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Model Development for Allocation of Raw Material in Timber Processing Industry in Indonesia

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Abstract**—**This research is intended to develop a raw material allocation model in timber processing industry in Perum Perhutani Unit I, Central Java, Indonesia. The model can be used to determine the quantity of allocation of timber between chain in the supply chain to select supplier considering factors that are log price and the distance. In determining the quantity of allocation of timber between chains in the supply chain, the model considers the optimal inventory in each chain. Whilst the optimal inventory is determined based on demand forecast, the capacity and safety stock. Problem solving allocation is conducted by developing linear programming model that aims to minimize the total cost of the purchase, transportation cost and storage costs at each chain. The results of numerical examples show that the proposed model can generate savings of the purchase cost of 20.84% and select suppliers with mileage closer.

Keywords**—**Allocation model, linear programming, purchase costs, storage costs, suppliers, transportation costs.

I. Introduction

TIMBER processing industry in Indonesia faces many problems to grow. It is indicated by the trend of decreasing number of SME in timber processing and the decreasing of the total exports. In the last 4 years, export volume of wooden furniture export decreasing about 9% per year, while the export value decreasing about 6% per year [1]-[2].

This condition is caused by many factors, but at least we can mention that few of the causea are raw material scarcity, inefficiency in operations management and marketing problems [3]. To solve one of those problems, that is inefficiency in operation management, we can use an approach called supply chain management.

Lee and Billington in [4] defines supply chain as a network of facilities that involve functions of materials movement, transformation of materials into semi-finished and finished goods, and distributions of finished goods to consumers. Managing supply chain can effectively improve customer service levels, reduce excess inventory in the system and reduce the excessive costs of the logistics network. Distribution is the activity undertaken to move and store the product from the supplier to the consumer in the supply chain [5]. Distribution will take place at every level in the supply chain. Implementation of supply chain management gives benefits to companies, included companies that undertake efforts in the forestry, such as Perhutani Unit I Central Java.

Perum Perhutani Unit I Central Java as supplier of raw material and also producer of the product has a distribution network design in accordance with the objectives to be achieved. Distribution of industrial raw materials includes various echelon distributions, before the raw material transform to finished products received by the consumer. Supplier of industrial raw materials derived from various Forest Management Units (FMU) with various grade quality of teak and the price. The various locations of FMU cause various transportation costs for the procurement of raw materials to different industries. The procurement cost of raw materials becomes more vary due to the different location timber processing area. Other complexity comes from various capability of supplier and various production capacity of furniture factory. Thus it is necessary to determine the optimal allocation of appropriate capacity and the need for each processing unit timber that will minimize total cost of purchasing and distribution cost.

Recently in Perum Perhutani, raw material allocation is based on the capability of each FMU to supply timber with forest sustainability consideration based on Annual Allowance Cut. The allocation aims to provide certain quantity of timber needed by manufacturer without considering variables such as inventory cost and transportation cost. This decision may impacts in efficiency. In example, a certain quantity of timber is taken from FMU A, but actually it will cheaper if it taken from FMU B.

Many studies about supply chain in furniture industry have been conducted, such as [6]-[8]. But those research cannot solve the specific problem in furniture industry in Indonesia. In example, inefficiency in operation management that may be no more problem in other country, but it is still a serious problem in Indonesia.

This study discusses the determination of the amount of the allocation of raw materials as well as the amount of inventory in each chain in order to minimize transportation costs, storage costs, and purchasing cost of raw materials industries. Performance criteria for determining the allocation of industrial raw materials supplier can be measured by

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minimizing storage costs, minimizing transportation costs and purchase cost.

II. System Description and Notation

A. System Description

Perum Perhutani has several stages of the process, starting from procurement of raw materials from multi-supplier to timber processing with multi-production lines. Distribution of teak for the needs of the industry is a multi echelon distribution model. The characteristics of multi-echelon systems are shown in Fig. 1. Line I is the forest as a source of raw materials. Line II is TPK KPH (Timber Hoarding of FMU) as supplier of timber. Line III is TPK IK (Timber Hoarding of Furniture factory) as a storage timber for industrial raw materials. Timber furniture factories are divided into three region, that are Cepu, Randublatung, and Brumbung. In the first stage after the raw material in the form of AII (log timber with diameter between 20-30 cm) and AIII (log timber with diameter more than 30 cm) from a supplier, then sawed lumber in sawmill machinery (PGM) so as to produce a form of Rough Sawn Timber (RST) or semi-finished industrial products and then taken to furniture factory to do the finishing process.

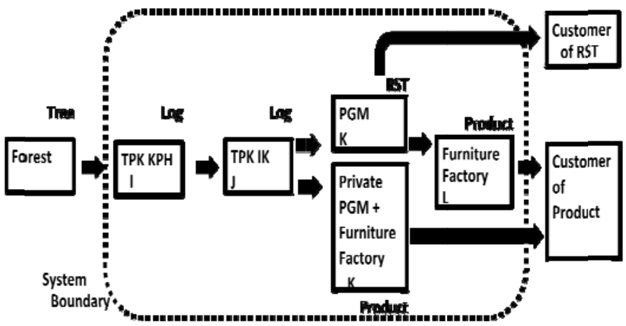

Fig. 1 The characteristics of multi-echelon systems

The variables considered in this allocation model is the inventory cost, the transportation cost and the purchase cost. Inventory cost is the cost charged to the storage timber in TPK KPH and TPK IK dependent on the amount of timber stored in each period. Transportation costs are charged to expense in the transportation of raw materials from TPK KPH to TPK IK. The purchase cost is charged to expense in the purchase of raw materials depends on the number of purchases and the price of timber from a supplier.

Discussion of this research was limited the flow of raw materials from TPK KPH until the flow of RST on furniture factory. Transportation costs from the logging in forest toward TPK KPH and transportation cost of materials from IK towards consumers are not taken into account. For description of the system characteristics, consumer demand is as the basis for demand of raw material.

B. Notations

Notations used to develop model are:

C_{si} : the purchase price of log s from KPH supplier *i*
T : transportation cost from TPK KPH toward TPK IK (Rp/km m^3)
S_{ij} : distance between TPK KPH *i* toward TPK IK *j*
H_{sit} : inventory cost of log *s* that stored in TPK KPH *i* in period *t*
H_{sjt} : inventory cost of log *s* that stored in TPK IK *j* in period *t*
H_{skt} : inventory cost of log *s* that stored in warehouse PGM k in period *t*
D_{plt} : Demand of finished product *p* in furniture factory *l* in period *t*
D_{rkt} : Demand RST *r* yang terjual dari PGM *k* pada waktu *t*
a_{rp} : conversion value of product *p* to RST *r*
b_{sr} : conversion value of RST *r* to log *s*
SS_{sit} : *Safety stock* of log *s* in TPK KPH *i* in period *t*
SS_{sjt} : *Safety stock* of log *s* in IPKJ *j* in period *t*
K_i : Storage capacity of TPK KPH *i*
K_j : Storage capacity of TPK IK *j*
K_k : Storage capacity of TPK PGM *k*
P_k : Production capacity of PGM *k* per month (m^3)
P_l : Production capacity of furniture factory *l* per month (m^3)
P_i : Production capacity of KPH *i* per month (m^3)
JPT_i : Annual allowance cut of KPH *i*
Q_{sit} : lot size allocation of log *s* of TPK KPH *i* in period *t*
Q_{sijt} : lot size allocation of log *s* from TPK KPH *i* toward TPK IK *j* in period *t*
Q_{sjkt} : *lot size* allocation of log *s* from TPK IK *j* toward PGM *k* in period *t*
Q_{rklt} : *lot size* allocation of RST *r* from PGM *k* toward furniture factory *l* in period *t*
Y_{plt} : Production volume of finished product *p* of furniture factory *l* in period *t*
X_{rkt} : Production volume of RST *r* of PGM *k* in period *t*
A_{sit} : volume of log *s* stored in TPK *i* in period *t*
B_{sjt} : volume of log *s* stored in IK *j* in period *t*
C_{skt} : volume of log *s* stored in warehouse PGM *k* in period *t*
T : length of planning horizon
I : Number of TPK KPH
J : Number of TPK IK
K : Number of PGM
L : Number of furniture factory
R : Number of RST type
P : Number of Product type
S : Number log diameter type

III. Model Development

A. Objective Function

Objective function of the model developed is minimize total logistics costs consist of the cost of purchasing raw materials, the cost of transportation of raw materials and the cost of raw materials store. Purchase cost of raw materials can be formulated as the product of the basic sale price of timber on each KPH (C_{si}) with a large quantity of timber purchased (Q_{sit}). The determination of the purchase cost of raw materials can be mathematically formulated as:

$$\sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{s=1}^{S} C_{si} Q_{sit} \tag{1}$$

The cost of transportation of raw materials is determined by the cost per m^3 of timber transportation (T), the quantity of timber moves from TPK KPH to TPK IK (Q_{sij}) and the distance between TPK KPH to TPK IK (S_{ij}). So the cost of transportation of raw materials can be formulated as

$$\sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{i-1}^{I} \sum_{s=1}^{S} T Q_{sijt} S_{ij} \tag{2}$$

Furthermore, the determination of the inventory cost in TPK KPH, TPK IK and warehouse of PGM can be formulated by multiplying the cost savings per unit on each line with the amount of timber stored.

$$\sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{s=1}^{S} H_{sit} A_{sit} + \sum_{t=1}^{T} \sum_{j=1}^{J} \sum_{s=1}^{S} H_{sjt} B_{skt} + \sum_{t=1}^{T} \sum_{k=1}^{K} \sum_{s=1}^{S} H_{skt} C_{skt} \tag{3}$$

B. Contrains

i. Constrains of Inventory

Constrain of inventory aims to determine inventory levels of type log s stored in TPK KPH *i*, in TPK IK *j*, in warehouses PGM k, RST materials stored in the warehouse PGM k. The amount of inventory in TPK KPH *i* (A_{sit}) is the stock in the previous month ($A_{si(t-1)}$) plus a lot size allocation of supplier KPH (Q_{sit}) minus the timber allocated towards TPK IK j (Q_{sijt}). The amount of inventory in TPK IK j (B_{sjt}) is the timber supply in the previous month ($B_{sj(t-1)}$) plus a lot size allocation of TPK KPH *i* Q_{sijt}) minus log of TPK KPH allocated towards warehouse of PGM k (Q_{sjkt}). While the size of the timber supply sortimen PGM (C_{skt}) is a timber inventory in the warehouse k in the previous PGM ($C_{sk(t-1)}$) plus the amount of log allocated from TPK IK to warehouse PGM k (Q_{sjkt}) subtracted by the need for the production of RST in PGM at the period ($b_{sr}X_{rk(t+1)}$). So inventory constraints can be formulated as

$$A_{sit} = A_{si(t-1)} + Q_{sit} - \sum_{j=1}^{J} Q_{sijt}, \ \forall i,s,t \tag{4}$$

$$B_{sjt} = B_{sj(t-1)} + \sum_{i=1}^{I} Q_{sijt} - \sum_{k=1}^{K} Q_{sjkt}, \ \forall j,s,t \tag{5}$$

$$C_{skt} = C_{sk(t-1)} + \sum_{j=1}^{J} Q_{sjkt} - r_s\, b_{sr} X_{rk(t+1)}, \ \forall k,s,t \tag{6}$$

The production amount of RST in each period (X_{rkt}) can be determined by adding the amount of RST sold (D_{rkt}) by the amount of RST allocated to the furniture factory (Q_{rklt}). The amount of RST allocated from PGM to the furniture factory in the period is determined by the needs for production of furniture factory in the next period. While the need for production of furniture factory in a period (Y_{plt}) is determined by demand for timber in the period. So the constrains can be formulated as:

$$X_{rkt} = \sum_{l=1}^{L} Q_{rklt} + D_{rkt}, \ \forall k,t \tag{7}$$

$$\sum_{k=1}^{K} Q_{rklt} = a_{rp} Y_{pl(t+1)} \ \forall l,t \tag{8}$$

$$Y_{plt} = D_{plt}, \ \forall l,t \tag{9}$$

In anticipation of the uncertainty of the number of demand, so the amount of inventory in TPK KPH *i* (A_{sit}), and TPK IK j (B_{sjt}), each of which must be determined is greater than or equal to the amount of safety stock (SS_{sjt}) of each product.

$$\sum_{i=1}^{I} \sum_{s=1}^{S} A_{sit} \geq SS_{sit}, \forall t \tag{10}$$

$$\sum_{s=1}^{S} B_{sjt} \geq SS_{sjt}, \ \forall t, j \tag{11}$$

ii. Constrains of capacity of TPK

These constrains are intended to ensure that the timber is allocated to TPK KPH i (Q_{sit}) will not exceed the maximum storage capacity of TPK KPH *i* (K_i), the timber allocated towards TPK IK *j* (Q_{sijt}) shall not exceed the storage capacity of TPK IK j (K_j), and the amount of timber allocated to the warehouse of PGM (Q_{sjkt}) does not exceed the storage capacity of the warehouse PGM (K_k).

$$\sum_{s=1}^{S} Q_{sit} \leq K_i, \ \forall i,t \tag{12}$$

$$\sum_{i=1}^{I} \sum_{s=1}^{S} Q_{sijt} \leq K_j, \ \forall j,t \tag{13}$$

$$\sum_{j=1}^{J} \sum_{s=1}^{S} Q_{sjkt} \leq K_k, \ \forall k,t \tag{14}$$

iii. Constrains of production capacity of KPH, PGM and Furniture Factory

These constarins are intended to ensure that the amount of timber allocated from the timber supplier KPH *(Q_{sit})* does not exceed the production capacity of KPH *(P_i)*, the production amount of of RST in a month on PGM k *(X_{rkt})*, does not exceed the production capacity on PGM k *(P_k)* and the amount of production in a month at the furniture factory *(Y_{plt})* does not exceed the production capacity *(P_l)*.

$$\sum_{s=1}^{S} Q_{sit} \leq P_i, \ \forall i,t \tag{15}$$

$$X_{rkt} \leq P_k, \forall k,t \tag{16}$$

$$Y_{plt} \leq P_l, \forall l,t \tag{17}$$

iv. Constrains of annual allowable cut

Forest management should Perum Perhutani should consider environment, mainly forest sustainability. So the annual harvest plans are based on the amount of Annual Allowable Cut (AAC) that determined by the planning division. So it is necessary to determine the constrain to limit the total harvest for each FMU in one year must be less than AAC.

$$\sum_{t=1}^{T}\sum_{s=1}^{S} Q_{sit} \leq JPT_i, \ \forall i \tag{18}$$

v. Constrains of inventory at the end of period

This constrain is used to ensure that the inventory at the end of a period is sufficient for the need for the next period.

$$\sum_{i=1}^{I}\sum_{s=1}^{S} A_{si} \geq ENDINV \tag{19}$$

$$B_{si} \geq ENDINV_i, \ \forall s \tag{20}$$

ENDINV is the amount of timber in the end of a perid in TPK KPH dan $ENDINV_i$ is the amount of timber in the end of a perid in TPK IK.

vi. Constrains of nonnegativity

These constrains are intended to ensure that the amount of timber allocated in every line is nonnegative.

$$Q_{sit}, Q_{sijt}, Q_{sjkt}, Q_{rklt} \geq 0, \ \forall j,i,t,s,k,l \tag{21}$$

$$X_{rkt}, Y_{plt} \geq 0, \ \forall k,l,t \tag{22}$$

$$A_{sit}, B_{sjt}, C_{skt} \geq 0, \ \forall j,i,k,t \tag{23}$$

IV. Results and Discussions

A. Data Collections

In this research, planning and allocation of raw material inventory conducted for a period of 1 years. Demand of RST and product demand can be seen in Table I. Meanwhile, the production capacity of the factory unit on PGM and Furniture Factory are shown in Table II. Inventory Cost was set at Rp. 320/m^3 of timber that stored and transportation costs is Rp. 2520/km.m^3 of timber.

TABLE I
Demand of RST and Product

	Demand of RST					Demand of Product			
Month	PGM Cepu	PGM Randublatung	KSP IK C	PGM Brumbung	KSP IK B	IK Cepu	KSP IK C	IK Brumbung	KSP IK B
1	127.41	297.32	567.27	101.25	580.41	249.67	226.91	91.56	232.17
2	138.85	266.31	705.56	106.30	1432.31	112.90	282.22	27.35	572.93
3	38.45	48.28	582.77	15.81	997.41	105.77	233.10	84.32	398.96
4	51.05	234.56	901.06	59.31	1494.96	266.90	360.42	45.92	597.98
5	55.48	265.34	826.41	92.08	768.57	442.17	331.30	87.59	307.43
6	31.88	37.72	502.77	187.98	807.06	127.99	201.11	57.39	322.82
7	64.81	157.63	528.33	117.94	832.39	270.49	211.33	54.51	332.95
8	42.92	61.72	956.26	52.51	1114.75	202.77	382.50	47.96	445.90
9	146.24	118.88	388.16	52.69	1162.40	100.06	155.26	26.82	464.96
10	99.27	21.05	880.44	87.76	1284.90	102.98	352.18	42.21	513.96
11	119.83	109.72	523.32	67.73	938.77	506.81	209.33	34.22	375.51
12	82.83	134.72	697.87	264.19	1192.61	203.36	279.15	25.01	477.04

TABLE II
PRODUCTION CAPACITY OF PGM DAN FURNITURE FACTORY

TPK IK	Production Capacity of PGM (m3/month)	Production Capacity of Moulding (m3/month)
Cepu	800	1.000
Randublatung	800	-
IK C	2.000	1.250
Brumbung	800	500

In this study, the determination of safety stock is needed for anticipation of the excess demand in a particular period. Determination of the amount of safety stock begins by calculating the standard deviation of demand during lead time using a formula that developed by [9]. Meanwhile, to aggregate safety stock is using the model developed by [5]. Safety stock at TPK KPH I is determined at 176.88 m^3 and the TPK IK J at 271.07 m^3. Meanwhile, the conversion value of the volume of the finished product to the volume of RST was set at 1.25 and the conversion value of the volume of RST to the volume of logs was set at 2.5.

B. Analysis of Determination of the Safety Stock

So far, the company determines the amount of safety stock based on the needs of the company for 1.5 months. Based on the data obtained from the company found that the average amount of safety stock at KBM TPK TPK KBM Sar and IK, respectively for 8315.59 and 9329.43 m^3/month. While the calculation of safety stock is equal to 176.89 m^3/month proposal for KBM TPK Sar and 271.07 m^3/month for KBM TPK IK. Safety stock value is so much different than the current system. Reduced safety stock is due to the aggregation of the entire request. Aggregation can reduce the amount of safety stock without reducing the value of service level expected. Fig. 2 shows the inventory levels compared to the demand and safety stock planned. From the graph shows that the determination of safety stock, inventory will not experience stockout and the level of inventory each period tend not to be too high. Due to the relative inventory level is lower in each period, so the company can reduce the inventory costs.

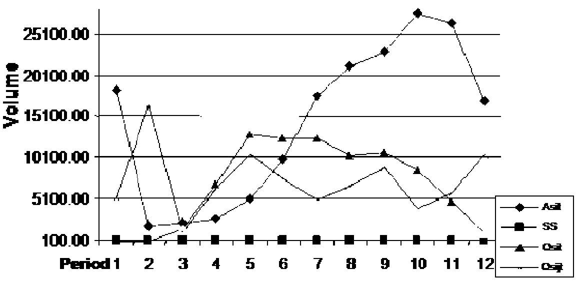

Fig. 2 Comparison between Inventory Level and Safety Stock

C. Analysis of Raw Material Allocation Determination

In the planning of the proposed allocation of raw materials to the proposed model, showed that the largest log AII timber allocation was allocated from Kendal in the amount of 15809.96 m^3. The largest allocation for timber AIII is allocated from KPH Balapulang with volume of 14204.17 m^3 . Total purchase cost of the enterprise system is Rp365,882,495,200.00 whereas the proposed system is Rp289,618,098,085. 49 and resulting in a savings of 20.84%. Total volume of timber allocated to the company's plan is 81, 500 m3, while the proposed plan amounted to 81,209.04. It is reduced by 290.95 m^3 or about 0.36% of the company's plans. Percentage of cost reduction is not proportional to the percentage reduction in volume allocation, so that the main influence in the reduction of the cost of the purchase is to select the right supplier. In planning the allocation from TPK KPH I to TPK IK J (Q_{sijt}) found that timber allocation towards TPK IK Cepu most come from TPK KPH Blora is equal to 2463.69 m3 and KSP IK Cepu came from TPK KPH Cepu is equal to 6093.77 m^3. Timber allocation towards TPK IK Randublatung most come from TPK KPH Randublatung is equal to 8633.40 m^3. Timber allocation towards TPK KBM IK Brumbung most come from TPK KPH Kendal is equal to 1791.98 m^3. Timber allocation towards TPK KBM KSP IK Brumbung most come from TPK KPH Kendal is equal to 17296.98 m^3. Proposed models have a tendency to choose the supplier of raw materials to the relative mileage closer for minimizing the transportation cost.

Comparison sortimen allocation from TPK IK J toward warehouse of PGM K (Q_{sjkt}) with production and stock needed for 12 periods can be seen in Fig. 3. It shows that the planned allocation capable of minimizing the inventory costs. It appears that the level of inventory each period is relatively low so that the cost of inventory can be minimized. This is because the amount timber log s allocation determined by the level of inventory in the previous period. When the inventory is high in the previous period, the allocation in the period will be reduced, and vice versa. Comparison of RST allocation from TPK IK K, towards Furniture factory L (Q_{rklt}) with production needs in the coming months can be seen in Fig. 4. RST amount allocated is determined by demand of product on furniture factory in the next period multiplied by the conversion of the product into RST is 1.25. It appears that the allocation of RST is likely to increase if the needs of the production in the next period also increased.

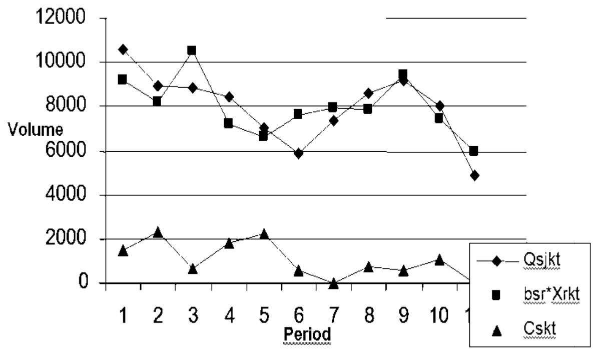

Fig. 3 Comparison between PGM allocation and Production Need

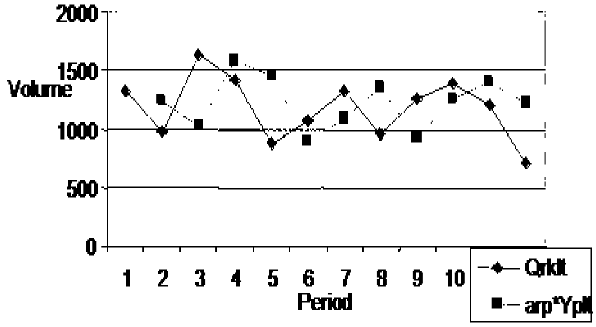

Fig. 4 Comparison between RST allocation to Furniture Factory and Production Need

D. Analysis of Production Quantity

The results of the proposed model calculations show that the largest amount of production RST *(X_{rkt})* is in the 4th period that is equal to 4201.55 m^3 while the smallest is the period of 6th that is equal to 2654.01m^3. Total production of the largest conducted in PGM KSP unit IK Brumbung with the percentage 48.86% of the total production. The number of RST produced is the demand in that period added to the amount RST allocated to furniture factory to provide for production needs in the next period. Thus there is no inventory in the form of RST. The largest production of the product *(Y_{plt})* was in the period 4 in the amount of 1271.22 m^3, while the number of the smallest production occurs in period 6 that is 715.31m^3. The largest production between furniture factories is IK Brumbung with 43.53% percentage of the total production. The number of products produced *(Y_{plt})* is determined by the number of product demand in that period so there is no inventory in the form of finished products.

V. Conclusion

This study has discussed the model of industrial raw material allocation in multi-stage supply chain with the purpose to minimize the cost of purchase, transportation and inventory. The model is developed considering the demand, production capacity, storage capacity and safety stock. Calculation results indicate that the proposed model is able to provide the total cost savings of 20.84% when compared to the model of company policy. The amount of proposed safety stock is proved to reduce the level of safety stock of the company amounted to 97.46% of the determination of safety stock used by the company today.

Further research can be done by considering the production process reliability, because in many practical situations found the fact that the production system does not always produce a good product, but it might result in a defective product. In addition, further research could also focus on developing an integrated decision support system in along the supply chain.

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