Application of MRP and MILP Methods to Prevent Material Shortages in the Gold Jewelry Industry

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Abstract

Along with the development of the Indonesian industrial sector, business competition is increasing, thus demanding increased efficiency in all fields. With this system, one method to accomplish this is through good inventory control planning, which ensures that the production process runs smoothly and that client expectations are satisfied on time and without delay. By utilizing the Material Requirement Planning (MRP), Mixed Integer Linear Programming (MILP) and Reverse Logistics Methods, this study assists firms in avoiding the danger of excess or shortage of raw materials. Using these approaches, the company can avoid the problem of raw material shortages. The study will use data from February to April 2022. Based on the research results, optimal results were obtained in planning gold supplies, namely the MRP method with a yield of 51,396 kg, followed by the Exponential Smoothing method with a yield of 36,467 kg and the MILP method with a yield of 30,983.7 kg. As for the large effective gold stock, modeling mathematics can be used to minimize total production costs. As a result, production costs were reduced by IDR 600,000,000.00.

Keywords

Material Requirement Planning, Mixed Integer Linear Programming (MILP), Reverse Logistics, Inventory.

1. Introduction

The rapid development of the times encourages companies to be more complex. The complexity of raw material inventory is one of them. In addition, companies use methods, technology, money, materials, people and markets as examples of resources. Inventory is defined as goods, including raw supplies, process of working, ancillary items, and for a specific amount of time-stored supplements. Inventory control is defined as a collection of procedures that specify the minimum amount of supply that must be kept on hand, the timing of orders for adding inventory, and the size of orders that must be placed. Material Requirements Planning (MRP) is one method for inventory control.

Traditional MRP and MILP models usually do not take into account the effects of product returns being carried through Reverse logistic on goods inventory. Reverse logistics is the act of transporting products backwards from one location to another with the aim of getting back the value or carrying out the proper processing of the remaining product. Especially for the gold jewellery industry, Reverse Logistic has a goal to recover value as an additional raw material. The return flow of goods affects inventory levels and the overall cost of stock, so that has to be taken into account when analysing an inventory system. The advantages obtained from the system Reverse Logistic is to increase customer satisfaction and decrease inventory levels and reduce costs. In the gold jewellery industry, the return of goods from consumers is not only influenced by the smooth or slow-moving sales conditions, but also by the payment mechanism. In addition, the company experienced material shortages which occurs in the first week of April. In the fourth week of March 2022 the company begins to merge inventory items that are slow moving as well as returned goods from consumers, so that in the first week of April there was an increase in raw material inventories.

Payment mechanisms affect the return of goods from consumers. Payments from shops are generally permitted in gold bars. When payment is due, merchants can choose to pay in cash or gold bars in the amount of the conversion price per gram on that day. This affects the condition of gold availability for suppliers. The image below describes a flowchart of the shop's mechanism for making gold returns as a form of payment. Apart from that, material shortages or supplies of melted materials must be prevented. Therefore, the authors are interested in analysing the direct impact of the MRP and MILP methods as well as Reverse Logistics to prevent material shortage problems from knowing the number of orders for raw materials that must be obtained and knowing the minimum and maximum quantities of raw material supplies.

1.1 Objectives

This research specifically discusses a company in the gold jewellery industry as an object. Operationally the company has not implemented the method Material Requirement Planning (MRP) and Mixed Integer Linear Programming (MILP) technically for inventory control. This results in a temporary shortage of raw supplies. when there are not sufficient raw materials, the company implements a mechanism of reverse logistic. In order for the research to be more specific and accurate, a research limitation consisting of research objects is inventory management in the gold jewellery industry, stakeholder involved in the model are supplier and customer, the owner of the problem is a gold manufacturing company in Indonesia, the data used is from February to April 2022, and data processing and analysis uses the POM-QM application (Publication Operation Management Quantitative Methods).

2. Literature Review

Inventory of raw materials should not be too small or too large. manufacturing operations may be hampered by a lack of raw materials; a stall in the manufacturing process will almost likely have an impact on sales resulting in the company's inability to meet consumer demand (Sakkung et al. 2011). This in turn has an impact on company profits and consumer confidence. In general, all firms engage in material planning and management with the intention of minimizing costs and increasing revenues within a predetermined time frame. The main problem in organizing and managing raw materials is managing the most appropriate supply of raw materials so that production activities are not interrupted, and the money spent on supplies is not exorbitant (Fahmi, 2018). To ensure a company's manufacturing runs smoothly, inventory control involves determining the assembly level and composition (parts) of inventory components, raw materials, and completed goods/products and sales processes as well as the learning needs of the company effectively. and efficient (Assauri, 2008). The raw inventory control process can use the Material Requirement Planning (MRP) method. Method Material Requirement Planning (MRP) is a way to determine what, when, and how much material is needed in the production plan needs. In general, the purpose of implementing MRP is to obtain a balanced company condition in terms of demand for raw materials and use of raw materials for production. The implementation of MRP that is carried out properly is the basis for optimal management of raw material planning systems by minimizing inventory, increasing efficiency, and maximizing services. Using MRP can also increase the efficiency of each company's operational units involved in the production process because everything is well planned. and can be implemented according to the target through the monitoring process. Companies that implement MRP can calculate the optimal time for part of their duties from the start of the production process to marketing and delivery so that customer service can be maximized. As opposed to that, the application of MRP in the field has problems where the relationship between resource utilization (production capacity) and lead time not considered carefully. This results in immature planning where there is a workload that fluctuates or exceeds working time capacity. This problem can be overcome by combining the MRP method with the approach mixed integer linear programming (MILP). The combination of the MRP and MILP methods allows calculations net requirement of all finished goods, semi-finished goods, and raw materials for all times in the MRP process. Whereas the MILP process allows the calculation of orders for all finished goods and semi-finished goods at any time not to exceed production capacity, can reduce storage costs, and exceed net requirements.

When a company does not implement inventory control properly, at some point, a shortage of raw materials may occur and disrupt the production process to distribution. To overcome this problem, it can be done reverse logistic by merging inventory items that are of a natures low moving. Reverse logistics is the method of organizing, carrying out, and managing the effective and economical movement of basic supplies at the spot of utilization to the site of creation in order to modify production conditions to meet consumer demands (Waites, 2015; Khor et al., 2016; Rogers et al., 1998).

Because the number of raw materials and raw materials for production is not always as planned, every company must have safety stock. Safety stock is a reserve inventory that must be maintained so that there is no shortage or run out of raw materials, especially gold. According to the results of company interviews, the company does not have safety stock. The results of this study will then be used to determine the amount safety stock required. POM-QM software is software operation research which is used to solve quantitative problems in the field of production and production management in terms of solving research operations problems. Main benefits software This is in terms of support for decision making and forecasting (forecasting). For example, in determining the appropriate combination of production in order to produce optimal profits. To determine which method to use, a comparison of methods is carried out. Technique lot sizing. The method used is the MRP method Lot For Lot (LFL). The technique is a technique lot sizing the simplest. The order is made taking into account the emphasis on saving cost. Net satisfaction of requirements takes place at each period that calls for it, but the order quantity is big (lot size) compared to the number of net needs that must be satisfied within the given time. This technique is usually used for items that have value the high or demand continuity tall one. However, the MRP method has a lack of production capacity and value constraints lead time predetermined. In the end, production practitioners decide lead time with the maximum value that can result in excessive working time inventory. Therefore, do the method Mixed Integer Linear Programming (MILP). Furthermore, a comparison is made for the two methods so that the company can choose the most efficient method to determine when and how much unprocessed product should be ordered in order to avoid material shortages.

3. Methods

This research used the MRP and MILP combination method, while the data processing and analysis used the POM-QM application. In the MRP method, lot sizing the proposed method is Lot for Lot (LFL). This LFL technique uses the concept of ordering which is carried out with the consideration of minimizing the cost of storage according to the net need. The size of lot size each period according to its net requirements (Net Requirements). With this method, net requirements are satisfied at each necessary time, and the amount of the order is the same as the net needs that have to be satisfied during the relevant period. This approach minimizes storage costs. With the application of MRP which is applied by combining the MILP method, order calculations can be carried out more optimally.

POM-QM software is an alternative application software to help a company make decisions such as determining when and how much material is needed to produce an item and also being able to predict the maximum profit. In operation, stock data and on data are collected, then Exponential Smoothing calculations are carried out. Exponential Smoothing is taking the average value of several periods to estimate the value of a period. The exponential smoothing equation is:

$$St + 1 = \alpha Xt + (1 - \alpha)\, St$$

Then an error evaluation is carried out to assess the level of accuracy with the formula:

$$MAPE = 100 \left[\frac{\sum_{i=1}^{N} \left| \frac{A_i - P_i}{A_i} \right|}{N} \right]$$

Forecast Error and Mean Absolute Deviation (MAD) calculations are also performed. MAD is one way that can be used to find out the size of forecasting errors. MAD stands for Mean Absolute Deviation. MAD is the average of the absolute deviation values. The MAD calculation formula is (Baktiar, 2015):

$$MAD = \frac{\sum_{t-1}^{n} |Y\,(t) - Y'(t)|}{n}$$

The last is analysis Forecasting Gold Stock Use Software POM-QM, divided into three Steps, the first is the analysis of the MRP method with instructions:

a) Item name breakdown is adjusted accordingly Bill of Material, adjust level work to be defined as input in the POM-QM software
b) Customize data lead time, on hand inventory and lot size to be inputted for each item Bill of Materials. Data lot size equated with level on Bill of Materials
c) Enter data minimum quantity based on data gold stock February-April multiplied by the value lead time
d) Enter data on hand inventory for 6 periods or 6 weeks for each item Bill of Materials
e) After all the data is inputted, click the solve button to show the forecasting results

The second step is the analysis of the Exponential Smoothing method with the instructions:

a) After the results of forecasting using the MRP method are obtained, the analysis's conclusions of the MRP method are accumulated to become a total gold stock per week to be continued with analysis using the exponential smoothing method.
b) Define module tree pada section exponential smoothing with trend
c) Enter the gold stock data resulting from forecasting based on the MRP method for 6 periods or 6 weeks
d) Adjust the alpha variable for smoothing, use the number 0 to be adjusted automatically by the POM-QM software
e) After all data is inputted completely, click solve to display the forecasting results using the exponential smoothing method

And, the final step is the analysis of the MILP method

a) Use the same data as the data used for the exponential smoothing analysis, namely data from forecasting gold stock from the MRP method
b) Define module tree pada section linear programming
c) Enter gold stock data from MRP forecasting results for 6 periods or 6 weeks
d) Click solve to display forecasting results using the MILP method

4. Results and Discussion

The main objective of the application of the MRP method is to get a balance for the company in terms of demand for raw materials and the use of raw materials for production. Table 1. below is the result forecasting gold stock using the MRP method.

Table 1. Gold Stock Forecasting Results with the MRP Method

Item Name (low level)	Pd0 and before	Pd1	Pd2	Pd3	Pd4	Pd5	Pd6
Gold(0)							
Gross REQ		47466	20279	11598	73416	48854	29299
ONHAND	51622	51622	4156				
SchdREC							
NET REQ			16123	11598	73416	48854	29299
PlanREC			16123	11598	73416	48854	29299
ORD REL		16123	11598	73416	48854	29299	
Balance CMK(1)							
Gross REQ		16123	11598	73416	48854	29299	
ONHAND	25207	25207	29590	22333			
SchdREC		20686	4341	1754	13989	1044	
NET REQ				49329	34865	28255	
PlanREC				49329	34865	28255	
ORD REL			49329	34865	29255		
Balance SKK(1)							
Gross REQ		16123	11598	73416	48854	29299	
ONHAND	7985	7985	11445	12176		4458	17963
SchdREC		7985	12329	9844	53312	42804	42579
NET REQ		153		51396			
PlanREC		11598		51396			

Item Name (low level)	**Pd0 and before**	**Pd1**	**Pd2**	**Pd3**	**Pd4**	**Pd5**	**Pd6**
ORD REL			51396				

From the table above, CMK and SKK balance data are used, which are two jewelry factories as research objects. Description Gross REQ indicates the initial data before forecasting, which is used as a template as data demand, while the ORD REL column is the result data forecasting each week it takes to fulfill demand. The On Hand data is an inventory item dead stock or slow-moving remelting is carried out to increase the amount of inventory. The Schedule Receipt column is inventory data that will be received in a certain period based on orders previously made. Considering the outcomes of the MRP analysis, the minimum gold stock value obtained was 29.255 Kg in the 4th week and the maximum value was 73.416 Kg in the 3rd week. The most effective value as a reference gold stock namely in the 2nd week of 51.396 Kg which can fulfill demand in the 3rd week of 73.416 Kg.

Method forecasting next is used exponential smoothing. Its application is by taking the average value of several periods to estimate the value in a period. As for the results forecasting gold stock shown in Table 2. following with data demand weekly presented in the first column after the column week.

Table 2. Gold Stock Forecasting Results with the Exponential Smoothing Method

Week	**Demand**	**Forecast**	**Error**	**Cum-Error**	**Cum abs error**	**Cum Abs**	**MAD**	**Track Signal**	**Error%**
Past Period 1	47466								0,00%
Past Period 2	20279	47466	-27187	-27187	27187	27187	27187	-1	2,34%
Past Period 3	11598	42300,5	-30702,5	-57889,47	30702,47	57889,47	28944,7	-2	3,65%
Past Period 4	73416	36467	36949	-20940,47	36949	94838,47	31612,8	-0,662	0,50%
Past Period 5	29299	43487,3	-14188,3	-35128,78	14188,31	109026,8	27256,7	-1,289	1,48%
Past Period 6	11598	40791,5	-29193,5	-64322,31	29193,53	138220,3	27644,1	-2,327	3,52%

Based on the Table 2, the results are obtained forecast which is a calculation of demand adjusted for an alpha value of 0.5. Results forecast will be used as a template in making graphics. There is value error indicates a large deviation between the results forecast with demand. The data from the table shows that percentage error of results forecasting quite low. Next, the value in the MAD column is displayed which is the average value of the value's absolute deviation (value absolute from column error). The most effective value is taken from the data error the lowest (0.50%) namely in the 4th week with a total gold stock (refinery) of 36.467 Kg. This result is also followed by a value gold stock minimum which is also in the 4th week of 36.467 Kg. Forecasting is presented as a graph in Figure 1. below.

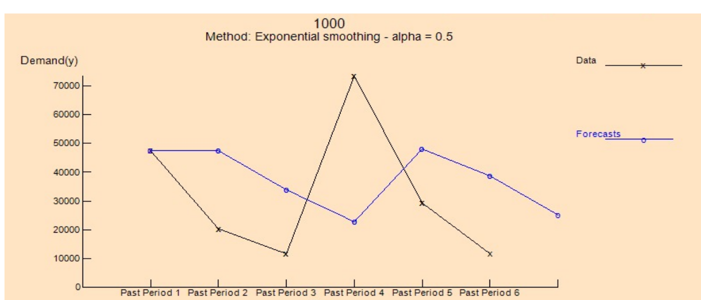

Figure 1. Graph of Gold Stock Forecasting Results with the Exponential Smoothing Method

Forecasting gold stock, the next step is to apply the MILP method. This method is a quantitative modelling in the form of an integer linear programming model whose main objective is to obtain optimization for a particular purpose. The desired result is a more optimal calculation of orders. Table 3 displays the forecasted results. below.

Table 3. Results of Gold Stock Forecasting with the MILP Method

Week-	Demand	Forecast	Error	Cum-Error	Cum abs error	Cum Abs	MAD	Track Signal	Error%
Past Period 1	47466	38737,6	8728,43	8728,43	8728,43	8728,43	8728,43	1	0,82%
Past Period 2	20279	36152,9	-15873,9	-7145,512	15873,94	24602,37	12301,2	-0,581	1,78%
Past Period 3	11598	33568,3	-21970,3	-29115,82	21970,31	46572,68	15524,2	-1,876	2,89%
Past Period 4	73416	30983,7	42432,32	13316,49	42432,32	89005	22251,3	0,598	0,42%
Past Period 5	29299	28399,1	899,945	14216,44	899,945	89904,95	17981	0,791	0,97%
Past Period 6	11598	25814,4	-14216,4	0,01	14216,43	104121,4	17353,6	0	2,23%

Table 4. Advantages of Using the MILP Method

Measure	Value	Future Period	Forecast
Error Measures		7	23229,8
Bias (Mean Error)	0,002	8	20645,17
MAD (Mean Absolute Deviation)	17353,56	9	18060,54
MSE (Mean Squared Error)	4,69E+08	10	15475,91
Standard Error (denom=n-2=4)	26524,9	11	12891,28
MAPE (Mean Absolute Percent Error)	78,26%	12	10306,66
Regression line		13	7722,027
Demand(y) = 41322,2		14	5137,398
-2584,629 * Time		15	2552,77
Statistics			
Correlation coefficient	-0,2		
Coefficient of determination (r^2)	0,04		

Table 4. shows the advantages of using the MILP method which can be aimed at forecasting long-term. In this research, forecasting with the MILP method used until the 15th week. The MSE column displays the value of the number of result deviations forecast with demand which is squared. The MAPE description shows the percentage of accuracy forecasting which from the research obtained a value of 78.26% so that it can be said to be quite accurate. For the maximum value in the 1st week of 38.737 Kg, while the minimum value obtained is in the 6th week of 25.814 Kg. As for value forecast the most effective is taken from the lowest error percentage, namely in the 4th

week of 0.42% with total gold stock (refinery) of 30,983.7 Kg. Figure 2. below shows a graph of the results forecasting with the MILP method.

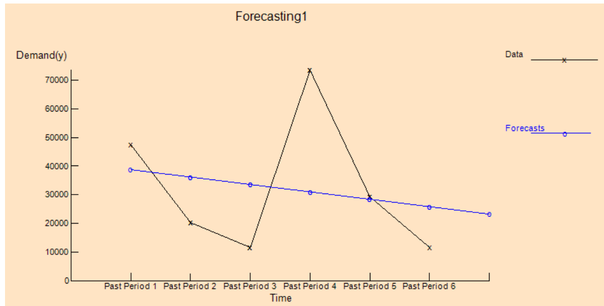

Figure 2. Graph of Gold Stock Forecasting Results with the MILP Method

The production process involves simultaneous back and forth movement. This includes collecting and returning gold from customers, procurement activities, and recycling of gold from suppliers. All of these activities impact the movement of gold materials and significantly affect the production planning process. In this proposed model, forward and backward material flow is considered. This includes internal processes such as recycling, reuse and repair, also including outside procedures like reprocessing dependent on suppliers, returns and customer collection, all of which involve gold as a raw material. Minimizing the total cost of production is one of this model's primary goals. The mathematical modelling used is formulated as follows.
Equation 1

$$\sum_{p=1}^{P}\sum_{t=1}^{T}(cp_u\,Prd_{pt} + ci_u\,Inv_{pt} + cdb_u\,Bd_{pt}) * g_p \quad (1a)$$

$$+ \sum_{j=1}^{J}\sum_{t=1}^{T}(cuc_j\,Ucr_{jt} + coc_j\,Ocr_{jt}) \quad (1b)$$

$$+ \sum_{i=1}^{I}\sum_{t=1}^{T}[(crr_i + crl_i) * Rcy_{it} + cru_i\,Reu_{it-Rup_i-1}] \quad (1c)$$

$$+ \sum_{p=1}^{P}\sum_{t=1}^{T}\left(cc_p\;Rcrt_{pt} + cr_p\;Rprt_{pt} + ci_p\;Rt_{pt}\right) * g_p \quad (1d)$$

$$+ \sum_{i=1}^{I}\sum_{t=1}^{T} cobl_i\,Bols_{it}. \quad (1e)$$

Information:

Prd_{pt} : *quantity to production* from *product* “p” n period “t.”

Inv_{pt} : *inventory* from *product* “p” at the end of the period “t.”

Bd_{pt} : *demand backlog* from *product* “p” at the end of the period “t.”

g_{ip}: *required quantity* of raw materials “i” to produce a unit *product* “p”, i=1 for gold so it can be denoted as

cuc_j : *unused capacity unit cost* from *resource* “j.”

Ucr_{jt} : *unused capacity* from *resource* “j” in period “t.”

coc_j : *overtime capacity unit cost* from *resource* “j.”

Ocr_{jt} : *overtime capacity* from *resource* “j” in period “t.”

crr_i : *recycle cost* of a unit of raw material “i.”

crl_i : *recycle-lost cost* of a unit of raw material “i.”

Rcy_{it} : *recycle quantity* of raw materials"i” in period “t.”

cru_i : *reuse cost* of a unit of raw material”i.”

Reu_{it}: *reuse quantity* of a unit of raw material”i"in period"t.”

Rup_i : *reuse period* of raw materials"i.”

cc_p : *variable cost of recycle* of a product unit$p$.”

$Rcrt_{pt}$: *quantity to send reusing process* of returned goods$p$"in period"t.”

cr_p : *variable cost of reprocess* of a product unit$p$.”

$Rprt_{pt}$: *quantity to remanufacture* of returned goods$p$"in period"t.”

ci_p : *inventory cost* of a product unit$p$.”

Rt_{pt}: *quantity returned* of the product"p"at the end of the period"t.”

$cobl_i$: *over balance cost of suppliers* for raw materials"i.”

$Bols_{it}$: *over balance limit of suppliers* for raw materials"i"in period"t.”

From the modeling above, Equation (1) has five terms that describe the overall manufacturing cost that must be minimized. Terms (1a) and terms (1b) symbolizes the costs of ordering, producing, stocking, and using resources. In addition, when raw material supply, recycling, and remanufacturing costs are added to the model, backward production flows are integrated into it. Term (1c) denotes the cost of recycling and reuse of raw materials. Term (1d) denotes the cost of returning, recycling, and remanufacturing the product. The cost of supply is represented by term (1e), which maintains a balance between supply and reuse, recycling, and remanufacturing while taking the cost of supply into consideration. Given that all cost coefficients are expressed as a ratio of production quantities in units of gold, terms (1a) and (1d) include products with the notation *gp*. The golden amount has been specified as the choice variable in terms (1a), (1d), and (1e). The objective is to keep these expenditures overall to a minimum. The mathematical modeling includes the sum of production value, inventory, capacity utilization, recycling expenses, reuse costs, loss and remanufacturing costs, and raw material procurement costs (Figure 3). The basic objective is to reduce these expenditures overall. In the application of mathematical modeling in this study, variables are used inventory and recycled materials as a limitation. Next will be shown the results of applying mathematical modeling to reduce the overall cost of manufacture.

```
Production_Optimization:
MINIMIZE
151448.4*RecycleQuantityRaw + 1.0
SUBJECT TO
_C1: 1900 QuantityToManufacture + 61499 ReturnedQuantityProduct
 - 40790 ReusedRecycleRaw = 1

_C2: - 42099 InventoryOfTheProduct + 1.4 RecycleableQuantityWaste
 + 35.7 RequieredQuantityRawMaterial + 1.3 ReusableQuantityScrap
 - 40790 ReusedRecycleRaw = 0

_C3: UnusedCapacity >= 0

_C4: OvertimeCapacityResource >= 0
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Figure 3**.** Results of Application of Mathematical Modeling to Minimize Total Production Cost

5. Conclusions and Future Research

In this study, optimal results were obtained in planning gold supplies, namely the MRP method with a yield of 51.396 kg, then the Exponential Smoothing method with a yield of 36.467 kg (Percentage of error = 0.50%) and the MILP method with a yield of 30,983.7 kg (Percentage of error = 0.42%). In addition, good inventory planning can keep the continuity of the production process running smoothly so that it can be further elaborated using the goal of reducing the total manufacturing expenses through mathematical modelling. Based on the results of mathematical modelling using two constraints, namely Inventory and recycle raw materials, it is proven that the total production cost can be minimized from the initial Rp. 4,665,017,750 (4.67 billion) to Rp. 4,079,000,000 (4.07 billion).

In this study, the researcher also added a few suggestions for further research. Adding variables that are related in order to develop existing mathematical models. Among others:

a. cobl$i$: over balance cost of suppliers for the raw material "i."
b. cdb$p$: backlogged demand cost of a unit of the product "p."
c. cuc$j$: unused capacity unit cost of the resource "j."
d. coc$j$: overtime capacity unit cost of the resource "j.
e. Bls$i$: supplier balance limit of the raw material "i."
f. B$si0$: supplier balance of the raw material "i" in period "t."
g. Bdpt: demand backlog of the product "p" at the end of period "t."
h. And others

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