub-chapter below:

3.1 Research Object

The research is conducted at UMKM Phia Deva and Koperasi Purosani and focused on developing integrated inventory model with probabilistic delay and identified its effect to total cost.

3.2 Mathematical Model

Mathematical Model consists of the explanation of mathematical notation, fuzzy logic, and integrated inventory model to be used in this research. The detail of each part is described as follow:

3.2.1 Mathematical Notation

The mathematical notations to be used in this research are mathematical fuzzy logic and integrated inventory model.

1. Integrated Inventory Model

D = *Demand rate in units per unit time*

1/p = *Production rate in units per unit time*

N = *Number of shipments from the vendor to buyer*

Q = *Size of equal shipments from vendor to the buyer*

s = *Reorder point*

K = *Setup cost incurred by the vendor*

A = *Ordering cost incurred by the buyer for each order of size nQ*

F = *Transportation cost incurred by the buyer on each shipment*

h_v = *Holding cost per unit per unit time for the vendor*

h_b = *Holding cost per unit per unit time for the buyer*

S = *Safety stock*

L(Q) = *Lead time*

b = *Delay due to unproductive time*

π = *Backorder cost for the buyer*

σ = *Standard deviation of demand*

2 Mathematical Fuzzy Logic

M = *Moving time*

W = *Waiting time*

Q = *Queuing time*

b = *Delay*

R = *Fuzzy Rule*

a = *Weight of M*

b = *Weight of W*

c = *Weight of S*

d = *constant*

R(r) = *Fuzzy rule in number r*

Several assumptions in this research are:

1. The product is manufactured with finite rate $1/p$ ($1/p > D$)
2. Demand during lead time is normally distributed with mean $DL(Q)$ and standard deviation $\sigma\sqrt{pQ+b}$
3. There is no crossing of reorder point at the time of receiving shipment
4. The average inventory level is approximated using common expression $\left(\frac{Q}{2} + \text{ } safety\ stock\right)$
5. Lead time is changed according to production quantity of vendor in addition with delay due to non productive time of production process
6. Transportation cost and ordering cost incurred by buyer

3.2.2 Integrated Inventory Model

The integrated inventory model to be used in this research is the current model proposed by Ben Daya and Hariga (2004). The integrated inventory model to minimize the expected total cost per unit time is given as follow:

$$ETC\ (Q,s,n) = \frac{D}{Q}\left(F + \frac{A+K}{n} + \pi\, b\,(s, L(Q))\right)$$

$$+\frac{Q}{2}\left[h_b + h_v\left[n(1-Dp) - 1 + 2Dp\right]\right] + h_b S \qquad (3.1)$$

The problem is to define the number of shipment (n), the shipment size (Q), and reorder point (s), which are those values could minimize the expected total cost.

By giving the assumption that demand during lead time is normally distributed, with the value of mean is $DL(Q)$, and standard deviation is $\sigma\sqrt{L(Q)}$, Thus;

$S = k\,\sigma\sqrt{p\,Q + b},$

$$b\big(s, L(Q)\big) = \int_{s}^{x} (x - s)\, f\big(x, DL(Q)\big), \sigma\sqrt{L\,(Q)}\; dx$$

$$= \sigma\,\sqrt{p\,Q + b}\;\psi\,(k) \tag{3.2}$$

Where,

$$k = \left(\frac{s - DL(Q)}{\sigma\sqrt{L(Q)}}\right) \tag{3.3}$$

And

$$\psi\,(k) = \int_{k}^{\infty} (z - k)\,\phi\,(z)dx \tag{3.4}$$

Where $\phi(fz)$ is the standard probability density function.

If the equation (3.1) simplified:

$$G\,(n) = F + \frac{A+K}{n}$$

$$H\,(n) = h_b + h_v\left[n\left(1 - Dp\right) - 1 + 2Dp\right]$$

Then, the initial equation of expected total cost will be rewritten as follow:

$$\text{ETC}\,(Q,k,n) = \frac{G(n)D}{Q} + \frac{Q}{2}\;H(n) + h_b\,k\sigma\,\sqrt{pQ+b} + \frac{\pi D\sigma\sqrt{pQ+b}}{Q}\;\psi\,(k) \tag{3.5}$$

In order to define the constant n value, take the derivatives with the respect to Q and s, and set to zero. The equation will be written as follow:

$$\frac{\partial\,ETC}{\partial\,Q} = -\frac{G(n)D}{Q^2} + \frac{H(n)}{2} + \frac{h_b\,k\sigma p}{2\sqrt{pQ+b}} + \pi D\sigma\psi(k)\,\frac{\dfrac{pQ}{2\sqrt{pQ+b}} - \sqrt{pQ+b}}{Q^2} = 0 \tag{3.6}$$

$$\frac{\partial\,ETC}{\partial k} = \sigma h_b\sqrt{pQ+b} - \frac{\pi D}{Q}\;\sigma\bar{F}(k)\sqrt{pQ+b} = 0 \tag{3.7}$$

Where $\bar{F}(k)$ is the complement of cumulative distribution function. If the equation (6) and (7) are simplified, the equation will be rewritten as follow:

$$\frac{2D}{Q^2}\left[G(n)+\pi\sigma\psi(k)\sqrt{pQ+b}\right] = H(n) + \frac{h_b\sigma p}{\sqrt{pQ+b}}\left[k+\frac{\psi(k)}{\overline{F}(k)}\right] \tag{3.8}$$

$$\overline{F}(k)= \frac{h_b\, Q}{\pi\, D} \tag{3.9}$$

Based on the equations above, it is shown that the expected total cost shown in the equation (1) is convex in *k*, if taking from the derivatives from equation (7). However, the expected total cost equation is not convex in *Q*. Then the derivative equation (6) could be rewritten as follow:

$$Q = \sqrt{2D\,\frac{G(n)+\pi\sigma\psi(k)\sqrt{pQ+b}}{H(n)+\frac{h_b\,\sigma\, p}{\sqrt{pQ+b}}\left[k+\frac{\psi(k)}{\overline{F}(k)}\right]}} \tag{3.10}$$

Where the k value defined from the equation:

$$\overline{F}(k)= \frac{h_b\, Q}{\pi\, D} \tag{3.11}$$

In order to define the solution for the equations written above, it is needed to have the iterative procedure to approximate each value mentioned. Ben Daya and Hariga (2004) wrote the iterative procedure as the algorithm to solve the problem mentioned. The algorithm is written as follow:

Step 0: Set the value of $ETC^* = \infty$, and number of shipment $n = 1$

Step 1: Calculate the value of *Q* using: $Q = \left[\sqrt{2\text{ D (G)n / H(n)}}\right]$, Where [*x*] value is the nearest integer to *x*

Step 2: Define the *k* value from the equation (3.11), and then define *ψ(k)* using equation (3.4)

Step 3: Define the *Q’* value by using equation (3.10), and then set the result into *Q’* = [Q’]

Step 4: Calculate *Q’*- *Q*, then set the value into |*Q’*-*Q*|. if the result is equal to zero |*Q’* - *Q*| = *0*, then the iteration continue to *Step 5.* If the result is greater than zero |*Q’*

$- Q| > 0$, and then set Q' to Q, and repeat the *Step 2*

Step 5: Define the Expected Total Cost value from equation (3.5). Then, compare the ETC value resulted with *ETC** defined in *Step 0.* If *ETC** value is greater than ETC computed, ETC* ≥ ETC (*Q,n*), set ETC (*Q,n*) into *ETC**, where *Q* change into *Q**, *s* change into *s**. Then, set $n + 1$ be *n*, and repeat the algorithm from *Step 1.* Otherwise, if the value $ETC^* \leq ETC$ (*Q,n*), set $n - 1$ to n^*. And the algorithm is finished.

In developing this model, Ben Daya and Hariga (2004) assumed lead time is proportional to the number of quantity adding by constant delay. The assumption of constant delay in lead time is contrary to the actual dynamic condition, where lead time is uncertainty. Therefore, this research is developing the integrated inventory model by changing constant delay into probabilistic delay using fuzzy logic

3.2.3 Fuzzy Logic Model for Probabilistic Delay of Lead Time

The fuzzy logic model development will be described as follow:

1. Determination of Input and Output Variables

The input variables to be analyzed are moving time *(M)*, waiting time *(W)*, and queuing time *(Q)*. The output variable is delay time, which will substitute to lead time formula of integrated inventory model.

2. Fuzzy Set and Membership Function

Fuzzy set of moving time *(M)*, waiting time *(W)*, and queuing time *(Q)* will be shown in figure below:

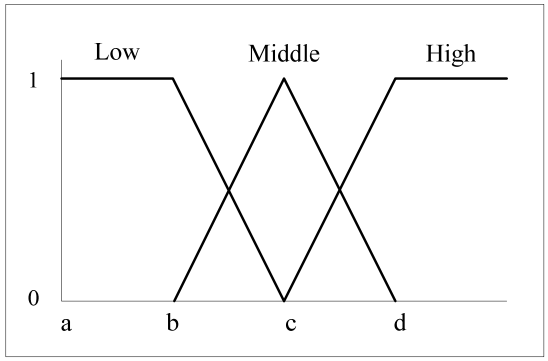

Figure 3.1 Fuzzy Set Representation of Moving Time *(M)*

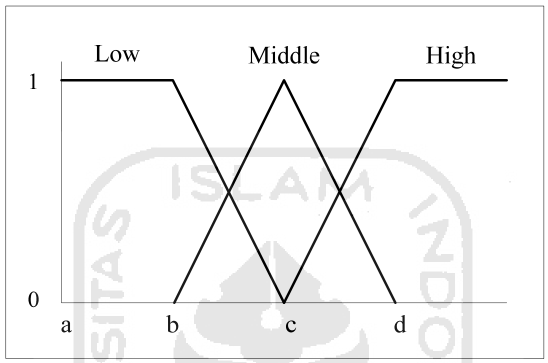

Figure 3.2 Fuzzy Set Representation of Waiting Time *(W)*

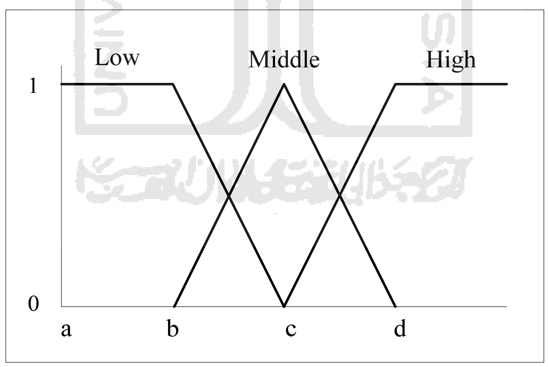

Figure 3.3 Fuzzy Set Representation of Queuing Time *(Q)*

Membership function will be described as follow:

$$\mu A\ Low\ (x) = \begin{cases} 0; & x \geq c \\ 1; & x \leq b \\ \dfrac{c-x}{c-b}; & b \leq x \leq c \end{cases} \tag{3.12}$$

$$\mu A\ Middle\ (x) = \begin{cases} 0; & x \leq b \\ \dfrac{x-b}{c-b}; & b \leq x \leq c \\ \dfrac{d-x}{d-c}; & c \leq x \leq d \\ 0; & x \geq d \end{cases} \tag{3.13}$$

$$\mu A\ High\ (x) = \begin{cases} 0; & x \geq c \\ \dfrac{x-c}{d-c}; & c \leq\ x \leq b \\ 1; & x\ \geq\ d \end{cases} \tag{3.14}$$

3. Fuzzy Rule

The general form of fuzzy rules of delay time is written as follow:

R_i = If M is $\widetilde{M}$ AND W is $\widetilde{W}$ AND Q is $\tilde{Q}$ THEN $b = a_iM + b_iW + c_iQ + d_i$;

$\forall$i, I = 1, 2, …,27 (3.15)

Where:

$\widetilde{M}$ = *Fuzzy universe of discourse of M*

$\widetilde{W}$ = *Fuzzy universe of discourse of W*

$\tilde{Q}$ = *Fuzzy universe of discourse of Q*

b = *Delay*

a = *Weight of M*

b = *Weight of W*

c = *Weight of S*

d = *constant*

i = *rule index*

4. Defuzzyfication

Defuzzification process is using weighted average technique. The crisp value of delay time will be modeled as follow:

$$b = \frac{\sum_{i=1}^{r} \mu A(x)\, x(b) Rr}{\sum_{i=1}^{r} \mu A(x)} \tag{3.16}$$

5. Fuzzy Logic Optimization using Branch and Bound Technique

Branch and Bound is used to obtain optimal solution of fuzzy logic rule weight. The algorithm steps to obtain optimal solution are given as follow:

1. Branching; Select new sub problem, and choose the first variable in the ordering to be branching variable among integer restricted which have non integer for linear programming relaxation.
2. Bounding; Apply simplex method or dual simplex method for reoptimizing to linear programming relaxation and use objective function for resulting optimal solution to obtain its bound
3. Fathoming; Apply fathoming test to each sub problems and discard the sub problems that have no feasible solution
4. Optimality test; the iteration is stopped when there are no sub problems remaining, and the incumbent has feasible solution.

3.3 Data Collection

3.3.1 Data Requirement

The data required to support the problem solving are

1. Inventory Management

   The data involved are the actual demand of buyer, and total inventory of the vendor.

2. Production Data

   The data required are total production and production time data of vendor includes unproductive time such as setup, waiting, moving, and queuing time.

3. Cost Data

   The data required are ordering cost, holding cost, and transportation cost.

3.3.2 Data Collection Method

The methods for collecting data are:

1. Primary Data

   Primary data are obtained by conducting direct observation and interview toward owner or worker to record any information about supply process.

2. Secondary Data

   Secondary data are obtained from gathering historical data about total production, costs and inventory in the company.

3.4 Analysis Tool

The data processing and analysis for developing integrated inventory model is using spreadsheet Ms. Excel. The optimization of fuzzy logic model tool is using solver in spreadsheet Ms. Excel.

3.5 Research Flowchart

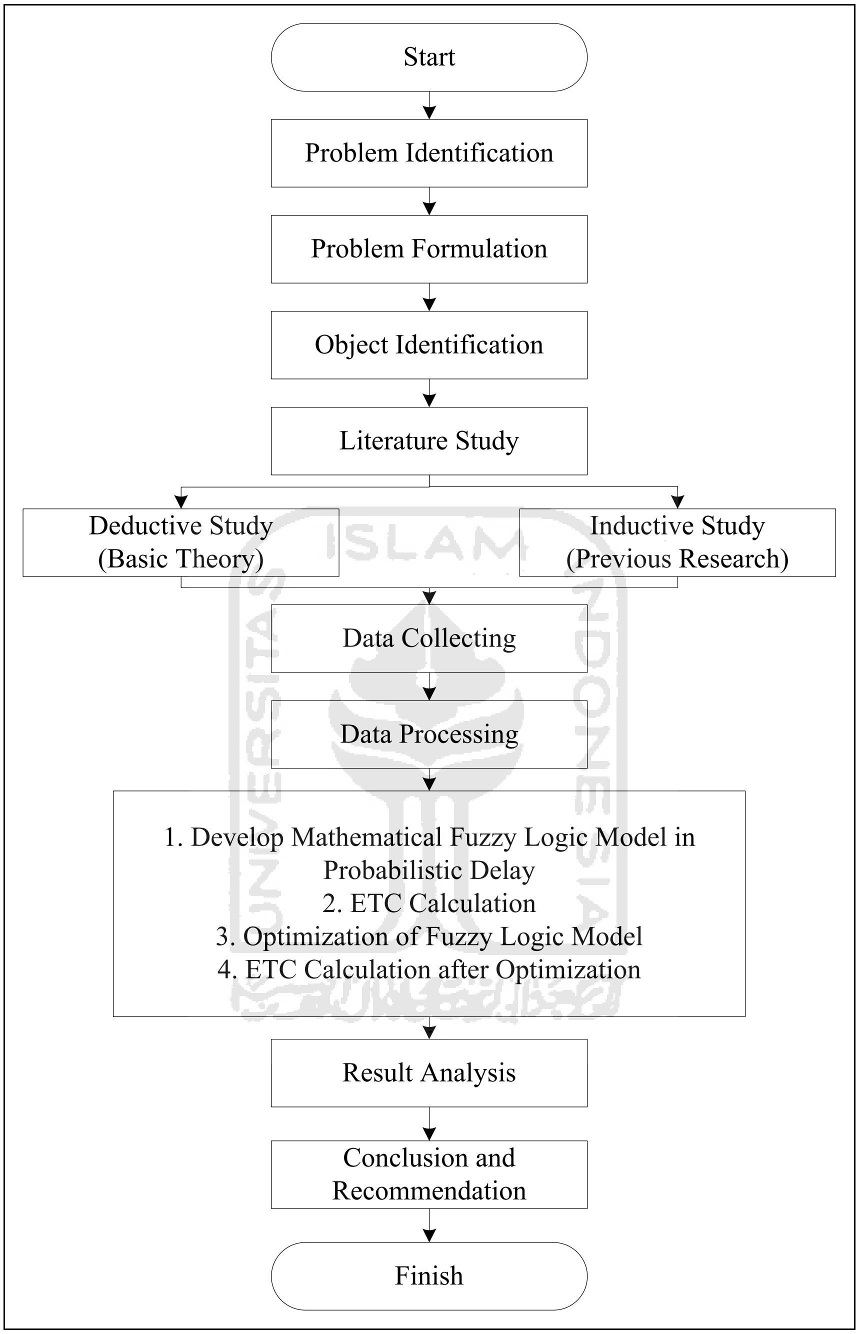

Figure 3.4 Research Flowchart

Explanation of research flowchart are given as follows:

1. Problem Identification

Problem identification is identifying the problem that faced by Phia Deva which is focused on production planning and inventory. The process is done by field observation .

2. Problem Formulation

   Determining the critical problem that are faced by the company and analysing the causes of problem.

3. Literature Review

   Reviewing related studies that are might supported this research. The study are focused on supply chain management, and production planning and inventory management.

4. Data Collecting

   Data collecting is conducted by doing some observations, interviews, and documentations on the company.

5. Data Processing

   Data processing is conducted by developing an integrated inventory model by changing the constant delay into probabilistic delay based on non productive time on production process using fuzzy logic. An optimization of fuzzy logic model is required if fuzzy logic model has high error percentage. Then, determining the expected total cost and analyzing the effect of delay toward total cost.

6. Result Analysis

   Analyzing the mathematical result whether it is valid or not. The analysis is conducted by analyzing the effect of delay of non productive time on production process to total cost.

7. Conclusion and Recommendation

The last stage is conducted by giving research conclusions, further research is needed to develop this study, and giving the recommendations needed to improve the company performance especially on inventory planning.

CHAPTER IV

DATA COLLECTING AND PROCESSING

4.1 Data Collecting

This research used secondary data obtained from Phia Deva as vendor and Koperasi Purosani as buyer. Detail of each data is explained in sub chapter below.

A. Koperasi Purosani Data

The data of Actual demand of Buyer, Element Cost, and Holding Cost of Buyer are shown in Table 4.1, Table 4.2, and Table 4.3 respectively.

Table 4.1 Actual Demand of Buyer

No	Month	Amount of Demand
1	January	1470
2	February	1225
3	March	1420
4	April	1116
5	May	1347
6	June	1185
7	July	1490
8	August	1235
9	September	1440
10	October	1190
11	November	1324
12	December	1229
Total		15671

Table 4.2 Element Cost Data

No.	Cost Element	Quantity	Cost

No.	Cost Element	Quantity	Cost
1	Ordering Cost	1 order	Rp10,000.00
2	Transportation Cost	1 shipment	Rp5,500.00
3	Backorder cost for buyer (π)	1 box	Rp1,250.00

Table 4.3 Holding Cost of Buyer

No.	Detail Setup Cost	Duration	Cost
1	Electricity	1 month	Rp300,000.00
2	Warehouse Staff	1 month	Rp500,000.00
Total			Rp800,000.00

B. Phia Deva Data

The data of Finished Product Inventory of Vendor, Actual Production of Vendor, Non Productive Time, Setup Time, and Holding Cost of Vendor are shown in Table 4.4 to Table 4.8 respectively.

Table 4.4 Actual Inventory of Vendor

No	Month	Amount of Inventory	Amount of End Inventory
1	January	464	643
2	February	307	1128
3	March	442	594
4	April	446	797
5	May	499	862
6	June	470	932
7	July	429	499
8	August	476	965
9	September	259	452
10	October	399	1147
11	November	466	774
12	December	393	988
Total		5050	9781

Table 4.5 Actual Production of Vendor

No	Month	Amount of Production
1	January	1649
2	February	2046

No	Month	Amount of Production
3	March	1572
4	April	1467
5	May	1710
6	June	1647
7	July	1560
8	August	1724
9	September	1633
10	October	1938
11	November	1632
12	December	1824
Total		20402

Table 4.6 Ratio of Non Productive Time in Vendor Production Process

No	Moving Time	Waiting Time	Queuing Time
1	0.0006	0.0121	0.0029
2	0.0006	0.0121	0.0041
3	0.0006	0.0092	0.0056
4	0.0007	0.0088	0.0040
5	0.0007	0.0097	0.0061
6	0.0006	0.0086	0.0046
7	0.0006	0.0056	0.0067
8	0.0006	0.0125	0.0056
9	0.0006	0.0139	0.0039
10	0.0006	0.0120	0.0056
11	0.0005	0.0115	0.0039
12	0.0006	0.0084	0.0050
13	0.0005	0.0079	0.0046
14	0.0005	0.0085	0.0034
15	0.0005	0.0060	0.0031
16	0.0004	0.0100	0.0049
17	0.0005	0.0078	0.0041
18	0.0006	0.0069	0.0053
19	0.0006	0.0076	0.0048
20	0.0007	0.0079	0.0066
21	0.0005	0.0146	0.0057
22	0.0007	0.0123	0.0038
23	0.0006	0.0132	0.0034
24	0.0006	0.0129	0.0053
25	0.0006	0.0099	0.0041
26	0.0006	0.0126	0.0057
27	0.0007	0.0115	0.0044
28	0.0006	0.0089	0.0060
29	0.0006	0.0059	0.0045
30	0.0006	0.0062	0.0066

Table 4.7 Setup Time of Vendor

No.	Detail Setup Cost	Quantity	Cost
1	Machine Preparation Time per day	15 minutes	
2	Working Time per month	9600 minutes	
3	Regional Standard Salary per month	1 worker	Rp800,000.00

Table 4.8 Holding Cost of Vendor

No.	Detail Holding Cost	Duration	Cost
1	Electricity	1 month	Rp500,000.00
2	Warehouse Staff	1 month	Rp1,000,000.00
Total			Rp1,500,000.00

4.2 Data Processing

4.2.1 Integrated Inventory Model for Constant Delay of Lead Time

A. Data of Integrated Inventory Model

Data input required for calculating total cost is described as follow:

1. Standard Deviation of Demand

Standard deviation of demand is as follow:

$$Average\ Demand\ per\ month = \frac{\sum_{i=1}^{n} X_i}{n}$$

$$Average\ Demand\ per\ month = \frac{15671}{12} = 1306$$

$$\sigma = \sqrt{\frac{\sum(x - \overline{x})^2}{n-1}}$$

$$\sigma = \sqrt{\frac{(1470 - 1306)^2 + (1225 - 1306)^2 + \cdots + (1229 - 1306)^2}{12 - 1}}$$

$$\sigma = 126.29$$

2. Setup Cost

Setup cost incurred by vendor is described as follow:

$$Setup\ Cost\ (K) = \frac{Machine\ Preparation\ Time}{Working\ Hour}\ x\ Opportunity\ Loss$$

$$Setup\ Cost\ (K) = \frac{15}{9600}\ \text{x [(Rp 800,000.00 x 26) + Rp 1,500,000.00]}$$

Setup Cost (K) = Rp. 34,800.00

3. Holding Cost

Holding Cost per unit per unit time for Buyer:

$$Holding\ cost\ (h_b) = \frac{Holding\ cost}{Capacity\ of\ Inventory}$$

$$Holding\ cost\ (h_b) = \frac{\text{Rp 800.000,00}}{1500} = \text{Rp 550,00 per unit}$$

Holding Cost per unit per unit time for Vendor:

$$Holding\ cost\ (h_v) = \frac{Holding\ cost}{Capacity\ of\ Inventory}$$

$$Holding\ cost\ (h_v) = \frac{\text{Rp 1.500.000,00}}{5000} = \text{Rp 300,00 per unit}$$

B. Total Cost of Integrated Inventory for Constant Delay of Lead Time

1. Input Variables

Summary of Integrated inventory model is shown in Table 4.9

Table 4.9 Parameter Input

Parameter	Value
D	15671 unit
$1/p$	20402 unit
K	Rp34,800.00
A	Rp10,000.00
F	Rp5,500.00
h_v	Rp300.00
h_b	Rp550.00
π	Rp1,250.00
σ	126.29

2. Total Cost of Integrated Inventory

The integrated inventory model to be used in this research is the current model proposed by Ben Daya and Hariga (2004). The Integrated Inventory Calculation described in the procedures below using proposed model has been described in previous Chapter.

Calculation of Integrated inventory model for constant delay using the assumption that delays due to unproductive time is 0.016. The calculation of expected total cost for constant delay is explained below.

Step 0 *S*et the value of $ETC^* = \infty$, and number of shipment $n = 1$

Iteration 1:

Step 1 Calculate the value of Q using: $Q = \left[\sqrt{2\ D\ G(n\ )/\ H(n)}\right]$, Where $[x]$ value is the nearest integer to x

$$G\ (n) = F + \frac{A+K}{n}$$

$$G\ (n) = 5500 + \frac{10000+34800}{1} = 50300$$

$$H\ (n) = h_b + h_v\left[n\left(1 - Dp\right) - 1 + 2Dp\right]$$

$$H(\text{n}) = 550 + 300\left[1\left(1 - \left(\frac{15671}{20402}\right)\right) - 1 + 2\left(\frac{15671}{20402}\right)\right] = 780.43$$

$$Q = \sqrt{2D\,\frac{G(n)}{H(n)}}$$

$$Q = \sqrt{2\,(15671)\,\frac{50300}{780.43}} = 1422$$

Step 2, Iteration 1: Define the *k* value from the Equation (3.9), and then define *ψ(k)* using Equation (3.4),

$$k = \frac{h_b\,Q}{\pi\,D}$$

$$k = \frac{(550)\,(1422)}{(34800)\,(15761)} = 0.040$$

$$\psi\,(k) = \int_{k}^{\infty} (z - k)\,\phi\,(z)dx$$

$$\psi\,(k) = \text{Z}\,(1\text{-}0.040) \times (0.95) = 1.368$$

Step 3 Define the *Q'* value by u*Q'*sing Equation (3.10), and then set the result into *Q' = [Q'] Q'*

$$Q' = \sqrt{2D\,\frac{G(n) + \pi\sigma\psi(k)\sqrt{pQ + b}}{H(n) + \frac{h_b\,\sigma\,p}{\sqrt{pQ+b}}\left[k + \frac{\psi(k)}{\bar{F}(k)}\right]}}$$

$$Q' = \sqrt{2(15671)\,\frac{50300 + (34800)(126.29)(1.368)\sqrt{\frac{1422}{20402} + 0.016}}{780.43 + \frac{(550)(126.29)\left(\frac{1}{20402}\right)}{\sqrt{\frac{1422}{20402} + 0.016}}\left[0.040 + \frac{1.368}{0.040}\right]}}$$

$$Q' = 1741$$

Step 4 Calculate *Q'*- *Q*, then set the value into |*Q'*-*Q*|. if the result is equal to zero |*Q'* - *Q*| = 0, then the iteration continue to **Step 5**. If the result is greater than zero $|Q' - Q| > 0$, and then set Q' to Q, and repeat the **Step 2**

$|Q' - Q| = |1741 - 1422| = 319$; Where $319 > 0$

Since $|Q' - Q| > 0$, Then set $Q \leftarrow Q'$, and the calculation is repeated to **Step 2**

Step 2, Iteration 2:

$$k = \frac{h_b\, Q}{\pi\, D}\, \frac{(550)\,(1741)}{(34800)\,(15761)} = 0.049$$

$$\psi\ (k) = \int_k^{\infty} (z - k)\, \phi\ (z) dx = \mathrm{Z}\ (1\text{-}0.049) \times (0.95) = 1.364$$

Step 3, Iteration 2:

$$Q' = \sqrt{2D\, \frac{G(n) + \pi\sigma\psi(k)\sqrt{pQ + b}}{H(n) + \frac{h_b\, \sigma\, p}{\sqrt{pQ+b}} \left[k + \frac{\psi(k)}{F(k)}\right]}}$$

$$Q' = \sqrt{2(15671)\, \frac{50300 + (34800)(126.29)(1.364)\sqrt{\frac{1741}{20402} + 0.016}}{780.43 + \frac{(550)(126.29)\ \left(\frac{1}{20402}\right)}{\sqrt{\frac{1741}{20402} + 0.016}} \left[0.049 + \frac{1.364}{0.049}\right]}}$$

$Q' = 1862$

Step 4, Iteration 2:

$|Q' - Q| = |1860 - 1740| = 120$; Where $120 > 0$

Step 2, Iteration 3:

$$k = \frac{h_b\, Q}{\pi\, D} = \frac{(550)\,(1862)}{(34800)\,(15761)} = 0.052$$

$$\psi\ (k) = \int_k^{\infty} (z - k)\, \phi\ (z) dx = \mathrm{Z}\ (1\text{-}0.052) \times (0.95) = 1.363$$

Step 3, Iteration 3:

$$Q' = \sqrt{2D \frac{G(n) + \pi\sigma\psi(k)\sqrt{pQ+b}}{H(n) + \frac{h_b\, \sigma\, p}{\sqrt{pQ+b}} \left[k + \frac{\psi(k)}{\bar{F}(k)}\right]}}$$

$$Q' = \sqrt{2(15671) \frac{50300 + (34800)(126.29)(1.363)\sqrt{\frac{1862}{20402} + 0.016}}{780.43 + \frac{(550)(126.29)\left(\frac{1}{20402}\right)}{\sqrt{\frac{1862}{20402} + 0.016}} \left[0.052 + \frac{1.364}{0.052}\right]}}$$

$Q' = 1901$

Step 4, Iteration 3:

$|Q' - Q| = |1901 - 1862| = 39$; Where $39 > 0$

Step 2, Iteration 4:

$$k = \frac{h_b\, Q}{\pi\, D} = \frac{(550)\,(1901)}{(34800)\,(15761)} = 0.053$$

$$\psi\ (k) = \int_k^{\infty} (z - k)\, \phi\ (z) dx = \mathrm{Z}\ (1\text{-}0.053) \times (0.95) = 1.362$$

Step 3, Iteration 4:

$$Q' = \sqrt{2D \frac{G(n) + \pi\sigma\psi(k)\sqrt{pQ+b}}{H(n) + \frac{h_b\, \sigma\, p}{\sqrt{pQ+b}} \left[k + \frac{\psi(k)}{\bar{F}(k)}\right]}}$$

$$Q' = \sqrt{2(15671) \frac{50300 + (34800)(126.29)(1.362)\sqrt{\frac{1901}{20402} + 0.016}}{780.43 + \frac{(550)(126.29)\left(\frac{1}{20402}\right)}{\sqrt{\frac{1901}{20402} + 0.016}} \left[0.053 + \frac{1.362}{0.053}\right]}}$$

$Q' = 1913$

Step 4, Iteration 4:

$|Q' - Q| = |1913 - 1901| = 12$; Where $12 > 0$

Step 2, Iteration 5:

$$k = \frac{h_b\,Q}{\pi\,D} = \frac{(550)\,(1913)}{(34800)\,(15761)} = 0.054$$

$$\psi\ (k) = \int_k^{\infty} (z - k)\,\phi\ (z) dx = \mathrm{Z}\ (1\text{-}0.054)\ \mathrm{x}\ (0.95) = 1.362$$

Step 3, Iteration 5:

$$Q' = \sqrt{2D\,\frac{G(n) + \pi\sigma\psi(k)\sqrt{pQ+b}}{H(n) + \frac{h_b\,\sigma\,p}{\sqrt{pQ+b}}\left[k + \frac{\psi(k)}{\bar{F}(k)}\right]}}$$

$$Q' = \sqrt{2(15671)\,\frac{50300 + (34800)(126.29)(1.362)\sqrt{\frac{1913}{20402} + 0.016}}{780.43 + \frac{(550)(126.29)\left(\frac{1}{20402}\right)}{\sqrt{\frac{1913}{20402} + 0.016}}\left[0.054 + \frac{1.362}{0.054}\right]}}$$

$Q' = 1917$

Step 4, Iteration 5:

$|Q' - Q| = |1917 – 1913| = 4$; Where $4 > 0$

Step 2, Iteration 6:

$$k = \frac{h_b\,Q}{\pi\,D} = \frac{(550)\,(1917)}{(34800)\,(15761)} = 0.054$$

$$\psi\ (k) = \int_k^{\infty} (z - k)\,\phi\ (z) dx = \mathrm{Z}\ (1\text{-}0.054)\ \mathrm{x}\ (0.95) = 1.362$$

Step 3, Iteration 6:

$$Q' = \sqrt{2D\,\frac{G(n) + \pi\sigma\psi(k)\sqrt{pQ+b}}{H(n) + \frac{h_b\,\sigma\,p}{\sqrt{pQ+b}}\left[k + \frac{\psi(k)}{\bar{F}(k)}\right]}}$$

$$Q' = \sqrt{2(15671)\,\frac{50300 + (34800)(126.29)(1.362)\sqrt{\frac{1917}{20402} + 0.016}}{780.43 + \frac{(550)(126.29)\left(\frac{1}{20402}\right)}{\sqrt{\frac{1917}{20402} + 0.016}}\left[0.054 + \frac{1.362}{0.054}\right]}}$$

$Q' = 1918$

Step 4, Iteration 6:

$|Q' - Q| = |1918 - 1917| = 1$; Where $1 > 0$

Step 2, Iteration 7:

$$k = \frac{h_b\, Q}{\pi\, D} = \frac{(550)\,(1918)}{(32800)\,(15761)} = 0.054$$

$$\psi\,(k) = \int_k^{\infty} (z - k)\,\phi\,(z)dx = \text{Z}\,(1\text{-}0.054) \times (0.95) = 1.362$$

Step 3, Iteration 7:

$$Q' = \sqrt{2D\,\frac{G(n) + \pi\sigma\psi(k)\sqrt{pQ + b}}{H(n) + \frac{h_b\,\sigma\,p}{\sqrt{pQ+b}}\left[k + \frac{\psi(k)}{\bar{F}(k)}\right]}}$$

$$Q' = \sqrt{2(15671)\,\frac{50300 + (34800)(126.29)(1.362)\sqrt{\frac{1918}{20402} + 0.016}}{780.43 + \frac{(550)(126.29)\left(\frac{1}{20402}\right)}{\sqrt{\frac{1918}{20402} + 0.016}}\left[0.054 + \frac{1.362}{0.054}\right]}}$$

$Q' = 1918$

Step 4, Iteration 7:

$|Q' - Q| = |1918 - 1918| = 0$; Where $0 = 0$

Since $|Q' - Q| = 0$, the calculation is continued to ***Step 5***

Step 5 Define the Expected Total Cost value from equation (3.5). Then, compare the *ETC* value resulted with *ETC** defined in *Step 0.* If *ETC** value is greater than *ETC* computed, $ETC^* \geq ETC\ (Q,n)$, set $ETC\ (Q,n)$ into ETC^*, where Q change into Q^*, s change into s^*. Then, set n + 1 be n, and repeat the algorithm from *Step 1*. Otherwise, if $ETC^* \leq ETC\ (Q,n)$, the algorithm is finished.

$$ETC\ (Q,n) = \frac{G(n)\,D}{Q} + \frac{Q}{2}\,H(n) + h_b\,k\sigma\,\sqrt{pQ+b} + \frac{\pi D\sigma\sqrt{pQ+b}}{Q}\,\psi\,(k)$$

$$ETC\ (Q,n) = \frac{(50300)(15671)}{(1916)} + \frac{(1918)}{2}\,(780.43) + (550)(0.052)(126.29)\sqrt{\frac{1918}{20402}+0.016} + \frac{(1250)\,(15671)\,(126.29)\sqrt{\frac{1918}{20402}+0.016}}{1918}\,(1.362)$$

$ETC\ (Q,n)$ = Rp 1,165,287.57

Since $ETC\ (Q,n) \leq ETC^*$, then set $ETC^* \leftarrow ETC\ (Q,n)$, $n \leftarrow n+1$, and the calculation of ETC is repeated to ***Step 1***

The example ETC calculation is using number of shipment n=1, then continue to number of shipment n=2,3,…,n until the result shows $ETC \geq ETC^*$. The summary of solution procedures is shown in Table 4.10

Table 4.10 Summary of Solution procedures for constant delay of lead time

b	*n*	*Q*	*ETC*
0.016	1	1362	Rp1,165,287.57
	2	1657	Rp974,235.30
	3	1510	Rp912,360.90
	4	1405	Rp887,194.38
	5	1326	Rp878,494.87
	6	1262	Rp878,617.19

Expected total cost calculation explained above is using constant delay due to un productive time. Since constant delay assumption is contrary to the actual dynamic environment, this research proposed an integrated inventory model by changing constant delay into probabilistic delay using fuzzy logic model.

4.2.2 Integrated Inventory Model for Probabilistic Delay of Lead Time

A. Development of Fuzzy Logic Model for Probabilistic Delay of Lead Time

1. Input and Output Variables

The input variables to be analyzed are moving time (M), waiting time (W), and queuing time (Q). The output variable is delay time, which will substitute to lead time formula of integrated inventory model.

2. Fuzzy Set and Membership Function

Fuzzy Set and Membership function for input variables will be described as follow:

1. Fuzzy Set and Membership Function of Moving Time (*M*)

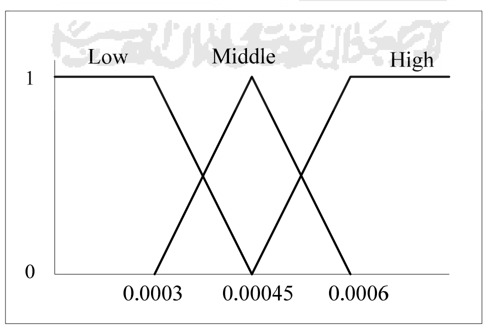

Figure 4.1 Fuzzy Set and Membership Function of Moving Time *(M)*

$$\mu A\ Low\ (x) = \begin{cases} 0; & x \geq 0.0003 \\ 1; & 0 \leq x \leq 0.0003 \\ \dfrac{0.00045 - x}{0.00045 - 0.0003}; & 0.0003 \leq x \leq 0.00045 \end{cases} \quad (4.1)$$

$$\mu A\ Middle\ (x) = \begin{cases} 0; & x \leq 0.0003 \\ \dfrac{x - 0.0003}{0.00045 - 0.0003}; & 0.0003 \leq x \leq 0.00045 \\ \dfrac{0.0006 - x}{0.0006 - 0.00045}; & 0.00045 \leq x \leq 0.0006 \\ 0; & x \geq 0.0006 \end{cases} \tag{4.2}$$

$$\mu A\ High\ (x) = \begin{cases} 0; & x \leq 0.0006 \\ \dfrac{x - 0.0006}{0.0006 - 0.00045}; & 0.00045 \leq x \leq 0.0006 \\ 1; & x \geq 0.0006 \end{cases} \tag{4.3}$$

2. Fuzzy Set of Wating Time (*W*)

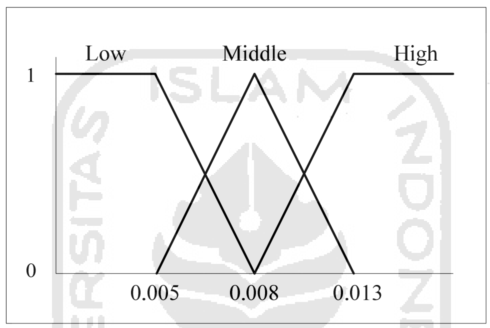

Figure 4.2 Fuzzy Set and Membership Function of Waiting Time (*W*)

$$\mu A\ Low\ (x) = \begin{cases} 0; & x \geq 0.005 \\ 1; & 0 \leq x \leq 0.005 \\ \dfrac{0.008 - x}{0.008 - 0.005}; & 0.005 \leq x \leq 0.008 \end{cases} \tag{4.4}$$

$$\mu A\ Middle\ (x) = \begin{cases} 0; & x \leq 0.005 \\ \dfrac{x - 0.005}{0.008 - 0.005}; & 0.005 \leq x \leq 0.008 \\ \dfrac{0.013 - x}{0.013 - 0.008}; & 0.008 \leq x \leq 0.013 \\ 0; & x \geq 0.013 \end{cases} \tag{4.5}$$

$$\mu A\ High\ (x) = \begin{cases} 0; & x \leq 0.013 \\ \dfrac{x - 0.008}{0.013 - 0.008}; & 0.008 \leq x \leq 0.013 \\ 1; & x \geq 0.013 \end{cases} \tag{4.6}$$

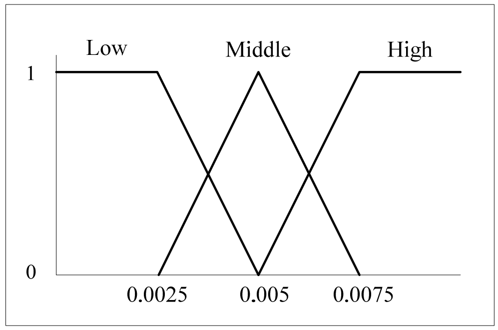

Figure 4.3 Fuzzy Set and Membership Function of Queuing Time (Q)

$$\mu A\ Low\ (x) = \begin{cases} 0; & x \geq 0.0025 \\ 1; & 0 \leq x \leq 0.0025 \\ \dfrac{0.005 - x}{0.005 - 0.0025}; & 0.0025 \leq x \leq 0.005 \end{cases} \quad (4.7)$$

$$\mu A\ Middle\ (x) = \begin{cases} 0; & x \leq 0.0025 \\ \dfrac{x - 0.0025}{0.005 - 0.0025}; & 0.0025 \leq x \leq 0.005 \\ \dfrac{0.0075 - x}{0.0075 - 0.005}; & 0.005 \leq x \leq 0.0075 \\ 0; & x \geq 0.0075 \end{cases} \quad (4.8)$$

$$\mu A\ High\ (x) = \begin{cases} 0; & \mathrm{x} \leq 0.0075 \\ \dfrac{\mathrm{x} - 0.005}{0.0075 - 0.005}; & 0.02 \leq \mathrm{x} \leq 0.0075 \\ 1; & \mathrm{x} \geq 0.0075 \end{cases} \quad (4.9)$$

3. Fuzzy Rules

Development of fuzzy system is using Single Order – Sugeno Inference System. The general form of fuzzy rules is shown as below.

R_1 : IF *M* is low AND *W* is low AND *Q* is low THEN $b=a_1M+b_1W+c_1Q+d_1$

R_2 : IF *M* is middle AND *W* is low AND *Q* is low THEN $b=a_2M+b_2W+c_2Q+d_2$

R_3 : IF *M* is high AND *W* is low AND *Q* is low THEN $b=a_3M+b_3W+c_3Q+d_3$

R_4 IF *M* is low AND *W* is middle AND *Q* is low THEN $b=a_4M+b_4W+c_4Q+d_4$

R_5 : if *M* is middle AND *W* is middle AND *Q* is low THEN $b=a_5M+b_5W+c_5Q+d_5$

R_6 : IF M is high AND W is middle AND Q is low THEN $b=a_6M+b_6W+c_6Q+d_6$

R_7 : IF M is low AND W is high AND Q is low THEN $b=a_7M+b_7W+c_7Q+d_7$

R_8 : IF M is middle AND W is high AND Q is low THEN $b=a_8M+b_8W+c_8Q+d_8$

R_9 : IF M is high AND W is high AND Q is low THEN $b=a_9M+b_9W+c_9Q+d_9$

R_{10} : IF M is low AND W is low AND Q is middle THEN $b=a_{10}M+b_{10}W+c_{10}Q+d_{10}$

R_{11} : IF M is middle AND W is low AND Q is middle THEN $b=a_{11}M+b_{11}W+c_{11}Q+d_{11}$

R_{12} : IF M is high AND W is low AND Q is middle THEN $b=a_{12}M+b_{12}W+c_{12}Q+d_{12}$

R_{13} : IF M is low AND W is low AND Q is high THEN $b=a_{13}M+b_{13}W+c_{13}Q+d_{13}$

R_{14} : IF M is middle AND W is low AND Q is high THEN $b=a_{14}M+b_{14}W+c_{14}Q+d_{14}$

R_{15} : IF M is high AND W is low AND Q is high THEN $b=a_{15}M+b_{15}W+c_{15}Q+d_{15}$

R_{16} : IF M is low AND W is middle AND Q is middle THEN $b=a_{16}M+b_{16}W+c_{16}Q+d_{16}$

R_{17} : IF M is middle AND W is middle AND Q is middle THEN $b=a_{17}M+b_{17}W+c_{17}Q+d_{17}$

R_{18} : IF M is high AND W is middle AND Q is high THEN $b=a_{18}M+b_{18}W+c_{18}Q+d_{18}$

R_{19} : IF M is low AND W is middle AND Q is high THEN $b=a_{19}\mathrm{M}+b_{19}\mathrm{W}+c_{19}\mathrm{Q}+d_{19}$

R_{20} : IF M is middle AND W is middle AND Q is high THEN $b=a_{20}M+b_{20}W+c_{20}Q+d_{20}$

R_{21} : IF M is high AND W is middle AND Q is high THEN $b=a_{21}M+ b_{21}W+c_{21}Q+d_{21}$

R_{22} : IF M is low AND W is high AND Q is middle THEN $b=a_{22}M+b_{22}W+ c_{22}Q +d_{22}$

R_{23} : IF M is middle AND W is high AND Q is middle THEN $b=a_{23}M+b_{23}W$

$+c_{23}Q+d_{23}$

R_{24} : IF M is high AND W is high AND Q is middle THEN $b=a_{24}M+b_{24}W+c_{24}Q+d_{24}$

R_{25} : IF M is low AND W is high AND Q is high THEN $b=a_{25}M+b_{25}W+c_{25}Q+d_{25}$

R_{26} : IF M is middle AND W is high AND Q is high THEN $b=a_{26}M+b_{26}W+c_{26}Q+d_{26}$

R_{27} : IF M is high AND W is high AND Q is high THEN $b=a_{27}M+b_{27}W+c_{27}Q+d_{27}$

It is known that there are 117 parameters in rule consequent. Parameters on fuzzy sets have been described in Equation (4.1) to (4.9). Parameters on fuzzy rules consequent is shown in Table 4.11:

Table 4.11 Weight of fuzzy rules consequent

i	*a*	*b*	*c*	*d*
1	0.0242	0.0236	0.0242	0.0204
2	0.0184	0.0213	0.0213	0.0177
3	0.0190	0.0190	0.0240	0.0187
4	0.0245	0.0196	0.0237	0.0190
5	0.0202	0.0233	0.0162	0.0200
6	0.0243	0.0241	0.0160	0.0161
7	0.0232	0.0169	0.0220	0.0206
8	0.0185	0.0249	0.0205	0.0241
9	0.0192	0.0229	0.0231	0.0184
10	0.0167	0.0216	0.0228	0.0163
11	0.0213	0.0214	0.0218	0.0247
12	0.0232	0.0194	0.0187	0.0189
13	0.0228	0.0171	0.0206	0.0182
14	0.0165	0.0242	0.0197	0.0162
15	0.0229	0.0172	0.0177	0.0231
16	0.0207	0.0229	0.0208	0.0226
17	0.0207	0.0208	0.0181	0.0182
18	0.0213	0.0170	0.0210	0.0170
19	0.0217	0.0238	0.0203	0.0246
20	0.0199	0.0182	0.0206	0.0224

i	*a*	*b*	*c*	*d*
21	0.0187	0.0179	0.0210	0.0250
22	0.0173	0.0190	0.0168	0.0233
23	0.0183	0.0200	0.0246	0.0171
24	0.0168	0.0192	0.0189	0.0213
25	0.0196	0.0185	0.0215	0.0222
26	0.0162	0.0244	0.0240	0.0204
27	0.0216	0.0197	0.0160	0.0217

3. Summary of Fuzzy Calculation

No	Moving Time	Waiting Time	Queuing Time	delay	a cut R1	a cut R2	…	a cut R27	Fr1	Fr2	…	Fr27	R1	R2	...	R27	Output (b)
1	0.0006	0.0121	0.0029	0.0156	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0167
2	0.0006	0.0121	0.0041	0.0168	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0221	0.0000	0.0000	...	0.0000	0.0200
3	0.0006	0.0092	0.0056	0.0154	0.0000	0.0000	…	0.0614	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0014	0.0198
4	0.0007	0.0088	0.0040	0.0134	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0174
5	0.0007	0.0097	0.0061	0.0164	0.0000	0.0000	…	0.1438	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0032	0.0211
6	0.0006	0.0086	0.0046	0.0138	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0176
7	0.0006	0.0056	0.0067	0.0129	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0222
8	0.0006	0.0125	0.0056	0.0187	0.0000	0.0000	…	0.2099	0.0209	0.0181	…	0.0221	0.0000	0.0000	...	0.0046	0.0215
9	0.0006	0.0139	0.0039	0.0185	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0221	0.0000	0.0000	...	0.0000	0.0204
10	0.0006	0.0120	0.0056	0.0181	0.0000	0.0000	…	0.1802	0.0208	0.0181	…	0.0221	0.0000	0.0000	...	0.0040	0.0212
11	0.0005	0.0115	0.0039	0.0158	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0193
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
25	0.0006	0.0099	0.0041	0.0147	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0183
26	0.0006	0.0126	0.0057	0.0189	0.0000	0.0000	…	0.2549	0.0209	0.0181	…	0.0221	0.0000	0.0000	...	0.0056	0.0216
27	0.0007	0.0115	0.0044	0.0166	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0198
28	0.0006	0.0089	0.0060	0.0155	0.0000	0.0000	…	0.0715	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0016	0.0207
29	0.0006	0.0059	0.0045	0.0111	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0219	0.0000	0.0000	...	0.0000	0.0185
30	0.0006	0.0062	0.0066	0.0134	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0220

Figure 4.4 Summary of Fuzzy Calculation

The comparison of actual and prediction delay is shown in Figure 4.5

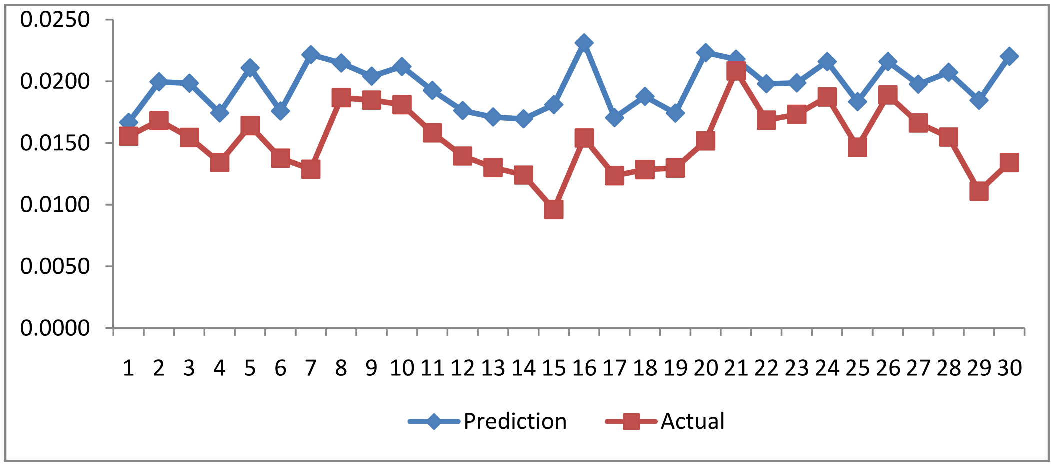

Figure 4.5 Comparison of Actual and Initial Prediction Delay

The comparison of Actual and Initial Prediction delay has MSE value 2.41E-05 and PME 22.513%. It is indicated that fuzzy logic model has high error and the model is not valid, then the fuzzy model need to be optimized. The parameter to be optimized is weight of fuzzy rules consequent.

B. Total Cost of Integrated Inventory

Total cost of integrated inventory for probabilistic delay calculation is using model proposed by Ben Daya and Hariga (2004). Fuzzy logic model result is substituted into lead time equation in integrated inventory model. The solution procedure of total cost of integrated inventory calculation is based on current model by substituted fuzzy logic result. One of total cost of integrated inventory summary using delay $b_1 = 0.0167$ is shown in Table 4.12. Total cost of integrated inventory calculation is continued until delay ratio $b_{30} = 0.0220$. Complete summary of total cost of integrated inventory calculations are shown in Appendix 3. The relation between delay and total cost is shown in figure 4.6

Table 4.12 Summary of Solution procedures for delay $b_1 = 0.0167$

b	n	Q	ETC
0.016	1	1362	Rp1,165,287.57
	2	1657	Rp974,235.30
	3	1510	Rp912,360.90
	4	1405	Rp887,194.38
	5	1326	Rp878,494.87
	6	1262	Rp878,617.19

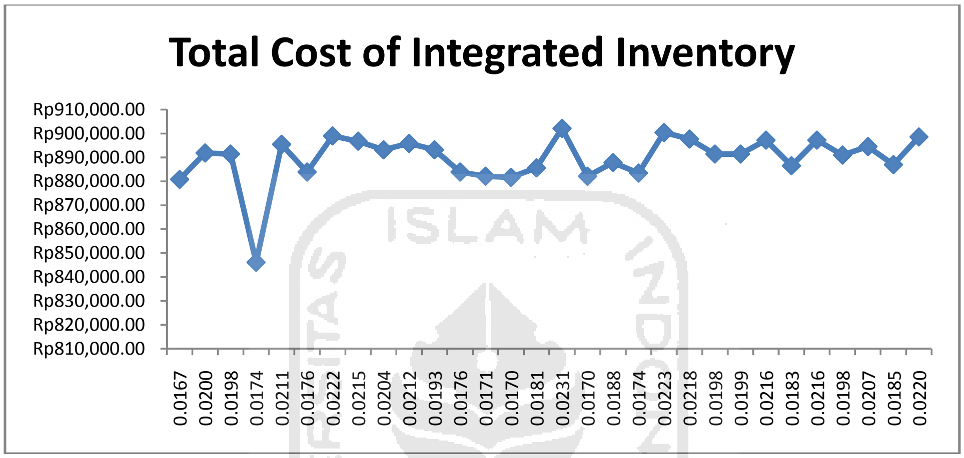

Figure 4.6 Effect of Delay to Total cost of integrated inventory

The figure above shows the effect of delay to expected total cost. The minimum value of total cost is shown at delay b_3= 0.0174 with total cost Rp 845,122.46. Since the fuzzy model has error 22.513%, it is considered to be inaccurate. In order to obtain more accurate total cost, the model is needed to be optimized. The optimization is performed using solver by changing weight of fuzzy rules consequent.

C. Fuzzy Logic Optimization

Fuzzy logic model optimization is performed using solver in Ms. Excel. Parameter to be optimized is weight of fuzzy rule consequent. The dialog window procedure to perform optimization is shown in Figure 4.7

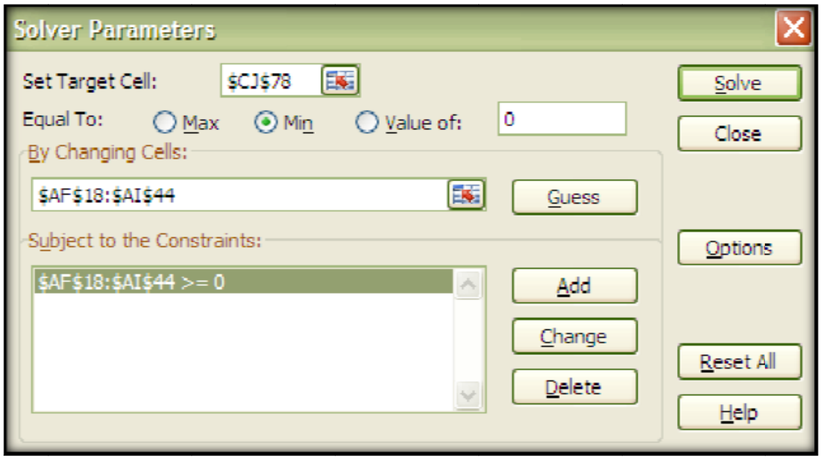

Figure 4.7 Solver Parameters

The steps to perform Ms. Excel solver are:

1. Fill "Set Target Cell" by selecting MSE value
2. Choose minimum at "Equal To" to be objective function
3. Fill "By Changing Cells" by selecting weight cells
4. Select weights of fuzzy consequent cells to be >= 0 as constraints at "Subject to the Constraints"

The calculation result of fuzzy logic optimization is shown in Figure 4.8

No	Moving Time	Waiting Time	Queuing Time	delay	a cut R1	a cut R2	…	a cut R27	Fr1	Fr2	…	Fr27	R1	R2	…	R27	Output (b)
1	0.0006	0.0121	0.0029	0.0156	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0151
2	0.0006	0.0121	0.0041	0.0168	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0170
3	0.0006	0.0092	0.0056	0.0154	0.0000	0.0000	…	0.0614	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0015	0.0155
4	0.0007	0.0088	0.0040	0.0134	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0247	0.0000	0.0000	…	0.0000	0.0133
5	0.0007	0.0097	0.0061	0.0164	0.0000	0.0000	…	0.1438	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0036	0.0167
6	0.0006	0.0086	0.0046	0.0138	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0247	0.0000	0.0000	…	0.0000	0.0137
7	0.0006	0.0056	0.0067	0.0129	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0129
8	0.0006	0.0125	0.0056	0.0187	0.0000	0.0000	…	0.2099	0.0209	0.0181	…	0.0248	0.0000	0.0000	…	0.0052	0.0190
9	0.0006	0.0139	0.0039	0.0185	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0248	0.0000	0.0000	…	0.0000	0.0179
10	0.0006	0.0120	0.0056	0.0181	0.0000	0.0000	…	0.1802	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0045	0.0184
11	0.0005	0.0115	0.0039	0.0158	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0162
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
25	0.0006	0.0099	0.0041	0.0147	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0147
26	0.0006	0.0126	0.0057	0.0189	0.0000	0.0000	…	0.2549	0.0209	0.0181	…	0.0248	0.0000	0.0000	…	0.0063	0.0194
27	0.0007	0.0115	0.0044	0.0166	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0164
28	0.0006	0.0089	0.0060	0.0155	0.0000	0.0000	…	0.0715	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0018	0.0156
29	0.0006	0.0059	0.0045	0.0111	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0111
30	0.0006	0.0062	0.0066	0.0134	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0247	0.0000	0.0000	…	0.0000	0.0134

Figure 4.8 Summary of Optimized Fuzzy Calculation

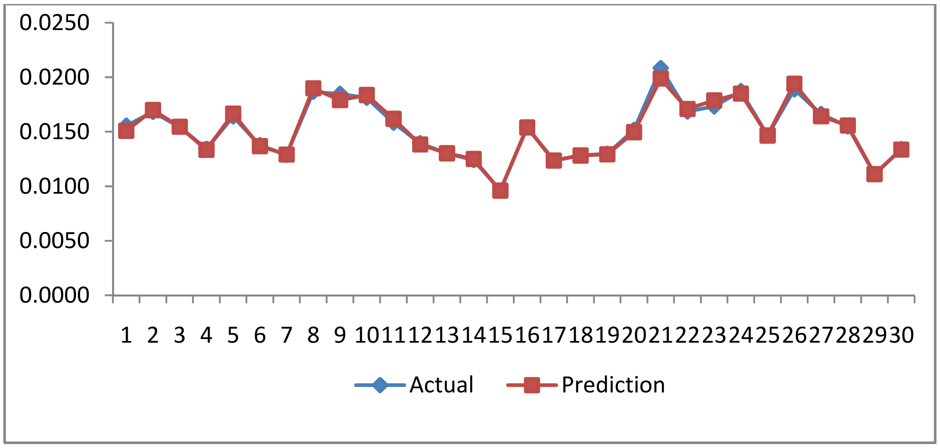

Figure 4.9 Comparison of Actual and Optimized delay Prediction

The comparison of Actual and optimized Prediction delay has MSE value 8.96E-08 and PME 1.17%. Since the percentage error is lower than 10%, the fuzzy model is more accurate than initial fuzzy model. Delay prediction result will be closed to actual.

D. Total Cost of Integrated Inventory Calculation using Optimized Fuzzy Logic Model

Calculation of expected total cost after fuzzy logic model optimization is performed by using data input in Table 4.9. Summary of total cost calculation using delay b_1= 0.0151 is shown in Table 4.13. The complete summary of total cost calculation after optimization is shown in Appendix 4. The relation of delay to total cost is depicted in Figure 4.10

Table 4.13 Summary of Solution procedures for delay b_1 = 0.0151

b	n	Q	ETC
0.015	1	1910	Rp1,163,850.41
	2	1646	Rp972,078.75
	3	1497	Rp909,461.80

b	n	Q	ETC
	4	1392	Rp883,912.44
	5	1313	Rp875,262.70
	6	1249	Rp875,085.79

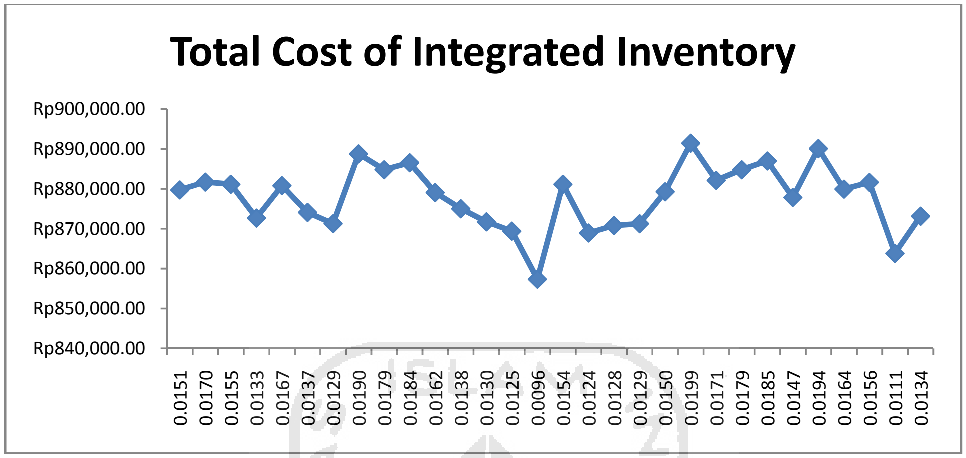

Figure 4.10 Effect of Delay to total cost of integrated inventory using Optimized Fuzzy Logic Model

The result of ETC calculation after fuzzy model optimization shows the minimum ETC is at delay b_{15}= 0.0096 with total cost Rp. 857,326.25.

E. Total cost of Integrated Inventory Prediction

Prediction of integrated inventory total cost is conducted using 10 data. The prediction is performed using optimized fuzzy logic model. Data input is shown in Table 4.14

Table 4.14 Data input for total cost of integrated inventory prediction

No	Moving Time	Waiting Time	Queuing Time
1	0.0006	0.0063	0.0059
2	0.0007	0.0126	0.0042
3	0.0007	0.0131	0.0035
4	0.0006	0.0077	0.0052
5	0.0006	0.0102	0.0053
6	0.0006	0.0128	0.0059
7	0.0007	0.0114	0.0042
8	0.0006	0.0087	0.0060
9	0.0006	0.0063	0.0048
10	0.0006	0.0064	0.0070

The result of delay prediction shows the MSE and PMES value is 2.81E-7 and 2.20% respectively. The comparison of actual and prediction delay is shown in Figure 4.11.

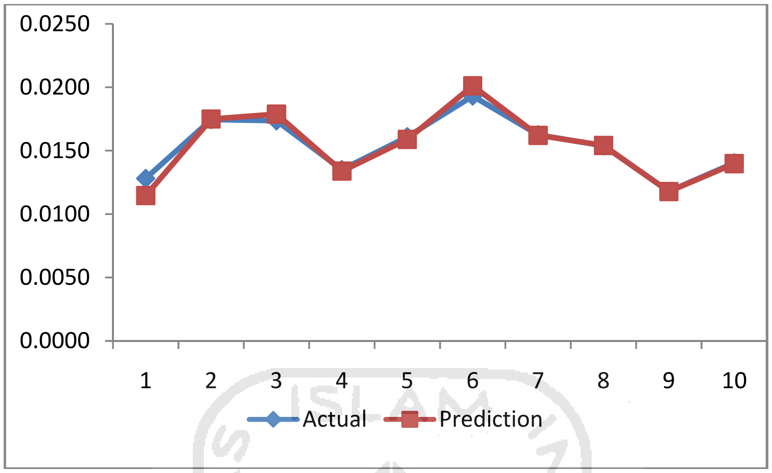

Figure 4.11 Comparison of Actual and Optimized delay Prediction

Prediction result is substituted into lead time equation in integrated inventory model. The optimal n, Q, and ETC is shown in Table 4.15 and the solution procedures is shown in Appendix 5

Table 4.15 Total Cost of Integrated Inventory Prediction

No	Number of Shipment (n)	Batch Size (Q)	Total Cost of Integrated Inventory
1	7	1164	Rp865,191.83
2	7	1214	Rp888,721.46
3	6	1271	Rp884,771.55
4	7	1181	Rp873,126.28
5	6	1255	Rp877,727.14
6	6	1288	Rp892,313.90
7	6	1258	Rp879,041.38
8	7	1198	Rp881,127.46
9	7	1167	Rp866,586.11
10	7	1186	Rp875,472.90

CHAPTER V

DISCUSSION

It is generally known that demand and lead time are problems occurred in dynamic supply chain environment. Coordination within the organization in the network is necessary to increase supply chain performance. Coordination in managing inventory is a way to face the uncertainty in lead time and increase supply chain performance.

This research concerned in development of integrated inventory model by involving delay in lead time which consists of non productive time in internal processes. The objective of this research is to determine the total cost of integrated inventory and analyze the effect of delay to total cost.

Based on the data processing results on Chapter 4, current integrated inventory model assuming lead time is affected by constant delay. Calculation of total cost using constant delay is performed by assuming delay ratio due to unproductive time is 0.016. The assumption is based on unproductive time observed per total production in year. The optimal total cost of integrated inventory obtained is Rp 878,617.19, and delivery shipment (n) is 6. The condition is contrary to the actual stochastic condition, although the optimal total cost is obtained. Therefore, this research developing integrated inventory model by changing constant delay into probabilistic delay using fuzzy logic model to predict delay ratio.

The first step to develop an integrated inventory model is building prediction model for delay using fuzzy logic. The objective is to predict delay ratio. Fuzzy logic model is developed based on unproductive time such as waiting, moving, and queuing time. Thus, there are three fuzzy set; they are moving, waiting, and queuing time. The memberships for each fuzzy set are low, middle, and high. Total fuzzy rules used in this study are 27 rules, which determined based on combination of linguistic variables in data input. Each rule has membership value between 0 and 1. If membership value is 0, then the rule does not have effect to output. Based on the result of 30 data tested, there are 12 of 27 rules have effect to the output. Rule 16 has 4% effect to output; Rule 15 is 15%; Rule 3 is 19%; Rule 19 is 22%; Rule 9 is 19%; Rule 8 and 27 is 30%; Rule 4 and 11 is 41%; Rule 21 is 44%; Rule 6 is 52%, Rule 24 and 10 is 74%; and Rule 18 is 96%. Whereas, Rule number 1, 2, 5, 7, 8, 10, 11, 13, 14, 17, 20, 22, 23, 25 and 26 have membership value 0, which means those rules do not have effect to the output. Therefore, the rules can be eliminated.

The initial delay prediction of fuzzy logic model shows MSE value is 2.41E-5 and PME value is 22.513%. The result of fuzzy logic is substituted to lead time equation in integrated inventory model. The result shows that optimal expected total cost is Rp. 846.122,46, quantity (Q) is 1124, and shipment (n) is 7 at delay b = 0.0174. Since the initial fuzzy logic model has high error percentage, the result of total cost is inaccurate and need to be optimized. Branch and bound technique is used for optimizing fuzzy logic model by optimized weight of fuzzy consequent.

The optimization is performed using Ms. Excel solver by optimizing rule weight parameter of fuzzy consequent. The MSE and PME value after optimization is 8.96E-8 and 1.170%. Since the error percentage is less than 10%, the model is valid. Expected total cost of integrated inventory model is recalculated after optimization performed. The optimal expected total cost is Rp. 857,326.25, quantity (Q) is 1147, and shipment frequency (n) is 7 at delay 0.0096.

Based on the calculation of total cost for each delay, the result shows that delay has significant effect to optimal total cost. It is shown that short delay time leads to low total cost. Otherwise, long delay time leads to high total cost. It is shown at highest point where delay ratio after optimization is 0.0199; the total cost of integrated inventory is Rp. 891,425.20. Whereas, if the delay ratio is 0.0096, then the total cost of integrated inventory is Rp. 857,326.25. It is shown that lower delay ratio leads to lower quantity of product and lower re-order point, and higher delay ratio leads to higher quantity.

Prediction of integrated inventory total cost is performed using 10 data. The prediction is conducted using optimized fuzzy logic model. The result shows that the MSE value is 2.81E-7 and PME is 2.20%. It is shown that fuzzy logic model is valid.

From the result obtained, development of integrated inventory model by involving fuzzy logic in delay provides benefits to control production process. The benefits of implementing integrated inventory model for vendor is to determine delivery shipment, and control production process by reduce non productive time. The benefits for buyer are to determine the order quantity, and order time.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

a. Conclusion

The conclusions based on problem formulation are:

1. MSE value for initial fuzzy logic model is 2.41E-5, and PME value is 22.513%. After optimization of fuzzy logic model, MSE value reduced into 8.96E-8 and PME value reduced into 1.170%. Fuzzy logic model validation is conducted, and the result shows that MSE value is 2.81E-7 and PME is 2.20%.
2. Total cost of integrated inventory at delay ratio b = 0.0096 is Rp. 857,326.25, and quantity Q = 1147, and total cost of integrated inventory at b = 0.0199 is Rp. 891,425.20 and quantity = 1248. It is shown that high delay ratio leads to high total cost of integrated inventory and high quantity
3. Optimization is conducted using Branch and Bound technique by optimizing weight of fuzzy consequent. By applying solution procedures, the optimal total cost of integrated inventory is Rp. 857,326.25, and optimal quantity Q = 1147.

b. Recommendation

Several recommendations after conducting this research are:

1. The implementation of integrated model is performed in controlling unproductive time to reduce total holding cost and maintain relationship between vendor and buyer

2. For the development of research and technology, further research is performing artificial neural network in integrated inventory model for lead time and demand is uncertainty.

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APPENDICES

Appendix 1 Summary of Fuzzy Calculation

No	Moving Time	Waiting Time	Queuing Time	delay	a cut R1	a cut R2	…	a cut R27	Fr1	Fr2	…	Fr27	R1	R2	...	R27	Output (b)
1	0.0006	0.0121	0.0029	0.0156	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0167
2	0.0006	0.0121	0.0041	0.0168	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0221	0.0000	0.0000	...	0.0000	0.0200
3	0.0006	0.0092	0.0056	0.0154	0.0000	0.0000	…	0.0614	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0014	0.0198
4	0.0007	0.0088	0.0040	0.0134	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0174
5	0.0007	0.0097	0.0061	0.0164	0.0000	0.0000	…	0.1438	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0032	0.0211
6	0.0006	0.0086	0.0046	0.0138	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0176
7	0.0006	0.0056	0.0067	0.0129	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0222
8	0.0006	0.0125	0.0056	0.0187	0.0000	0.0000	…	0.2099	0.0209	0.0181	…	0.0221	0.0000	0.0000	...	0.0046	0.0215
9	0.0006	0.0139	0.0039	0.0185	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0221	0.0000	0.0000	...	0.0000	0.0204
10	0.0006	0.0120	0.0056	0.0181	0.0000	0.0000	…	0.1802	0.0208	0.0181	…	0.0221	0.0000	0.0000	...	0.0040	0.0212
11	0.0005	0.0115	0.0039	0.0158	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0193
12	0.0006	0.0084	0.0050	0.0139	0.0000	0.0000	…	0.0008	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0176
13	0.0005	0.0079	0.0046	0.0130	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0171
14	0.0005	0.0085	0.0034	0.0124	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0170
15	0.0005	0.0060	0.0031	0.0096	0.0000	0.0000	…	0.0000	0.0206	0.0179	…	0.0219	0.0000	0.0000	...	0.0000	0.0181
16	0.0004	0.0100	0.0049	0.0154	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0231
17	0.0005	0.0078	0.0041	0.0124	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0170
18	0.0006	0.0069	0.0053	0.0128	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0188
19	0.0006	0.0076	0.0048	0.0130	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0174
20	0.0007	0.0079	0.0066	0.0152	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0223
21	0.0005	0.0146	0.0057	0.0208	0.0000	0.0000	…	0.2810	0.0209	0.0182	…	0.0221	0.0000	0.0000	...	0.0062	0.0218
22	0.0007	0.0123	0.0038	0.0168	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0221	0.0000	0.0000	...	0.0000	0.0198
23	0.0006	0.0132	0.0034	0.0173	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0221	0.0000	0.0000	...	0.0000	0.0199
24	0.0006	0.0129	0.0053	0.0187	0.0000	0.0000	…	0.0991	0.0209	0.0181	…	0.0221	0.0000	0.0000	...	0.0022	0.0216
25	0.0006	0.0099	0.0041	0.0147	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0183
26	0.0006	0.0126	0.0057	0.0189	0.0000	0.0000	…	0.2549	0.0209	0.0181	…	0.0221	0.0000	0.0000	...	0.0056	0.0216
27	0.0007	0.0115	0.0044	0.0166	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0000	0.0198
28	0.0006	0.0089	0.0060	0.0155	0.0000	0.0000	…	0.0715	0.0208	0.0181	…	0.0220	0.0000	0.0000	...	0.0016	0.0207
29	0.0006	0.0059	0.0045	0.0111	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0219	0.0000	0.0000	...	0.0000	0.0185
30	0.0006	0.0062	0.0066	0.0134	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0220	0.0000	0.0000	...	0.0000	0.0220

Appendix 2 Summary of Fuzzy Calculation after Optimization

No	Moving Time	Waiting Time	Queuing Time	delay	a cut R1	a cut R2	…	a cut R27	Fr1	Fr2	…	Fr27	R1	R2	…	R27	Output (b)
1	0.0006	0.0121	0.0029	0.0156	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0151
2	0.0006	0.0121	0.0041	0.0168	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0170
3	0.0006	0.0092	0.0056	0.0154	0.0000	0.0000	…	0.0614	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0015	0.0155
4	0.0007	0.0088	0.0040	0.0134	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0247	0.0000	0.0000	…	0.0000	0.0133
5	0.0007	0.0097	0.0061	0.0164	0.0000	0.0000	…	0.1438	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0036	0.0167
6	0.0006	0.0086	0.0046	0.0138	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0247	0.0000	0.0000	…	0.0000	0.0137
7	0.0006	0.0056	0.0067	0.0129	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0129
8	0.0006	0.0125	0.0056	0.0187	0.0000	0.0000	…	0.2099	0.0209	0.0181	…	0.0248	0.0000	0.0000	…	0.0052	0.0190
9	0.0006	0.0139	0.0039	0.0185	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0248	0.0000	0.0000	…	0.0000	0.0179
10	0.0006	0.0120	0.0056	0.0181	0.0000	0.0000	…	0.1802	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0045	0.0184
11	0.0005	0.0115	0.0039	0.0158	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0162
12	0.0006	0.0084	0.0050	0.0139	0.0000	0.0000	…	0.0008	0.0207	0.0180	…	0.0247	0.0000	0.0000	…	0.0000	0.0138
13	0.0005	0.0079	0.0046	0.0130	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0130
14	0.0005	0.0085	0.0034	0.0124	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0125
15	0.0005	0.0060	0.0031	0.0096	0.0000	0.0000	…	0.0000	0.0206	0.0179	…	0.0246	0.0000	0.0000	…	0.0000	0.0096
16	0.0004	0.0100	0.0049	0.0154	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0154
17	0.0005	0.0078	0.0041	0.0124	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0124
18	0.0006	0.0069	0.0053	0.0128	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0128
19	0.0006	0.0076	0.0048	0.0130	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0129
20	0.0007	0.0079	0.0066	0.0152	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0150
21	0.0005	0.0146	0.0057	0.0208	0.0000	0.0000	…	0.2810	0.0209	0.0182	…	0.0248	0.0000	0.0000	…	0.0070	0.0199
22	0.0007	0.0123	0.0038	0.0168	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0171
23	0.0006	0.0132	0.0034	0.0173	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0179
24	0.0006	0.0129	0.0053	0.0187	0.0000	0.0000	…	0.0991	0.0209	0.0181	…	0.0248	0.0000	0.0000	…	0.0025	0.0185
25	0.0006	0.0099	0.0041	0.0147	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0147
26	0.0006	0.0126	0.0057	0.0189	0.0000	0.0000	…	0.2549	0.0209	0.0181	…	0.0248	0.0000	0.0000	…	0.0063	0.0194
27	0.0007	0.0115	0.0044	0.0166	0.0000	0.0000	…	0.0000	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0000	0.0164
28	0.0006	0.0089	0.0060	0.0155	0.0000	0.0000	…	0.0715	0.0208	0.0181	…	0.0247	0.0000	0.0000	…	0.0018	0.0156
29	0.0006	0.0059	0.0045	0.0111	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0246	0.0000	0.0000	…	0.0000	0.0111
30	0.0006	0.0062	0.0066	0.0134	0.0000	0.0000	…	0.0000	0.0207	0.0180	…	0.0247	0.0000	0.0000	…	0.0000	0.0134

Appendix 3 Summary of Integrated Inventory Total Cost Solution Procedures

Total Cost of Integrated Inventory for b_1=*0.0167*

b	n	Q	ETC
0.0167	1	1918	Rp1,165,288.83
	2	1657	Rp975,033.09
	3	1510	Rp913,639.57
	4	1405	Rp888,645.46
	5	1326	Rp880,496.34
	6	1262	Rp880,798.48

Total Cost of Integrated Inventory for b_2=*0.0200*

b	n	Q	ETC
0.0200	1	1935	Rp1,168,389.66
	2	1679	Rp981,013.25
	3	1534	Rp921,446.20
	4	1430	Rp897,843.49
	5	1351	Rp890,659.97
	6	1287	Rp891,867.96

Total Cost of Integrated Inventory for b_3=*0.0198*

b	n	Q	ETC
0.0198	1	1934	Rp1,168,207.59
	2	1679	Rp981,009.27
	3	1533	Rp921,119.80
	4	1429	Rp897,474.18
	5	1350	Rp890,252.04
	6	1286	Rp891,423.76

Total Cost of Integrated Inventory for b_4=*0.0174*

b	n	Q	ETC
0.0174	1	1922	Rp1,166,012.58
	2	1576	Rp953,398.48
	3	1416	Rp883,584.07
	4	1313	Rp855,261.48
	5	1236	Rp844,352.30
	6	1175	Rp842,682.36
	7	1124	Rp846,122.46

Total Cost of Integrated Inventory for b_5=*0.0211*

b	n	Q	ETC
0.0211	1	1941	Rp1,169,497.82
	2	1687	Rp983,206.97
	3	1542	Rp924,071.53
	4	1438	Rp900,812.75
	5	1359	Rp893,938.93
	6	1295	Rp895,437.77

Total Cost of Integrated Inventory for b_6=*0.0176*

b	n	Q	ETC
0.0176	1	1923	Rp1,166,193.27
	2	1663	Rp976,656.27
	3	1517	Rp915,904.73
	4	1412	Rp891,209.98
	5	1333	Rp883,330.98
	6	1295	Rp883,886.37

Total Cost of Integrated Inventory for b_7=*0.0222*

b	n	Q	ETC
0.0222	1	1946	Rp1,170,430.28
	2	1694	Rp985,138.39
	3	1550	Rp926,705.16
	4	1446	Rp903,790.10
	5	1367	Rp897,226.04
	6	1303	Rp899,015.92

Total Cost of Integrated Inventory for b_8=*0.0215*

b	n	Q	ETC
0.0215	1	1943	Rp1,169,869.31
	2	1690	Rp984,031.50
	3	1545	Rp925,057.62
	4	1441	Rp901,927.71
	5	1362	Rp895,170.01
	6	1298	Rp896,777.75

Total Cost of Integrated Inventory for b_9=*0.0204*

b	n	Q	ETC
0.0204	1	1937	Rp1,168,760.21
	2	1682	Rp981,835.61

b	n	Q	ETC
	3	1537	Rp922,430.62
	4	1433	Rp898,956.98
	5	1354	Rp891,889.66
	6	1290	Rp893,206.75

Total Cost of Integrated Inventory for $b_{10}=0.0212$

b	n	Q	ETC
0.0212	1	1941	Rp1,169,500.53
	2	1688	Rp983,480.75
	3	1543	Rp924,399.05
	4	1439	Rp901,183.14
	5	1360	Rp894,347.96
	6	1296	Rp895,883.08

Total Cost of Integrated Inventory for $b_{11}=0.0193$

b	n	Q	ETC
0.0193	1	1937	Rp1,168,760.21
	2	1682	Rp981,835.61
	3	1537	Rp922,430.62
	4	1433	Rp898,956.98
	5	1354	Rp891,889.66
	6	1290	Rp893,206.75

Total Cost of Integrated Inventory for $b_{12}=0.0176$

b	n	Q	ETC
0.0176	1	1923	Rp1,166,194.39
	2	1664	Rp976,923.52
	3	1517	Rp915,906.42
	4	1412	Rp891,211.82
	5	1333	Rp883,332.95
	6	1269	Rp883,888.47

Total Cost of Integrated Inventory for $b_{13}=0.0171$

b	n	Q	ETC
0.0171	1	1921	Rp1,165,827.91
	2	1660	Rp975,843.19
	3	1513	Rp914,611.18
	4	1408	Rp889,745.53
	5	1329	Rp881,712.30

b	n	Q	ETC
	6	1265	Rp882,123.07

Total Cost of Integrated Inventory for b_{14}=*0.0170*

b	n	Q	ETC
0.0170	1	1920	Rp1,165,647.89
	2	1659	Rp975,572.83
	3	1512	Rp914,286.97
	4	1407	Rp889,378.49
	5	1328	Rp881,306.61
	6	1264	Rp881,681.15

Total Cost of Integrated Inventory for b_{15}=*0.0181*

b	n	Q	ETC
0.0181	1	1926	Rp1,166,737.49
	2	1667	Rp977,738.51
	3	1520	Rp916,882.89
	4	1416	Rp892,678.75
	5	1337	Rp884,954.16
	6	1273	Rp885,654.38

Total Cost of Integrated Inventory for b_{16}=*0.0231*

b	n	Q	ETC
0.0231	1	1950	Rp1,171,182.42
	2	1700	Rp986,801.81
	3	1556	Rp928,692.97
	4	1453	Rp906,404.61
	5	1374	Rp900,111.79
	6	1310	Rp902,156.65

Total Cost of Integrated Inventory for b_{17}=*0.0170*

b	n	Q	ETC
0.0170	1	1920	Rp1,165,650.36
	2	1660	Rp975,841.13
	3	1513	Rp914,608.84
	4	1408	Rp889,742.97
	5	1329	Rp881,709.56
	6	1265	Rp882,120.16

Total Cost of Integrated Inventory for b_{18}=*0.0188*

b	n	Q	ETC
0.0188	1	1929	Rp1,167,287.70
	2	1671	Rp978,829.08
	3	1525	Rp918,509.12
	4	1421	Rp894,519.80
	5	1342	Rp886,988.39
	6	1278	Rp887,869.84

Total Cost of Integrated Inventory for $b_{19}=0.0174$

b	n	Q	ETC
0.0174	1	1922	Rp1,166,012.29
	2	1662	Rp976,384.65
	3	1515	Rp915,260.33
	4	1411	Rp890,841.34
	5	1332	Rp882,923.62
	6	1268	Rp883,442.70

Total Cost of Integrated Inventory for $b_{20}=0.0223$

b	n	Q	ETC
0.02230	1	1947	Rp1,170,472.54
	2	1695	Rp985,563.87
	3	1551	Rp927,431.88
	4	1447	Rp904,772.35
	5	1368	Rp898,433.16
	6	1304	Rp900,429.29

Total Cost of Integrated Inventory for $b_{21}=0.0218$

b	n	Q	ETC
0.0218	1	1944	Rp1,170,058.36
	2	1692	Rp984,583.78
	3	1547	Rp925,717.79
	4	1443	Rp902,673.96
	5	1364	Rp895,993.83
	6	1300	Rp897,674.63

Total Cost of Integrated Inventory for $b_{22}=0.0198$

b	n	Q	ETC
0.0198	1	1934	Rp1,168,206.47
	2	1678	Rp980,739.23
	3	1533	Rp921,118.11

b	n	Q	ETC
	4	1429	Rp897,472.35
	5	1350	Rp890,250.08
	6	1286	Rp891,421.68

Total Cost of Integrated Inventory for $b_{23}=0.0199$

b	n	Q	ETC
0.0199	1	1935	Rp1,168,387.40
	2	1679	Rp981,010.25
	3	1533	Rp921,120.91
	4	1429	Rp897,475.38
	5	1350	Rp890,253.32
	6	1286	Rp891,425.12

Total Cost of Integrated Inventory for $b_{24}=0.0216$

b	n	Q	ETC
0.0216	1	1943	Rp1,169,872.26
	2	1690	Rp984,035.38
	3	1546	Rp925,386.01
	4	1442	Rp902,299.01
	5	1363	Rp895,579.97
	6	1299	Rp897,224.22

Total Cost of Integrated Inventory for $b_{25}=0.0183$

b	n	Q	ETC
0.0183	1	1927	Rp1,166,921.17
	2	1669	Rp978,280.19
	3	1522	Rp917,531.84
	4	1418	Rp893,413.54
	5	1339	Rp885,766.13
	6	1275	Rp886,538.75

Total Cost of Integrated Inventory for $b_{26}=0.0216$

b	n	Q	ETC
0.0216	1	1943	Rp1,169,872.28
	2	1690	Rp983,253.56
	3	1546	Rp924,059.28
	4	1442	Rp900,548.92
	5	1363	Rp893,481.86
	6	1299	Rp894,823.56

Total Cost of Integrated Inventory for b_{27}=*0.0198*

b	n	Q	ETC
0.0198	1	1934	Rp1,168,205.59
	2	1678	Rp980,738.07
	3	1533	Rp921,116.80
	4	1429	Rp897,470.92
	5	1349	Rp889,846.03
	6	1285	Rp890,981.60

Total Cost of Integrated Inventory for b_{28}=*0.0207*

b	n	Q	ETC
0.0207	1	1939	Rp1,169,127.99
	2	1685	Rp982,654.80
	3	1540	Rp923,411.16
	4	1436	Rp900,066.13
	5	1357	Rp893,114.65
	6	1293	Rp894,540.53

Total Cost of Integrated Inventory for b_{29}=*0.0185*

b	n	Q	ETC
0.0185	1	1927	Rp1,166,924.05
	2	1669	Rp978,284.02
	3	1523	Rp917,856.12
	4	1419	Rp893,780.70
	5	1340	Rp886,171.85
	6	1276	Rp886,980.65

Total Cost of Integrated Inventory for b_{30}=*0.0220*

b	n	Q	ETC
0.0220	1	1945	Rp1,170,245.38
	2	1693	Rp984,862.53
	3	1549	Rp926,375.30
	4	1445	Rp903,417.27
	5	1366	Rp896,814.47
	6	1302	Rp898,567.95

Appendix 4 Summary of Integrated Inventory Total Cost Solution Procedure after Optimization

Total Cost of Integrated Inventory for $b_1 = 0.0151$

b	n	Q	ETC
0.0151	1	1910	Rp1,163,850.41
	2	1646	Rp972,078.75
	3	1497	Rp909,461.80
	4	1392	Rp883,912.44
	5	1313	Rp875,262.70
	6	1249	Rp875,095.79
	7	1195	Rp879,713.52

Total Cost of Integrated Inventory for $b_2 = 0.0170$

b	n	Q	ETC
0.0170	1	1920	Rp1,165,648.63
	2	1659	Rp975,573.82
	3	1512	Rp914,288.10
	4	1407	Rp889,379.71
	5	1328	Rp881,307.92
	6	1264	Rp881,682.55

Total Cost of Integrated Inventory for $b_3 = 0.0155$

b	n	Q	ETC
0.0155	1	1912	Rp1,164,208.09
	2	1648	Rp972,617.24
	3	1500	Rp910,423.46
	4	1395	Rp885,002.24
	5	1316	Rp876,467.98
	6	1252	Rp876,409.23
	7	1198	Rp881,130.54

Total Cost of Integrated Inventory for $b_4 = 0.0133$

b	n	Q	ETC
0.0133	1	1994	Rp1,180,091.23
	2	1647	Rp972,429.98
	3	1484	Rp905,317.18
	4	1378	Rp878,847.73
	5	1298	Rp869,266.70
	6	1234	Rp868,560.28

b	n	Q	ETC
	7	1180	Rp872,661.55

Total Cost of Integrated Inventory for $b_5=0.0167$

b	n	Q	ETC
0.0167	1	1918	Rp1,165,288.51
	2	1657	Rp975,032.66
	3	1510	Rp913,639.08
	4	1405	Rp888,644.92
	5	1326	Rp880,495.77
	6	1262	Rp880,797.87

Total Cost of Integrated Inventory for $b_6=0.0137$

b	n	Q	ETC
0.0137	1	1902	Rp1,162,430.25
	2	1635	Rp969,152.97
	3	1486	Rp905,947.45
	4	1381	Rp879,928.18
	5	1301	Rp870,461.96
	6	1237	Rp869,863.28
	7	1183	Rp874,067.65

Total Cost of Integrated Inventory for $b_7=0.0129$

b	n	Q	ETC
0.0129	1	1898	Rp1,161,723.74
	2	1630	Rp967,826.04
	3	1480	Rp904,040.01
	4	1374	Rp877,410.49
	5	1295	Rp868,068.93
	6	1231	Rp867,254.56
	7	1177	Rp871,252.56

Total Cost of Integrated Inventory for $b_8=0.0190$

b	n	Q	ETC
0.0190	1	1930	Rp1,167,470.92
	2	1673	Rp979,370.75
	3	1527	Rp919,158.16
	4	1423	Rp895,254.54
	5	1344	Rp887,800.23
	6	1280	Rp888,754.03

Total Cost of Integrated Inventory for $b_9=0.0179$

b	n	Q	ETC
0.0179	1	1925	Rp1,166,555.10
	2	1665	Rp977,199.01
	3	1519	Rp916,555.50
	4	1415	Rp892,308.17
	5	1335	Rp884,144.83
	6	1271	Rp884,772.78

Total Cost of Integrated Inventory for $b_{10}=0.0184$

b	n	Q	ETC
0.0184	1	1927	Rp1,166,921.73
	2	1669	Rp978,280.94
	3	1522	Rp917,532.68
	4	1418	Rp893,414.46
	5	1339	Rp885,767.11
	6	1275	Rp886,539.79

Total Cost of Integrated Inventory for $b_{11}=0.0162$

b	n	Q	ETC
0.0162	1	1916	Rp1,164,925.63
	2	1653	Rp973,959.48
	3	1506	Rp912,351.03
	4	1401	Rp887,186.06
	5	1322	Rp878,882.83
	6	1258	Rp879,040.54

Total Cost of Integrated Inventory for $b_{12}=0.0138$

b	n	Q	ETC
0.0138	1	1903	Rp1,162,606.52
	2	1636	Rp969,419.10
	3	1382	Rp906,580.69
	4	1412	Rp880,290.84
	5	1303	Rp871,256.41
	6	1238	Rp870,300.36
	7	1185	Rp875,002.32

Total Cost of Integrated Inventory for $b_{13}=0.0130$

b	n	Q	ETC
0.0130	1	1899	Rp1,161,898.02

b	n	Q	ETC
	2	1630	Rp967,830.41
	3	1481	Rp904,357.04
	4	1375	Rp877,769.98
	5	1296	Rp868,466.80
	6	1232	Rp867,688.33
	7	1178	Rp871,720.67

Total Cost of Integrated Inventory for $b_{14}=0.0125$

b	n	Q	ETC
0.0125	1	1896	Rp1,161,371.25
	2	1627	Rp967,034.26
	3	1477	Rp903,087.94
	4	1371	Rp876,330.85
	5	1291	Rp866,482.85
	6	1227	Rp865,525.20
	7	1173	Rp869,386.13

Total Cost of Integrated Inventory for $b_{15}=0.0096$

b	n	Q	ETC
0.0096	1	1880	Rp1,158,593.03
	2	1604	Rp961,030.85
	3	1452	Rp895,241.90
	4	1345	Rp867,076.73
	5	1265	Rp856,239.61
	6	1201	Rp854,353.04
	7	1147	Rp857,326.25

Total Cost of Integrated Inventory for $b_{16}=0.0154$

b	n	Q	ETC
0.0154	1	1912	Rp1,164,206.36
	2	1648	Rp972,614.91
	3	1500	Rp910,420.81
	4	1395	Rp884,999.35
	5	1315	Rp876,068.83
	6	1251	Rp875,974.19
	7	1198	Rp881,127.05

Total Cost of Integrated Inventory for $b_{17}=0.0124$

b	n	Q	ETC

b	n	Q	ETC
0.0124	1	1895	Rp1,161,196.87
	2	1625	Rp966,511.98
	3	1475	Rp902,459.43
	4	1370	Rp875,970.83
	5	1290	Rp866,084.58
	6	1226	Rp865,090.98
	7	1172	Rp868,917.53

Total Cost of Integrated Inventory for $b_{18}=0.0128$

b	n	Q	ETC
0.0128	1	1898	Rp1,161,721.38
	2	1629	Rp967,563.72
	3	1479	Rp903,724.52
	4	1374	Rp877,406.49
	5	1294	Rp867,672.85
	6	1230	Rp866,822.70
	7	1176	Rp870,786.46

Total Cost of Integrated Inventory for $b_{19}=0.0129$

b	n	Q	ETC
0.0129	1	1898	Rp1,161,724.31
	2	1630	Rp967,826.82
	3	1480	Rp904,040.90
	4	1375	Rp877,765.48
	5	1295	Rp868,069.97
	6	1231	Rp867,255.67
	7	1177	Rp871,253.73

Total Cost of Integrated Inventory for $b_{20}=0.0150$

b	n	Q	ETC
0.0150	1	1909	Rp1,163,673.31
	2	1645	Rp971,811.68
	3	1496	Rp909,141.23
	4	1391	Rp883,549.13
	5	1312	Rp874,860.87
	6	1248	Rp874,657.90
	7	1194	Rp879,241.08

Total Cost of Integrated Inventory for $b_{21}=0.0199$

b	n	Q	ETC
0.0199	1	1935	Rp1,168,387.44
	2	1679	Rp981,010.31
	3	1533	Rp921,120.97
	4	1429	Rp897,475.45
	5	1350	Rp890,253.40
	6	1286	Rp891,425.20

Total Cost of Integrated Inventory for $b_{22}=0.0171$

b	n	Q	ETC
0.0171	1	1920	Rp1,165,651.50
	2	1660	Rp975,842.65
	3	1513	Rp914,610.57
	4	1408	Rp889,744.86
	5	1329	Rp881,711.58
	6	1265	Rp882,122.31

Total Cost of Integrated Inventory for $b_{23}=0.0179$

b	n	Q	ETC
0.0179	1	1924	Rp1,166,377.53
	2	1665	Rp977,198.10
	3	1519	Rp916,554.47
	4	1414	Rp891,945.33
	5	1335	Rp884,143.63
	6	1271	Rp884,771.50

Total Cost of Integrated Inventory for $b_{24}=0.0185$

b	n	Q	ETC
0.0185	1	1928	Rp1,167,102.72
	2	1670	Rp978,552.41
	3	1523	Rp917,857.82
	4	1419	Rp893,782.55
	5	1340	Rp886,173.83
	6	1276	Rp886,982.75

Total Cost of Integrated Inventory for $b_{25}=0.0147$

b	n	Q	ETC
0.0147	1	1908	Rp1,163,491.80
	2	1642	Rp971,014.94
	3	1494	Rp908,499.00

b	n	Q	ETC
	4	1389	Rp882,821.27
	5	1309	Rp873,661.02
	6	1245	Rp873,350.17
	7	1191	Rp877,830.06

Total Cost of Integrated Inventory for $b_{26}=0.0194$

b	n	Q	ETC
0.0194	1	1932	Rp1,167,838.58
	2	1676	Rp980,188.86
	3	1530	Rp920,137.82
	4	1426	Rp896,363.17
	5	1347	Rp889,024.89
	6	1283	Rp890,087.60

Total Cost of Integrated Inventory for $b_{27}=0.0164$

b	n	Q	ETC
0.0164	1	1917	Rp1,165,106.89
	2	1655	Rp974,495.59
	3	1508	Rp912,994.57
	4	1403	Rp887,915.00
	5	1324	Rp879,688.79
	6	1260	Rp879,918.67

Total Cost of Integrated Inventory for $b_{28}=0.0156$

b	n	Q	ETC
0.0156	1	1913	Rp1,164,385.37
	2	1649	Rp972,884.22
	3	1501	Rp910,744.01
	4	1396	Rp885,365.47
	5	1317	Rp876,869.68
	6	1253	Rp876,846.97
	7	1199	Rp881,602.80

Total Cost of Integrated Inventory for $b_{29}=0.0111$

b	n	Q	ETC
0.0111	1	1888	Rp1,159,976.67
	2	1616	Rp964,149.91
	3	1465	Rp899,306.85
	4	1359	Rp872,040.70

b	n	Q	ETC
	5	1279	Rp861,735.44
	6	1215	Rp860,348.17
	7	1161	Rp863,798.35

Total Cost of Integrated Inventory for $b_{30}=0.0134$

b	n	Q	ETC
0.0134	1	1901	Rp1,162,250.02
	2	1633	Rp968,621.44
	3	1484	Rp905,308.53
	4	1378	Rp878,848.80
	5	1299	Rp869,660.74
	6	1234	Rp868,561.80
	7	1181	Rp873,125.32

Appendix 5 Summary of Prediction of Integrated Inventory Total Cost Solution Procedures

Total Cost of Integrated Inventory for $b=0.0115$

b	n	Q	ETC
0.0115	1	1890	Rp1,160,323.73
	2	1619	Rp964,932.68
	3	1468	Rp900,249.16
	4	1362	Rp873,110.20
	5	1282	Rp862,919.14
	6	1218	Rp861,639.13
	7	1164	Rp865,191.83

Total Cost of Integrated Inventory for $b=0.0175$

b	n	Q	ETC
0.0175	1	1922	Rp1,166,014.19
	2	1663	Rp976,652.75
	3	1516	Rp915,581.87
	4	1411	Rp890,844.46
	5	1332	Rp882,926.96
	6	1268	Rp883,446.25
	7	1214	Rp888,721.46

Total Cost of Integrated Inventory for *b=0.0179*

b	n	Q	ETC
0.0179	1	1924	Rp1,166,377.56
	2	1665	Rp977,198.13
	3	1519	Rp916,554.51
	4	1414	Rp891,945.38
	5	1335	Rp884,143.67
	6	1271	Rp884,771.55

Total Cost of Integrated Inventory for *b=0.0134*

b	n	Q	ETC
0.0134	1	1901	Rp1,162,250.49
	2	1633	Rp968,622.08
	3	1484	Rp905,309.26
	4	1299	Rp878,849.59
	5	1335	Rp869,661.58
	6	1235	Rp868,990.85
	7	1181	Rp873,126.28

Total Cost of Integrated Inventory for *b=0.0159*

b	n	Q	ETC
0.0159	1	1914	Rp1,164,568.08
	2	1651	Rp973,421.65
	3	1504	Rp911,705.39
	4	1399	Rp886,454.79
	5	1319	Rp877,677.51
	6	1255	Rp877,727.14

Total Cost of Integrated Inventory for *b=0.0201*

b	n	Q	ETC
0.0201	1	1936	Rp1,168,572.78
	2	1680	Rp981,287.09
	3	1535	Rp921,774.05
	4	1431	Rp898,214.35
	5	1352	Rp891,069.55
	6	1288	Rp892,313.90

Total Cost of Integrated Inventory for *b=0.0162*

b	n	Q	ETC
0.0162	1	1916	Rp1,164,926.08

b	n	Q	ETC
	2	1654	Rp974,223.93
	3	1506	Rp912,351.71
	4	1401	Rp887,186.80
	5	1322	Rp878,883.63
	6	1258	Rp879,041.38

Total Cost of Integrated Inventory for *b=0.0154*

b	n	Q	ETC
0.0154	1	1912	Rp1,164,206.56
	2	1648	Rp972,615.18
	3	1500	Rp910,421.12
	4	1395	Rp884,999.68
	5	1316	Rp876,465.23
	6	1251	Rp875,974.57
	7	1198	Rp881,127.46

Total Cost of Integrated Inventory for *b=0.0118*

b	n	Q	ETC
0.0118	1	1892	Rp1,160,671.11
	2	1621	Rp965,458.95
	3	1365	Rp901,192.30
	4	1415	Rp874,180.47
	5	1285	Rp864,103.59
	6	1221	Rp862,930.85
	7	1167	Rp866,586.11

Total Cost of Integrated Inventory for *b=0.0140*

b	n	Q	ETC
0.0140	1	1904	Rp1,162,782.30
	2	1637	Rp969,684.47
	3	1489	Rp906,899.80
	4	1383	Rp880,652.49
	5	1304	Rp871,656.53
	6	1240	Rp871,165.50
	7	1186	Rp875,472.90