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Optimal Production Planning in Wiring Harness Assembling Process Using Mixed Integer Linear Programming

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***Abstract*— This study propose a real case of production planning in industry to face the uncertainty demand by optimizing the available resources to minimize the cost of production in wiring harness assembling process. Aggregate production planning is a tool to balancing uncertainty demand and available resources in short-medium term planning horizons. CV. XYZ is a subcontract company which engaged in wiring harness assembling process. Wiring harness is the wiring and power distribution system for the transmission of electric power and signal in automotives. This study use Mixed Integer Linear Programming (MILP) as a tool process to optimize the production plan. MILP is a method of mathematic program to achieve the optimal goal with the limits of available resources. This method allows researcher to optimize the production planning in wiring harness assembling process. Variable work time hour, the amount of man power used and inventory are the focus of this study. Result from this optimation model, by increasing the number of employees, it can minimize the total production cost in wiring harness assembling process by 0.4% from Rp. 2,043,458,430 to Rp. 2,036,236,800 or decrease Rp. 7,221,630 over 12 month planning period**

Keywords*— Production Planning, Optimization, Wiring Harness, Mixed Integer Linear Programming (MILP).

I. INTRODUCTION

This study is an example of a real case of production planning to minimize the cost of wiring harness assembling process. Wiring harness is the wiring and power distribution system for the transmission of electric power and signal in automotives. The difficulties in wiring harness assembly depends on the number of cables and component required. Each process has a variety of additions process depends on the type of component used.

Wiring harness orders had fluctuating demand in a certain period, causing an imbalance between orders received and available resources owned by the company. Required the optimal production planning to balance the demand and company's supply by optimizing the available resources.

The purpose of this study is to create an optimal production planning to minimize the production cost in wiring harness assembling process with variation of man power required, overtime hour and inventory. This study is using Mixed Integer Linear Programming (MILP) as a model formulation to solve this problem.

II. LITERATURE REVIEW

Aggregate production planning (APP) is a tool process in order to balance uncertainty demand and the available resources in short-medium term planning horizons. APP can minimize the cost of production or increase company revenues in their objective function (Chase, et al., 2006). APP can be implemented in various ways with the conditions and situation in the company by doing customer demand quantity analysis, fulfillment schedule, material availability, production capacity as well as other resources. In the management factory, a production manager must take a right decision of production planning for the coming period (Siswanto, 2006).

Buxey (2005) described that in APP there are some strategies can be done to meet customer demand and company's supply. Labor strategic and inventory levels are the most frequent choices taken by company. Using labor strategic will cause low inventory levels, make inventory holding cost to be low but the labor cost is higher. Liu & Tu (2008) described that by increasing inventory levels can balance customer demand and avoiding loss of sales, but inventory cost may increase. Reversely, if the company doesn't have or lack of inventory, will cause service to the customer not optimal.

Various methods have been developed in the previous aggregate production planning. Tang, et al. (1981) proposed a study of aggregate planning in the heavy equipment industry by using basic model of linear programming to minimize the production cost. Vercellis (1991) proposed model simulation scenario strategies can be done in APP. Production levels, inventory levels, or the combination of both strategy has been simulated to minimize the production cost. Nam & Longendran (1992) tried to classified any APP models into 2 group model, these are optimal model and near optimal model. Optimal model is a model that use exact mathematic programming to solve APP. Near optimal model is approach model based on Opinion Company's top management or an expert. Takey & Mesquita (2006) explained that in APP, mathematic model has important role in balancing supply and demand as to help managers take production planning decisions.

In a competitive competition, industry players must make their operation efficiency in allocation their available resources. Liu & Tu (2008) developed stockout model to balancing demand and supply in limited inventory integrated

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with algorithm polynomial time complexity model. Leung & Chan (2009) formulated goal programming model to increase company revenues with limited available resources. In Goal Programming, these are more than one objective functions to be achieved by giving weight to the each objectives. These weights mean that every objectives have a priority to be achieved. Leung & Chan (2009) provides first objective is to increasing sales profit, second objectives minimize maintenance cost, and last priority objective is to optimizing machine utilization. Al-e-hashem, et al. (2011) developed robust optimization models integrated with integer programming for multi product which had production in different places. In the same year Aghezzaf et al. (2011) also developed robust optimization model for the product which has 2 stages of production, where the first product or semi finish product is a product that has a relatively stable demand, and the second product or finish goods is a product which has fluctuating demand. More complexity of customer demand which had flexibility in delivery time studied by Al-e-hashem et al. (2013), he developed stochastic model integrated with linear programming for the multi product which has production in different places. Gansterer (2015) developed APP model to increase service level in Make to Order (MTO) industry.

III. PROBLEM DESCRIPTION

CV. XYZ is a subcontract company which engaged in wiring harness assembling process that will be supplied to the Automotives industry in Indonesia. Wiring harness is the wiring and power distribution system for the transmission of electric power and signal in automotives. The company was located in Bekasi, West Java. The company product is a component of wiring harness which is each type of product had different processing time and different amount of employees required in the assembling process.

As informed before that the products had a different processing time and amount of employee required, caused by orders received had a different process. To anticipate this problem, CV. XYZ had 2 plant where the first plant is to perform the assembling process, and the second plant is devoted to the process cutting and crimping. CV. XYZ divided their employees into several group based on the similarity of the use number employees needed. CV. XYZ had 4 group to perform the assembling process. Group A, B, C had a particular specialization in the assembling part number variants. While group D, is a special group to cut the wire which had a specific length.

As an assembly company, CV. XYZ is highly depend on the availability of their human resources in the assembling process. Appendix 1 is the CV. XYZ Monthly Delivery Realization. From the Appendix 1, by dividing the quantity with daily production capacity, we got the total working day needed of each group followed by the availability working days in each month.

For example in July 2016, the entire production in group A can only be resolved in 10 days, which meant that group A only had the effective 10 working days from 21 normal working days in a month. While the 11 rest days, they will be off. Of course this leads to the waste of resources. But in other months, working hour group A exceed the regular time, so it should go beyond the regular working time 21 working days within one month, it will make overtime increased. To anticipated the problem, CV. XYZ make overtime strategy to meet the exceed demand in certain months, and trying to allocate resources to help groups that had a exceed demand.

The imbalancement between the orders and the availability of the resources in certain periods led the company to improve their production planning as to improve their corporate profitability. It required balancing the customer demand and company's supply by optimizing the availability of existing resources. Overtime hours, the amount of labor (workforce) needed and stock (inventory) are the focus in this study, where the combination of these strategies will be compared with the company current strategy, which only using the strategy of working hours (overtime). This purpose is to obtain the optimal strategy to minimizing the cost of production in the assembling process.

IV. METHODOLOGY

A. *Research Framework*

In this research, the first step is to identifying the problem and to undestanding all the constraint in the company. The flow research is illustrated in figure 1 as attached below.

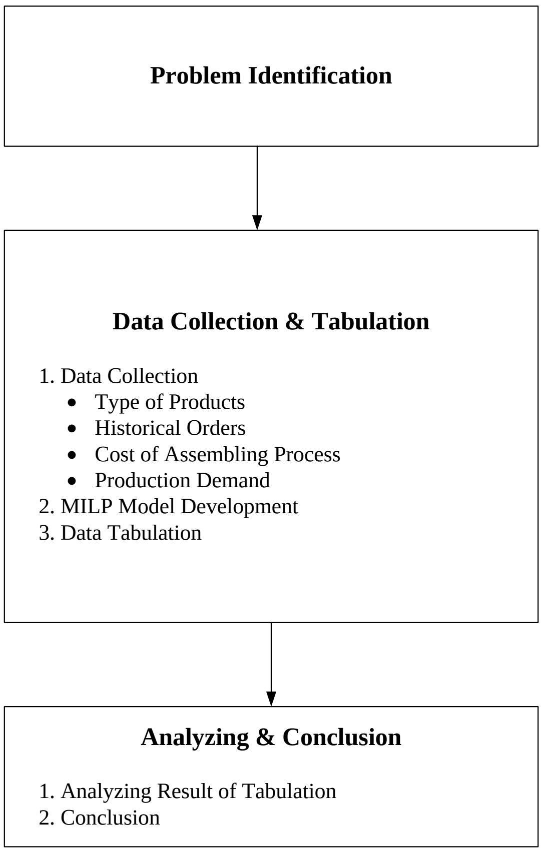

Figure 1. Research Flowchart

All data in this study were obtained from the company's books and also from doing interviews with the employees. These data have been specified as follows:

1. Types of Product

   There are 12 kind of main products CV. XYZ will be the subject in this study. Nine product is an assembly product, 3 product is a cutting product. Any products had different employee needed and different processing time.

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2. Cost of Assembling Process
   The cost of assembling process in this study is the operational cost and inventory cost. Operational cost including packaging cost, administration cost, transportation cost, labor cost, and monthly cost (water & power bills). These costs are very influence into the operational performance of the wiring harness assembling process. As a subcontracting company, CV. XYZ doesn't have cost of raw materials. Cost of raw materials are charged to the customer.
3. Assets Cost
   Assets cost is the cost of covering aspects of the equipment and the property. This cost is also a critical. Without assets cost, production activities cannot be performed. Assets cost include the cost of buildings and equipment cost.
4. Demand / Production Needs
   Production demand was generated from the historical data during previous 9 month production. These data then processed into the company's production targets for next 12 month planning. This production demand is adapted to company production target as to input for next 12 month planning.

B. Model Development

The selection model is taken based on the company's problem and constraint. This model adapted from Takey & Mesquita (2006) which is using Mixed Integer Linear Programming (MILP) as a model to generated APP. This model had a variation in overtime hour, workforce, subcontract and inventory. These variables have a similarity with the company's problem. Bit development model in this research is the model formulation in the requirement of working hour employees, where the process of assembling wiring harness had different process time and employees needed, deep formulation in inventory model where the component of wiring harness stored in a box, each box had the ability to store a components due to the size of the part number of components. And also elimination of subcontract strategy, because CV. XYZ is a subcontract company.

Index
i : Types of Product (12 part number)
t : Periods (12 Bulan)

Decision Variables
X_{it} : Quantity of product i during reguler time hours in t period (unit).
Y_{it} : Quantity of product i during overtime hours in t period (unit).
I_{it} : Amount of inventory product i in t period(unit).
W_{it}: Reguler time hours needed for product i in t period (man-hour).
U_{it} : Overtime hours needed for product i in t period (man-hour).
H_t : Amount of man power hired in t period (man).
F_t : Amount of man power fired in t period (man).
Man_t: Total of man power used in t period (man).

Parameters
D_{it} : Demand product i in t period (unit).
m_i : Operational & overhead cost except labor cost product i (rupiah per unit).
l_i : Cost of holding product i (rupiah per unit).
w_i : Cost of labor in reguler time product i (rupiah per man-hour).
u_i : Cost of labor in overtime product i (rupiah per man-hour).
b_i : The box ability to store product i (unit).
$Mbox$: Available / Maximum box allowable due to limited space constraint (unit).
h : Cost of hiring new employees (rupiah per man).
f : Cost of firing employees (rupiah per man).
p_i : Processing time for each product i (man-hour per unit).
AvR_t : Available reguler time hours in t period (hour).
AvO_t : Avaialble overtime hours in t period (hour).
Max: Allowable total man power used (man).

Objective function:

$$\min z = \sum_{i=1}^{m=12}\sum_{t=1}^{T=12} m_i.(X_{it}+Y_{it}) + \sum_{i=1}^{m=12}\sum_{t=1}^{T=12} l_i.I_{it} + \sum_{i=1}^{m=12}\sum_{t=1}^{T=12} w_i.W_{it} + \sum_{i=1}^{m=12}\sum_{t=1}^{T=12} u_i.U_{it} - \sum_{t=1}^{T=12}(h.H_t + f.F_t) \quad (1)$$

Constraint:

$$I_{it} = I_{i(t-1)} + X_{it} + Y_{it} - D_{it} \quad (2)$$

$$\sum_{i=1}^{m=12} \frac{I_{it}}{b_i} \le Mbox \quad (3)$$

$$p_i X_{it} = W_{it} \quad (4)$$

$$p_i Y_{it} = U_{it} \quad (5)$$

$$\sum_{i=1}^{m=12} W_{it} \le AvR_t \ x \ Man_t \quad (6)$$

$$\sum_{i=1}^{m=12} U_{it} \le AvO_t \ x \ Man_t \quad (7)$$

$$Man_t = Man_{t-1} + H_t - F_t \quad (8)$$

$$Man_t \le Max \quad (9)$$

$$Man_t \ integer \ non \ negatives \quad (10)$$

$$S_{it}, X_{it}, Y_{it}, I_{it}, H_t, F_t, W_{it}, U_{it} \ non \ negatives \quad (11)$$

The objective function (equation 1) is to minimize the production cost of wiring harness assembling process include product operational cost (regular and overtime), product inventory cost, workforce cost (regular and overtime), hiring and firing cost.

Equation 2 to 13 is a constraint of mathematic model, where the equation 2 is a material flow balance that inventory is equal to the amount of products in regular and overtime, plus inventory in previous month, minus the demand during t period.

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Equation 3 determine that product i stored in box cannot exceed the allowable maximum box. Due to limited space available.

Equation 4 determine the worktime hour needed for product i under regular time by multiplying processing time and amount of product i under regular time condition.

Equation 5 determine the worktime hour needed for product i under overtime by multiplying processing time and amount of product i under overtime condition.

Equation 6 determine the total of worktime hour under regular hours time cannot exceed the available reguler time hours during t period. Equation 7 determine the total of worktime hours under overtime hours cannot exceed the available overtime hours during t period.

Equation 8 balancing the number employees used in each month, considering the hired and fired worker. Equation 9 restrict the uses of man power used cannot exceed the allowable man power used.

Equation 10 indicated that during planning, amount of man power used is a integer. And equation 11 indicated that amount product in regular and overtime hour, inventory, hiring and firing are non negatives.

V. RESULT

The data was generated with software lindo 6.1. In this study, researcher did a comparation between current company strategy (overtime and fixed man power used) compare to alternative strategy (overtime, flexibility of man power used, and inventory) to obtained the best strategy to minimize the production cost of wiring harness assembling process.

Summary output from lindo programming can be seen in Appendix 4. The output show that the alternative strategy resulted in lower production cost than the company current strategy. Production cost is decline by 0.4% from Rp. 2,043,458,430 to Rp. 2,036,236,800 or decrease Rp. 7,221,630 over 12 month planning period.

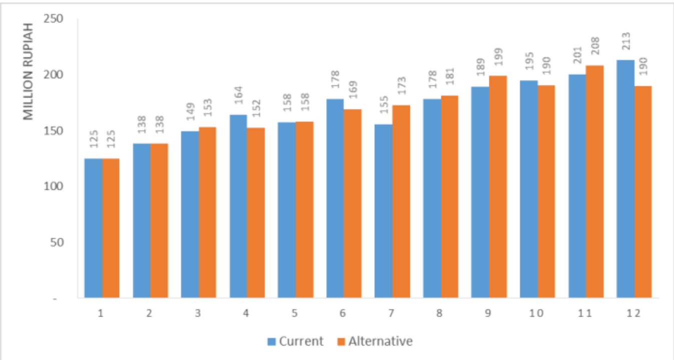

Figure 2. Wiring Harness Production Cost during Planning Horizon

As from the Figure 2, the production cost increase along the longer periods time, because the increased demand led to rise in production cost. In the early period, the company current strategy had a lower production cost than the alternative strategy. But after demand increase, alternative strategy generate lower production cost.

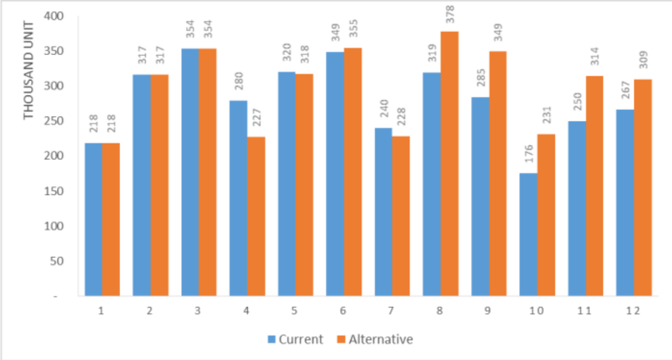

Figure 3. Production Units under Regular Time

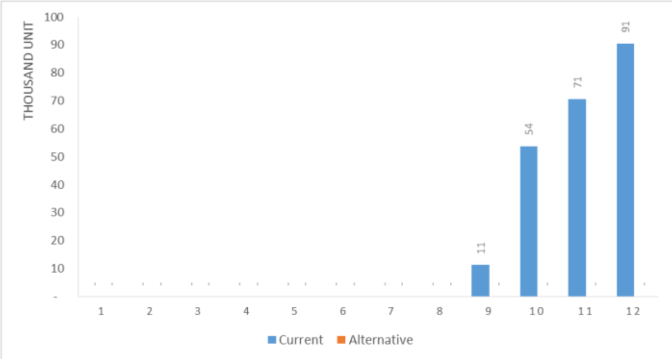

Figure 4. Production Units under Overtime Hour

In the Figure 3 & 4, it can be seen that alternative strategy can minimize the production cost by maximizing amount of production during regular time. This is because the labor cost on regular working time is relatively lower than labor cost in overtime. The alternative strategy had 6.7% greater in amount production unit during regular time compared to the company current strategy, where the production unit in company current strategy amounted to 3,372,913 units, while the alternative strategy had production unit in regular working hours amounted to 3,599,356 units or greater 226,453 units

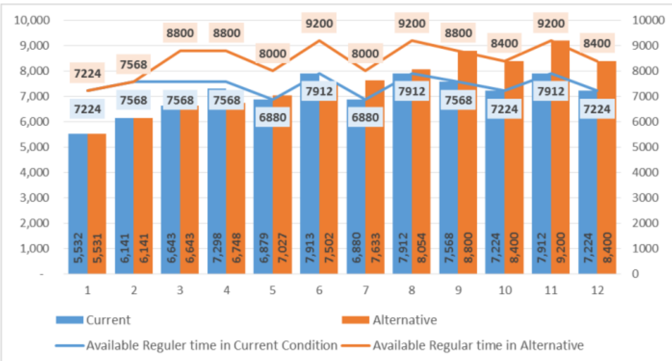

Figure 5. Regular Working Hour Needed (Man-Hour / Month)

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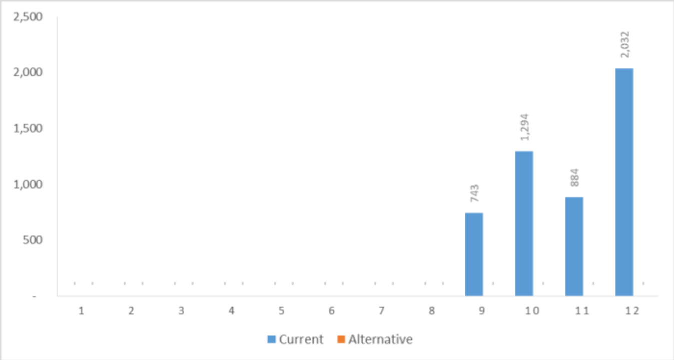

Figure 6. Overtime Hour Needed (Man-Hour / Month)

Figure 5 show the regular working hour needed between all the strategies. The company current strategy had lower availability of regular working time compared with alternative strategies. This is because the company current strategy, using a fixed number of 43 employees. While the alternative strategy had the flexibility in man power used. When demand increased, working hour need is increased too. So when the working hour need exceed the availability of regular working hours, it will cause overtime hours. As seen from the Figure 6.

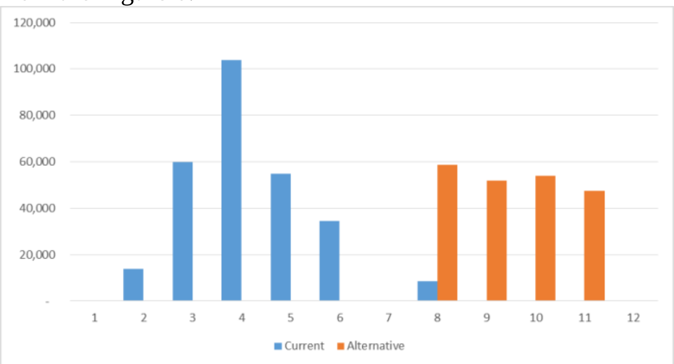

Figure 7. Inventory unit during Planning Horizon (Unit)

From figure 7 that the current condition of the company's strategy has inventory in the second period until sixth month of period. This is because in that period, the need of regular working hours under the availability of regular hours so it can be optimize the amount of production in regular working hours which can be increased to create inventory to anticipate the needs of working hour in the next period. Meanwhile, after the seventh and eighth periods, the company current strategy has no inventory because the needs of regular working hours had reached the limit availability. Diverted by using overtime, in the ninth period until the end of the period *(see figure 5 & 6)*.

The conditions of alternative strategies as shown in figure 7, to avoid the use of overtime hours, the company maximize regular working hours when demand increased to make inventories to anticipate the needs of the working hour in the next period.

The optimation result also performed a sensitivity analysis to determine changes of the parameters to the optimal solution. This sensitivity analysis is intended to test the reliability of the model. Some of the parameters to be analyzed is operational cost, labor cost, inventory cost and demand.

Table 1. Sensitivity of Parameter Change to the Optimal Solution

Parameter Change	Optimal Solution Change in Percentage				
	Operational Cost	Labor Cost	Inventory Cost	Hiring & Firing Cost	Demand
-10%	-6.0%	-4.0%	0.0%	0.0%	-10.2%
-5%	-3.0%	-2.0%	0.0%	0.0%	-5.1%
Fixed	-	-	-	-	-
5%	3.0%	2.0%	0.0%	0.0%	5.1%
10%	6.0%	4.0%	0.0%	0.0%	10.2%

Table 1 show the sensitivity analysis for every changes in all parameters to the optimal solution. As seen from the table 1, that in this model the most vulnerable parameter affects to the optimal solution is the parameter of demand from the customers. Where when customer demand decrease or increase by 10%, it will affects the optimal total production costs by 10%. This means that every 1% change in demand, will give a 1% impact on total cost of wiring harness assembling process. And for the sensitivity of cost parameter, the operational cost had the most cost sensitivity to affects the optimal solution by 6%, and labor cost affects the optimal solution by 0.4%. While inventory cost and hiring and firing cost, not too influential to the optimal solution.

VI. CONCLUSIONS

This research was conducted on a subcontracting company wiring harness. The study compared two strategies in aggregate production planning to minimize the production cost in wiring harness assembling process. The first strategy is the company current strategy using fixed amount of employees used and overtime used. The second strategy is an alternative strategy, which strategy to use flexibility in the number of employees.

From these results, that the alternative strategy can minimize the total production cost in wiring harness assembling process by 0.4% from Rp. 2,043,458,430 to Rp. 2,036,236,800 or decrease Rp. 7,221,630 over 12 month planning period. The alternative strategies can minimize the production cost by maximizing the amount of production in regular time and avoiding overtime labor costs.

This study is an applicative research and expected to be used for the similar problems. This research only used integer variables on amount of man power used. Given that is impossible to the company to produce a product with real number, it is suggested to the next researcher using integer on product and working hour variables. This research is expected to be used as a suggestion for CV. XYZ to minimizing the cost of their production by considering the changes in customer demand which is very vulnerable parameter to changes optimal solutions wiring harness assembly production costs.

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APPENDIX 1. CV. XYZ HISTORICAL MONTHLY DELIVERY REALIZATION

P/N	Group	Person	Capacity/Day	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Grand Total
01H002	A	15	1000	4,000	2,480	6,290	5,630	4,330	8,426		3,297	11,588	46,041
R1H090	A	15	2100	4,970	900	3,430	1,040		990	2,020	14		13,364
S1H103	A	15	2400	45,100	43,800	36,866	49,200	46,922	38,828	21,350	31,650	34,960	348,676
S1H005	B	8	1200		900	13,647	23,876			3,010	7,046	6,510	54,989
T1H21A	B	8	60	684		786		890	1,262	400	120	233	4,375
T1H40A	B	8	900	1,240	988	2,200	2,318	4,844	2,345	599	1,845	1,584	17,963
T1H40B	B	8	450		923	2,385	2,260	4,430	2,702	508	1,934	1,753	16,895
T1H046	C	16	34		15	156		5	52		42	41	311
T1H052	C	16	200	731	1,343	1,013	2,926	1,692	1,739	35		422	9,901
P1H175	D	4	14000	52,460		42,125	34,575	58,450	96,900		11,222	90,400	386,132
P1H177	D	4	14000	21,580			30,400	18,680	20,000		28,143	38,840	157,643
T1H072	D	4	14000	160,340	180,460	190,500	147,950	218,100	387,100	70,000	254,800	19,600	1,628,850

APPENDIX 2. INPUT DEMAND FOR 12 MONTH PLANNING

Demand	Period (Month)											
Product	1	2	3	4	5	6	7	8	9	10	11	12
01H002	5,858	6,238	11,811	7,323	7,703	13,276	8,788	9,168	14,741	10,253	10,633	16,206
R1H090	-	-	-	-	-	-	-	-	-	-	-	-
S1H103	31,880	34,986	31,910	28,950	32,057	28,981	26,021	29,128	26,051	23,092	26,198	23,122
S1H005	28,200	23,523	29,257	38,199	33,522	39,257	48,199	43,522	49,256	58,198	53,521	59,255
T1H21A	-	-	299	-	-	97	-	-	-	-	-	-
T1H40A	2,408	3,680	3,212	2,952	4,224	3,756	3,497	4,768	4,300	4,041	5,312	4,844
T1H40B	3,133	4,747	4,701	4,270	5,884	5,839	5,407	7,022	6,976	6,545	8,159	8,114
T1H046	22	44	104	32	55	115	43	65	126	54	76	137
T1H052	2,126	2,021	2,266	2,610	2,505	2,750	3,094	2,989	3,234	3,578	3,474	3,718
P1H175	30,236	25,331	77,945	31,772	26,867	79,480	33,308	28,402	81,016	34,843	29,938	82,552
P1H177	31,352	31,489	35,791	39,144	39,282	43,584	46,937	47,075	51,377	54,730	54,867	59,169
T1H072	90,655	184,563	156,492	71,864	165,772	137,702	53,074	146,982	118,911	34,283	128,191	100,121
Total	225,869	316,622	353,789	227,118	317,871	354,836	228,367	319,120	355,988	229,617	320,370	357,238

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APPENDIX 3. DATA INPUT FOR AGGREGATE PRODUCTION PLANNING

Data	Code	Unit (UOM)	Product											
			01H002	R1H090	S1H103	S1H005	T1H21A	T1H40A	T1H40B	T1H046	T1H052	P1H175	P1H177	T1H072
Demand	D_{it}	Unit	Attached in Appendix 2											
Product Price	r_i	Rp/Unit	754	1,520	1,610	1,410	3,948	2,364	2,630	14,000	14,950	30	29	25
Operational Cost	m_i	Rp/Unit	428	863	890	779	2,180	1,306	1,455	7,734	8,265	8	8	8
Regular Time Cost	w_i	Rp/manhour	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
Overtime Cost	u_i	Rp/manhour	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250
Inventory Cost	l_i	Rp/Unit	15	30	31	27	75	45	50	267	285	0.3	0.3	0.3
Initial Inventory	L_{it-1}	Unit	300	-	3,600	900	40	180	170	-	-	2,000	-	250
Max Inventory Stored in Box	Box_{it}	Unit	1,000	250	250	100	50	200	20	10	15	1,500	1,500	125
Max Box Allowed	Mbox	Unit	40											
Initial Man Power	$Man_{t=0}$	Person (in period)	43											
Hiring Cost	h	Rp/man	550,000	550,000	550,000	550,000	550,000	550,000	550,000	550,000	550,000	550,000	550,000	550,000
Firing Cost	f	Rp/man	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000
Max Man Power Allowed	Max	Person	50											
Man Power Needed		Person	15	15	15	8	8	8	8	16	16	5	5	5
Unit Process Time	p_i	Manhour/unit	0.031	0.063	0.065	0.057	0.159	0.095	0.106	0.563	0.601	0.001	0.001	0.001
Available Regular Hour	AvR_t	Hour in period	168	176	176	176	160	184	160	184	176	168	184	168
Available Overtime Hour	AvO_t	Hour in period	84	88	88	88	80	92	80	92	88	84	92	84