IOP Conference Series: Materials Science and Engineering

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To cite this article: C A Mursid *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **495** 012046

IOP Conf. Series: Materials Science and Engineering **495** (2019) 012046 doi:10.1088/1757-899X/495/1/012046

Master productions scheduling with goal programming on lithium battery production: case study

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Abstract. Production planning is intendedn to determines the course of a production process such as planning, managing resources, and producing output in accordance with orders from consumers that are arranged in Master Production Schedulling. The Baterai Smart Energi factory of UNS has not maximized the management of production capacity in determining the amount of production according to the order target of Lithium Ion batteries. This led to the remaining production orders that were quite large for the next period. The purpose of this study was to calculate the estimated demand and to develop aggregate production planning for the Battery Plant to meet the lowest cost demand. Data was collected through literature review and secondary data collected directly from the company itself. Then, a manual formulation by programming the content of the linear method of decision variables, objective function and constraint. The results show that model performance is superior to actual company performance in terms of total costs and an increase in the estimated window length can increase costs.

1. Introduction

Electric energy is crucial in the rapid development of technology both in terms of automotive and electronic equipment. Electric vehicle trends have increased dramatically. Which can be seen from the sales of electric cars reached 1% of all car sales in the world which is around 750 thousand units in 2016 [1]. The high market demand for electric vehicles also has an impact on the needs for lithium as the most important component in making batteries. In 2025, it is estimated that lithium carbonate demand will reach 785,000 tons per year, which is 3.6 times higher than the 2017 demand of 217,000 tons[1]. From the perspective of market aspect, the battery industry in Indonesia has not been able to meet the needs this type of battery, hence it still must import lithium batteries [2]. The output products in the form of battery cells from the company are the main components that are also used by institutions in the development of science and technology.

The government supports the electric vehicle and power supply development program in Indonesia in an effort to reduce the consumption of fuel oil initiated by the government [3]. Related to this, one of the government agencies cooperates with the UNS Battery Factory to increase production. The production target increased to 4000 per cell every week. Production planning of UNS battery factory is still only based on demand data. However, in fact, the UNS battery factory is often faced with the situation which uncomplete production target and not planning considering the available resources. Based on production data for initial period, UNS battery factories can produces 70% of the total production target per week. Figure 1 show the fulfilment of target production. To reach the target of production, usually the UNS battery factory imposes overtime hours. So that the UNS battery factory will incur additional costs for overtime hours for its workforce. For this reason, the UNS battery factory needs to maximize regular working hours so that overtime hours can be minimized.

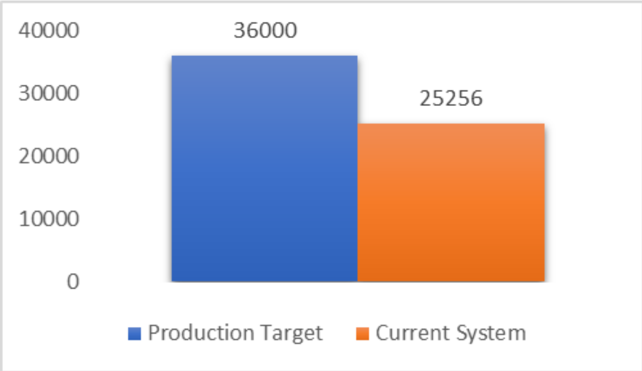

Figure 1. Current Company Production Capacity

One of the way to anticipate the production targets uncomplete is to make production planning. In the preparation of production planning there is an optimization of production so that the lowest level of cost can be achieved for the implementation of the production process. Production planning in the intermediate range of time is termed as Agregrate Planning. Agregrate planning is determination of production rate and the best strategy to meet the demand by considering sales forecasts, production capacity, inventory levels and work force for a medium period, often from 3 to 18 months in advance [4]. Other forms of aggregate planning such as master production schedules, capacity requirements planning and material requirements planning all depend on Agregrate Production Planning. the processing of aggregate models was carried out first and then detailed decisions were made with limitations. Detailed plans are carried out with the disaggregation of the aggregate plan to the master production schedule (MPS) for detailed production planning. The goals to be achieved in production planning determine the optimal amount of production based on the demand, minimize production costs and maximize working hours. These problems include problems with more than one goal or multiple-purpose linear programming, so the models used in this study using goal programming approach.

2. Literature Review

Therefore, an approach is needed to optimize the preparation of production schedules. The optimization method used in this research is to use linear programming (LP). According to Gaspersz [5] linear programming (LP) is an operational research technique that has been widely found to solve management problems.

In this research the writers take the topic of aggregate planning in the framework of the planning process by determining the level of output / production capacity as a whole in order to meet the level of demand obtained from orders with the aim of minimizing production costs. Various optimization techniques are implemented in aggregate planning, with the goal often encountered is finding the lowest cost [6]. In Heizer's [7] and Venkataraman's [8] research in developing aggregate planning for meeting production levels, labor levels and inventory levels. Pratanto [9] in Rahmadhani, Rahman & Tantrika [10] states that minimizing the amount of inventory by generating minimal costs to reduce aggregate work problems such as overtime and subcontracting, optimal and efficient use of resources and equipment is one of the goals of strategic planning. In the research of Noegraheni [11], Nowak [12], Gulsun [13], Madanhire [14], Simamora [15] and Leung [16], conduct research with aggregate production planning by minimizing production costs. Problems with more than one goal or linear programming are dual purposes using the goal programming approach. Research on the goal programming model application for solving optimization problems has been overwhelming. Ginting et al. [17], Alvarez et al [18], and Komsiyah et al [19] conduct research on the goal programming model application for problem solving as a problem solving solution in multi-target problem taking.

3. Method

This study will produce strategic planning to be proposed for the production management stage as an effort to to determine the best method to meet demand by adjusting the variables of labor, production level, overtime, inventory. Data collection is conducted in three ways. First, observation and data collection were carried out by making direct observations on production scheduling at UNS battery factory. Second, interviews and discussions were held to find out the problem and then collect reports and records from the company. Then analyzing the production capacity problem in the predetermined period at UNS battery factory by optimizing all resources to minimize costs production, with by conforming the production value based on the number of demand.

Baker [20] argues that the MPS problem is mostly related to one product. The focus of this research is on complex realistic problems in developing MPS of agregat planning in hierarchical production planning that uses goal programming approach. The APP and MPS model has interrelated relationships. The APP model provides results of weekly aggregate production, inventory, and overtime rates. These results become parameters of the MPS model constraints, figure 2 show the relationship between APP and MPS model. The minimum batch for each product is added to the constraint of the MPS model. The goal programming model in this study can be used to optimize the weekly period. Optimization analysis consists of three analyzes, namely analysis of the decision variable solution that produces decision variables at optimal levels, objective functions to determine achievement or lack of achievement of objectives and analysis of resource deviations to determine the amount of resources needed or used at optimal levels.

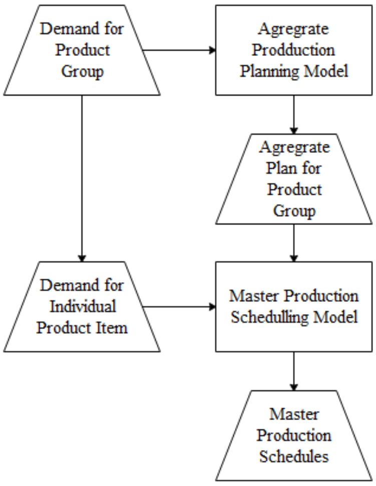

Figure 2. Two-level hierarchical production planning structure

4. Result And Discussion

The production target that must be produced is 80,000 cell batteries with details of 20,000 cells for lithium iron phosphate (LFP) batteries and 60,000 cells for Nickel cobalt aluminum (NCA) batteries. The agreed period of work is seven months with the fulfillment of a weekly period of 4000 cells per week. Some of the data that need to be calculated by aggregate planning is production process time, production cost, demand, labor cost and production capacity. In the calculation of aggregate planning, production cost is important role in calculation. In analyzing the capacity problem, battery production is analized to meet product demand optimization of all resources is performed to minimize the costs incurred. Table 1 show the data of production process time and capacity production for each machine

Table 1. Process Time And Production Capacity Data

Process	Proces Time		Capacity per day	
Mixing Anode	21600	second	236	sheet
Mixing Cathode	21600	second	284	sheet
Coating Anode	10	second	2520	cell
Coating Cathode	10	second	2520	cell
Pressing Anode	12	second	1890	sheet
pressing Cathode	12	second	1890	sheet
Slitting	2	second	11340	sheet
Welding	10	second	2268	sheet
Winding	15	second	1512	cell
Case joining	15	second	1680	cell
Whorl	5	second	5040	cell
Welding Explosive cap	5	second	5040	cell
Vacum Oven	86400	second	1000	cell
Filling Electrolite	20	second	1260	cell
Punching	10	second	2520	cell
Initiation charghing	86400	second	1000	cell
QC	5	second	4536	cell
shrinking	10	second	2520	cell

The period given to fulfill the request is 20 weeks. The battery factory targets production for every week of 4000 cell batteries per week with details of 3000 cell batteries for LFP and 1000 cell batteries for NCA. The regular working hours available at the battery factory consist of 8 hours a day and 4 hours for overtime. Within 1 week, it consists of 5 working days. Production cost per cell battery can be obtain by adding up the cost of machine and building costs raw materials and other costs. Working hours in the planning horizon are explained in the Table 2.

Table 2. Working Hours Capacity

Period (Weeks)	**Workdays**	**Regular Working Hours**	**Overtime Working Hours**
1	5	40	20
2	5	40	20
3	5	40	20
4	5	40	20
5	4	32	16
6	5	40	20
7	3	24	12
8	5	40	20
9	5	40	20
10	5	40	20
11	5	40	20

12	3	24	12
13	3	24	12
14	5	40	20
15	5	40	20
16	5	40	20
17	5	40	20
18	4	32	16
19	5	40	20
20	5	40	20

Based on the target production, agregrate plan for the product was developed using linear programming for 20 weeks. Production Planing Aggregate (APP) Model is to calculate the level of aggregate production, labor and workforce. Below is an APP problem formula. Model parameters, model constraints and model objective functions can be seen in table III.

Minimize: $\sum_{i=1}\sum_{t=1}(C_{it}\,X_{it} + h_{it}\,I_{it}) + \sum_{i=1}(a_t\;R_t + \;b_t\;\;O_t)$ (1)

Constraint :

$$\text{Xit + It, t-1 – Iit = dit} \tag{2}$$

$$\sum_{i=1}\sum_{t=1} m_{it}\,X_{it} \;\leq\; R_t +\; O_t \tag{3}$$

$$R_t \;\leq rm_t \tag{4}$$

$$O_t \;\leq om_t \tag{5}$$

$$I_{it} \;\leq Min_{it} \tag{6}$$

$$\sum_{i=1} X_{it} \;\leq CAP_{it} \tag{7}$$

Table 3. Notation Model APP

X_{it}	Unit of product i to be produced in period t
I_{it}	The number of product i to be kept in inventory in period t
R_t	Regular time hours to be used during period t
O_t	Overtime hours to be used during period t
C_{it}	Production Cost of unit product i in period t
h_{it}	Inventory holding cost per unit product i in period t.
a_t	Cost of man hours regular time in period t
b_t	Cost of man hours overtime in period t
m_{it}	Number of hours required to produce one unit of product i in period t
rm_t	Total regular time hours available in period t
om_t	Total overtime hours available in period t
Min_{it}	Minimum inventory level for unit product i in period t
CAP_t	Production Capacity available in period t
D_{it}	Demand rate for product group i in period t

The objective function (1) of APP Model is to minimize the total production. Equation (2) ensure that the number of product have balance with demand. Equation (3) (4) and (5) regulates that working hours used to produce group product units in each period must not exceed the total working hours available in that period. Equation (6) ensure that total production in units of all product groups in each period cannot exceed the available capacity for that period.

IOP Conf. Series: Materials Science and Engineering **495** (2019) 012046 doi:10.1088/1757-899X/495/1/012046

The agregrate production and inventory levels generated by APP model, the actual demand or target production for each product items provide input parameters for MPS model. Multiple goals are explicitly included in the model, then the aggregrate decisions are disaggregrate to an MPS using preemptive goal programming. Output of MPS model consists of production quantities for each product items, ending inventory, regular time and overtime levels for each weeks. Model parameters, model constraints and model objective functions can be seen in table III.

$$\text{Minimize: } \{ P_1 \sum_{t=1} \sum_{i=1} V_{it}^- + P_2 \sum_{t=1} \sum_{i=1} R_{it}^+ + P_3 \sum_{t=1} W_t^+ \} \tag{8}$$

Constraint :

$$\sum_{k=1} \sum_{i=1} X_{kit} \leq CAP_t \tag{9}$$
$$I_{kit} \geq L_{kit} \tag{10}$$
$$X_{kit} + I_{kit-1} - I_{kit} = F_{kit} \tag{11}$$
$$X_{kit} \geq B_k Y_{kit} \tag{12}$$
$$X_{kit} \geq M_k Y_{kit} \tag{13}$$

Goal Constraint

$$\sum_{k=1} X_{kit} + V_{it}^- - V_{it}^- = X_{it} \tag{14}$$
$$\sum_{k=1} I_{kit} + R_{it}^- - R_{it}^- = I_{it} \tag{15}$$
$$\sum_{t=1} \sum_{i=1} M_{kit} X_{kit} + U_t - O_t = (rm_t) \tag{16}$$
$$O_t + W_t^- - W_t^+ = (ov)_t \tag{17}$$

Table 4. Notation Model MPS

X_{kit}	Unit of item k of product group i to be produced in period t
I_{kit}	The number of item k of product group i to be kept in inventory in period t
V^-_{it}	Negative Deviational Variable or minimum quantity of production of product group i in period t.
V^+_{it}	Positive Deviational Variable or maximum quantity of production of product group i in period t
R^-_{it}	Negative Deviational Variable or minimum quantity of inventory per product i in period t
R^+_{it}	Positive Deviational Variable or maximum quantity of inventory per product i in period t
M_k	Upper bound for the amount of item k.
B_k	Minimum batch size production for item k.
W^-_t	Negative Deviational Variable of utilization of overtime available in period t
W^+_t	Positive Deviational Variable of overage in period t
Y_{kit}	0 or 1 and integers for r = 1
F_{kit}	Demand rate for item k of product group at period t
I_{it}	Desired aggregate ending inventory level for product group i at the end of period t
X_{it}	Desired aggregate production for product group i in period t
CAP_t	Production Capacity available in period t.
L_{kit}	Minimum required inventory level for item k of product group i in period t
$(rm)_t$	Total regular time hours available in period t
$(ov)_t$	Budgeted overtime hours for period t
m_{kit}	Number of hours required to produce one unit of item k of product i in period t
O_t	Overtime used in period t
U_t	Undertime used in period t

The objective function (8) of the model is to minimize deviations from the goals. The relative importance of the goals is reflected in the objective function by P_1, P_2 and P_3, where P_1 for minimize under production (maximize the number of production), P_2 for minimize over achievement of desired inventory levels and P_3 for minimize overtime hours. Equation (9) ensure the total production for each type of battery product cannot exceed the available capacity. Equation (10) determine the final inventory for each type of lithium battery for each period should at least be equal to the minimum inventory. Equation (11) ensure the demand for each period must be met from the production of that period or from the inventory of the previous period. Equation (11) and (12) represent the minimum batch size production constraint. Equation (13), (14), (15) and (16) represent the goal constraint of the model.

Furthermore, the aggregrate production problem and MPS problem are solved using ILOG CPLEX. Table IV display the summary of results obtained using APP model. It is known the number of products to be produced for each period with overtime needed to meet the amount of production. Additional overtime hours for several periods to meet production targets in that period. The increase of the number of production was due to reduced working hours so that the number of production to meet the production target for the week. Figure 3 show the minimization of cost production using APP model. Production costs decreased by 13% from actual production costs.

Table 5. Result Data With App Model

Period	**Battery (Cell)**	**Inventory (Cell)**	**Regular Work Hours**	**Overtime Work Hours**
(Weeks)	(X_{it})	(I_{it})	(R_t)	(O_t)
1	4100	100	2400	0
2	4000	100	2400	0
3	4000	100	2400	0
4	4000	100	2400	0
5	4000	100	2400	480
6	4400	500	2400	240
7	3600	100	2400	720
8	4000	100	2400	0
9	4000	100	2400	0
10	4000	100	2400	0
11	4800	900	2400	480
12	3600	500	2400	720
13	3600	100	2400	720
14	4000	100	2400	0
15	4000	100	2400	0
16	4000	100	2400	0
17	4000	100	2400	0
18	4000	100	2400	480
19	4000	100	2400	0
20	4000	100	2400	0

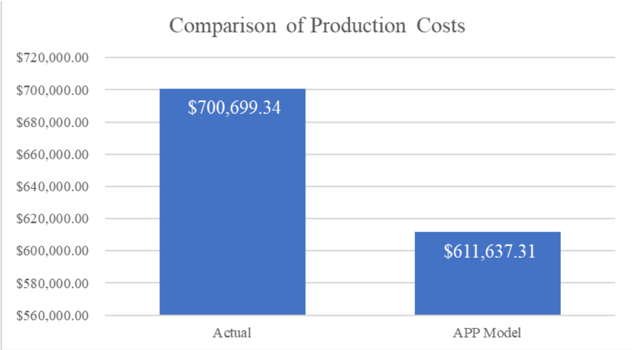

Figure 3. Comparison of Production Cost

The results master production schedules for all items obtained using the pre-emptive goal programming approach is provide in Table VI. The recommended amount of battery is produced at optimal levels. The pre-emptive goal programming approach focused on minimizing over inventory.

Table 6. Result Data With MPS Model

Period	**Battery (Cell)**		**Inventory (Cell)**		**Overtime Work Hours**
(Weeks)	LFP	NCA	LFP	NCA	**(Hours)**
1	1100	3100	100	100	0
2	1000	3000	100	100	0
3	1000	3000	100	100	0
4	1000	3000	100	100	0
5	1000	3000	100	100	480
6	1000	3400	100	500	240
7	1000	2600	100	100	720
8	1000	3000	100	100	0
9	1000	3000	100	100	0
10	1000	3000	100	100	0
11	1000	3800	100	900	480
12	1000	2600	100	500	720
13	1000	2600	100	100	720
14	1000	3000	100	100	0
15	1000	3000	100	100	0
16	1000	3000	100	100	0
17	1000	3000	100	100	0
18	1000	3000	100	100	480
19	1000	3000	100	100	0
20	1000	3000	100	100	0

The resulting solution model is influenced and limited by various constraints, both systemic or functional constraints and objective constraints. From the results of processing using the Goal

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Programming method, it is obtained that a certain amount of battery that is recommended is produced in such a way that the deviation from the destination is as small as possible. As it is known that the objective constraints are deviation deviations, the results of these deviations are constraints that cannot be met. As mentioned in the previous chapter, the first goal is the fulfillment of production targets with the hope that production is equal to or greater than the production target. The second goal is to keep inventory not exceeding the minimum inventory. The third objective is minimization of the workforce with the expectation that there is little overtime or excess hours of labor.

Table VII show the goals that have experienced neither achievement nor achievement. The value of achievement or achievement is a combined value of weekly period values. The target P_1 meets the number of product requests fulfilled because the total negative deviation to the number of requests (Vmin) is 0. The target of P_2 fulfilling the amount of inventory is required not to be able to apply the inventory limits. Minimization of labor hours is given the third priority because the value of non-occurrence that occurs in minimization is at a limit that does not exceed the tolerance value limit that is too significant. In excess hours of labor results in overtime hours that must be added to workers so that it can be interpreted that there are resources that must be added to each period.

Table 7. Result Data With MPS Model

Goal	Optimal Solution
P1 : Min ∑V_min	0
P2 : Min ∑R_max	100
P3 : Min ∑W_max	0

5. Conslusion

Based on the objectives and problems that exist in UNS Battery Factory, from the results of aggregate planning using APP the model produced an aggregate production plan for the product group and minimized production costs by 13% of the actual production costs and provided overall cost saving $ 89,062.

The agregrate production and inventory levels generated by APP model, the actual demand or target production for each product items provide input parameters for MPS model. The results of the MPS model, amount of battery for each type, is produced at optimal levels. It is show that if the company makes products in accordance with the optimal goal programming solution, the production costs and use of working hours for each product are more optimal. The goal programming method has the ability to achieve trade offs between conflicting aspects so that it is potentially used for production planning which is a complex problem because it contains different targets and complexes.

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