The Application of Linear Programming into Production Schedule at Electrical Panel Company

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Abstracts: This study aims to implement linear programming to produce an optimal production schedule to obtain the maximum profit for an electrical manufacturing company and deliver finished products to customers on time. Linear programming was applied as a tool to carry out optimal production planning [11] every month in a business calendar year, with the objective function of maximizing Profit [12], considering the limitations of existing resources within the company. The results showed that the proposed model's production schedule surpassed the company's target. Despite the target being eight panels per day or 1880 panels per year for 235 working days, the model delivers 2032 panels throughout the year, or 152 panels more significantly than the target set. Manufacturers produced twelve types of parent products. However, this study presented only five types of products as decision variables in the linear programming formulations. Due to time constraints and data readiness, it is hoped that the entire parent product type can be presented as a decision variable on the next occasion. This production planning model can be one of the solutions to support the Operational Management manager in solving the problems that usually occur in manufacturing, as well as a reference for the master production schedule for procuring material needs. This study contributes to planning electrical panel production scheduling to provide optimal planning and increase the knowledge base in operation.

Keywords: Optimization, Production Schedule, Production Planning, Linear Programming.

1. INTRODUCTION

The key performance indicators (KPIs) of the operational management of a manufacturing organization can be measured by transforming inputs into outputs. If the output is of the correct quantity, quality, time, and value according to an agreement with consumers, the KPI target of operational management is achieved [3].

However, the obstacle faced by the manufacturer in reaching this target is that the agreement with the customer in delivery time with the same budget calculation turns out to be irregular, which means that if the delivery schedule remains as planned, there will be additional costs in terms of procurement of materials or raw materials. However, the delivery schedule will be delayed if the procurement costs are the same as the budget set earlier.

In determining the number and type of product combination, the presence of resources and the time required to complete one product is an element in production planning [12]. Limited resources, both human resources and other resources, are operational management tasks for optimal production planning. Therefore, linear programming as a tool helps complete an optimal production planning system by utilizing the limited resources in the company to plan the number and type of production and the completion time of a product can be optimally achieved [7][9].

In addition, the Objective of this study was to define the number and type of electrical switchboard products produced by an Electrical Company in an Industrial Estate in Jakarta, Indonesia, as a subsidiary by considering limited resources while maximizing profit.

2. LITERATURE REVIEW

2.1. Operatıons Management

Management is generally defined as the process of planning, organizing, implementing, and controlling the use of human resources to achieve predetermined goals [14]. It is the transformation of inputs (into outputs in the form of appropriate goods and services) into quantity, quality, time, and value [5].

Operations management (OM), according to Heizer and Render [3], is a series of activities that transforms inputs into value-added output in the form of goods or services.

2.2. Manufacturıng Process

The manufacturing process involves the production of goods using labor, machinery, equipment, chemicals, and biological formulations [8]. The term manufacturing refers to a wide range of human activities, from handicrafts to high technology, but it is most often applied to the design industry, where raw materials from the primary sector are converted into finished goods on a large scale. Such goods can be sold to other manufacturers to produce more complex products (such as aircraft, home appliances, furniture, sports equipment, or automobiles) or distributed through tertiary industries to end users and consumers (usually through wholesalers, who in turn sell them to retailers, who then sell them to individual customers).

Manufacturing is a simple process; Raw materials or parts are purchased and turned into finished products. However, to be successful, manufacturers must be able to cover the cost of manufacturing products, meet demand, and create products that the market wants.

There are several types of manufacturing patterns known in the industrial world, namely MTO (make-to-order), make-to-stock (MTS), make-to-assemble (MTA), and engineering to Order (ETO), [13].

Make to Order manufacturing pattern carries out production activities when there is an order from the customer, where this pattern requires a longer lead time because the product produced is based on the design and quantity agreed by the manufacturer and customer; manufacturing only works when there is a request from the customer. The term in the industry is called pulling system, [14].

Make-to-stock is a type of push system, carrying out its production activities without having to wait for customer requests, but based on forecasting from the marketing department that thinks that customers need it, [15] Examples of products produced by MTS-type manufacturing are household needs, such as toiletries (soap, toothpaste, toothbrushes, and laundry soap).

The make to assemble manufacturing is a type of production that is almost similar to the make to stock manufacturing, which produces goods usually sub-assembling general parts of a finished product, such as the body and doors of a car, when there is an order just assembled and adjusted to the complementary needs of the car with the order [21].

Engineer-to-order is a production approach that includes engineering activities in the production process, so it is necessary to add lead time for engineering activities in the production process so; that the implication is that the production process needs a longer lead time than other types of production because there are several designs and analysis needed that must be done in the engineering department to meet the requirements needed for the product aforementioned, [22]. Lead time is the time needed to procure one product [22]. It can be the time needed for the production process or the time needed for the purchase process.

2.2.1 Production Planning and Scheduling

Manufacturing scenarios change drastically day by day to achieve various goals such as reduction of manufacturing lead times, production of a wide range of products, meeting product quality standards and customer needs at a decent cost, and adjustment (make-to-order) of customer demands, as well as to reduce energy consumption and pollutant emissions [16].

Planning and scheduling in manufacturing and service environments depend on one function and another in the organization, namely, the exchange of information between planning and scheduling and other decision-making functions [6][10]. Each activity could have a priority level with different goals, such as minimizing the completion time of an activity, maximizing the profit, and minimizing production costs.

2.3. Modeling System Principles

A model is a simplified, ideal representation of a real object, process, or system. A model proposed by Carter et al. [1]is formed from a mathematical structure in the form of equations, inequalities, matrices, functions, and operators. Mathematical structures are used to develop models describing a modeled entity's most prominent features. Building a system model involves areas that require study or improvement. After establishing the needs and targets for the investigation, an analyst must determine which aspects can be controlled and which do not identify the system targets or objectives [23].

The model that the Author hopes can be one of the problem-solving in production schedule is like the following scheme. (Figure 1, Production Planning Model)

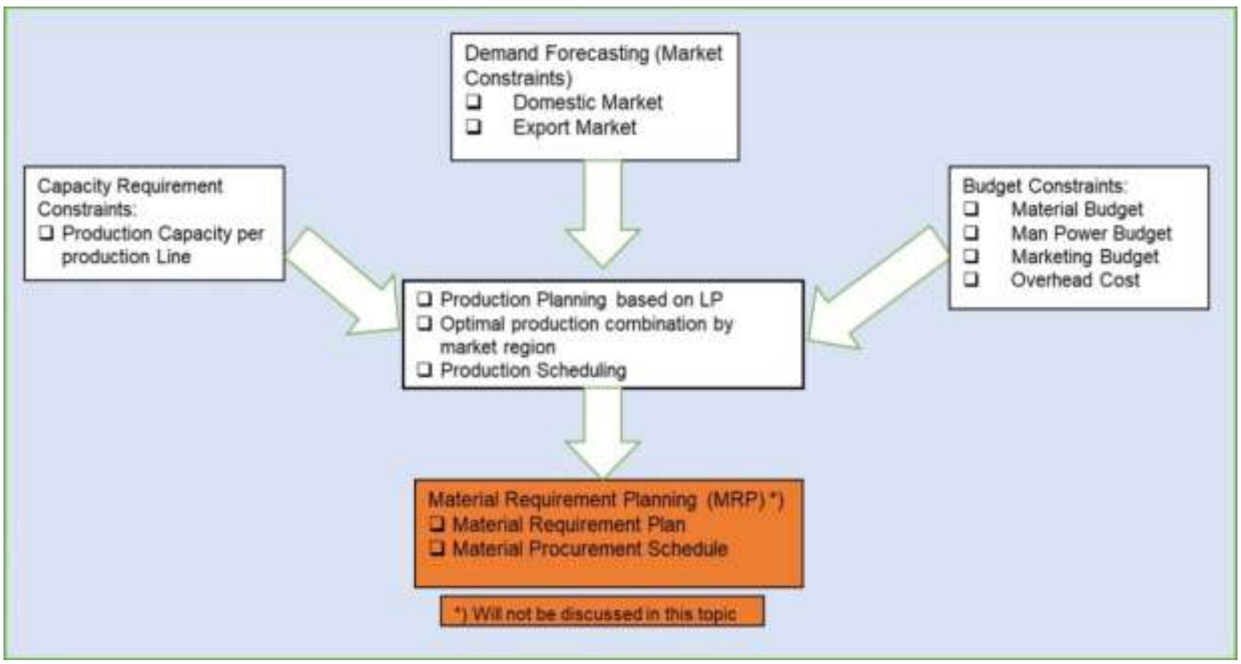

Figure 1. Production Planning Model

2.4. Linear Programming

Linear programming is a standard model that can solve problems by allocating limited resources among several competing activities in the best possible manner [3][7][9][10][11]. This problem arises if a person must choose or determine the level of each activity he will perform, where each requires the same source while the number is limited.

Certain assumptions in linear programs are required to use this linear technique to provide satisfaction without being bumped into various things. The assumptions were as follows [4] [10]:

1. ***Linearity****:* The objective *functions and* constraint *equations* can be created using a set of linear functions.

2. ***Proportionality:*** The rise and fall of the Z value and the use of available sources or facilities will change proportionally (proportionally) with the change in activity level.
3. ***Additivity:*** The goal value of each activity does not affect each other, or in linear programming, it is considered that the increase in the value of the goal (Z) resulting from the increase in an activity can be added without affecting the share of the Z value obtained from other activities.
4. ***Divisibility***: The value of a decision variable can be a fraction or an integer.
5. ***Deterministic***: All the limitations and variable coefficients of each constraint and function of the goal can be determined with certainty.
6. ***Nonnegativity:*** the value of the decision variable should not be negative or minimal = zero.

3. RESEARCH METHODS

The problem of linear programming can be resolved in various ways, such as through graphical methodology, simplex method, or other methods, such as an open solver [19]. The simplex method is one of the most frequently used techniques for solving linear programming problems, and finding a workable ideal solution requires iterations [12, p16]. With this technique, the value of the essential variable is transformed repeatedly to obtain the most significant value of the goal function.

This study looks for solutions (problem-solving) to the phenomena that occur in companies by applying optimal scheduling planning through linear programming [10].

The decision variable in this study was the type of electrical panel product (electrical switchboard), as follows:

1. X_1 is Panel Type A
2. X_2 is Panel Type B
3. X_3 is Panel Type C
4. X_4 is Panel Type D
5. X_5 is Panel Type E

The limitations of the resources in this research that are used as constraints are:

1. Production budget limits.
2. Material purchase budget limits.
3. Production capacity budgets in each production line consist of 6 lines the production process must pass for each product type.
4. Maximum sales in three the last year of each product, namely five types of products, are the object of this research.

4. DATA ANALYSIS TECHNIQUES

The general formula to determine the optimal amount and type of production using Linear Programming to maximize profits is as follows [7][11] [12]:

Objective Function:

$$\textbf{\textit{Max}} \quad Z = \sum_{j=1}^{n} C_j X_j \qquad (1)$$

Where,

- Z = Objective function

- *Cj* = Coefficient of the amount of profit per unit for the ith production
- X_j = number of the -I products sold based on calculations
- n = 1st product, i=1,2,3,...,n

Constraints Function:

$$S/t \quad \sum_{i=1}^{m} \cdot \sum_{j=1}^{n} a_{ij} x_j \leq b_i \qquad (2)$$

$$xj \geq 0, \quad j = 1, 2, \ldots, n \qquad (3)$$

- x_j = variable decision j,
- $a_{i,j}$ = Coefficient on x_j in constraint I,
- b_j = right-hand side coefficient on constraint i.

To generate the data processing and analysis in the LP model, QM software for Windows was used to find the optimum amount and combination of the product type and gain maximum profit.

5. RESULTS AND DISCUSSION

This study shows the role of linear programming as one of the most effective tools for optimal production planning and scheduling, which can then be used as a reference in planning the materials needed for each type of product.

At this stage, the LP model will be formulated first with the objective function of maximizing profit with several constraints [12]: the material expenditure budget was defined as IDR 29 billion per month, the overhead cost budget was IDR 3.5 billion per month, the available person-hours budget in each production line where the production process was passed by each product consisting of six production lines, and the maximum product demand of each type of product in the past.

5.1. Objectıve Functıon

The Objective Function of this model is profit maximization, and panels (A, B, C, D, and E) as decision variables, where the coefficients for Panel A are 50,229,693.31, Panel B is 52,994,029.47, Panel C is 55,485,423.07, Panel D is 53,961,982.86, and Panel E is 55,612,213.52.

Table 1. Profit per Product (KIDR= Kilo Indonesian Rupiah)

Panel Type	Panel A	Panel B	Panel C	Panel D	Panel E
Profit (KIDR)	50,229.69	52,994.029	55,485.42	53,961.98	55,612,21

5.2. Constraints

5.2.1. Overhead And Material Cost Budgets.

The First constraint is the overhead cost budget, where the coefficients of the decision variables are as in the following table values, and the budget set by the company is IDR 3.5 billion per month**.** The following constraint is the material purchase budget, where the variable coefficient of the decision is also contained in Table 2, where the budget is IDR 29 billion per month, valid for one calendar business year.

Table 2. Overhead Cost and Material Budget (KIDR)

Type Panel	Panel A	Panel B	Panel C	Panel D	Panel E

Total Overhead Cost	19,717.58	17,976.68	16,096.47	18,145.16	18,446.98
Material Cost	147,714.73	158,670.09	168,854.94	161,728.12	166,927.07

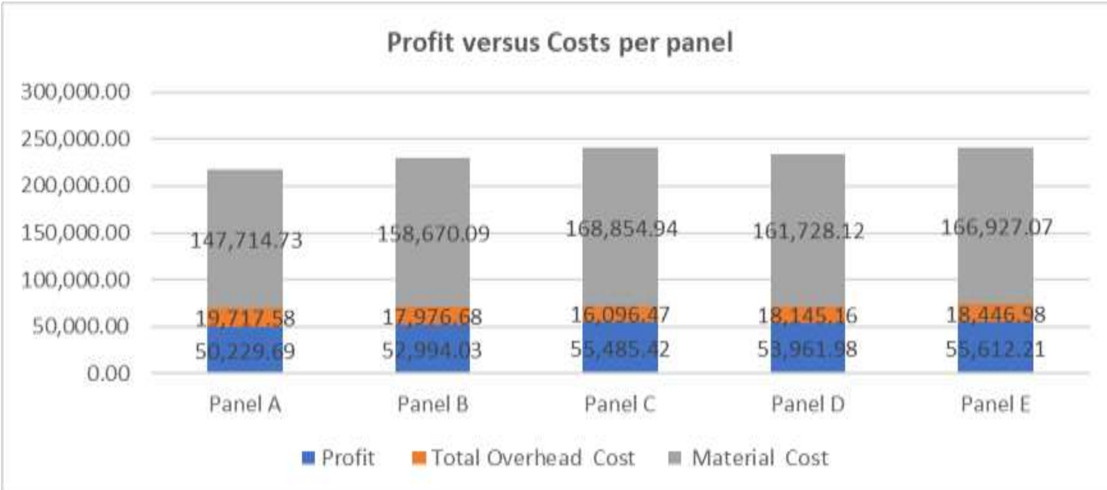

Figure2. The Bar chart of profit, total overhead, and material cost of each type of product

5.2.2. Man-Hour Consumption Budget

Table 3 shows the number of person-hours required by each product at a particular workstation. Panel B requires 9.12 working hours at the Machining (Pre-Fabrication) workstation, which functions as the X_2 Coefficient (panel B) on constraint no.3, as well as the case with Panel C as X_3 in constraint no 3 has a coefficient of 7.12, while panel D has a coefficient of 14.53 X_4 and Panel E 14.77 X_5, all these values are in constraint no.3.

Table 3Man-hour Consumption by each type of product

No	Work Station (Production Line)	Panel A	Panel B	Panel C	Panel D	Panel E
1	Pre-Fabrication	0	9,12	7,12	14,53	14,77
2	MV Assembly	48,96	37,78	29,50	60,47	61,16
3	LV Customization	88,04	67,10	52,38	106,20	109,32
4	Testing	15	15	15	15	15
5	Design Engineering	32	32	32	23	23
6	Project Management	27	27	27	2	2

Table 4 shows the number of person-hours available on each workstation or production line passed by each type of product; in other words, table 4 shows the right-hand side value for each constraint of the six workstations passed by each type of product for each month.

The number of person-hours in Table 4 is the number of person-hours available for each production line in a particular month. Every linear programming inequality uses values on the right-hand side (RHS). For example, 4536 is the number of person-hours available at the prefabricated production line in April, where this value becomes the right-hand side (RHS) in constraint no. 3. in this LP formula. Likewise, for the MV Assembling workstation in April with a value of 12432, which is the RHS on constraint no. 4, 12 LP formulations were included in this study. Each month has an LP formula, which will be tested and analyzed separately.

Table 4 Man-hours available on each Production Line in a Single Month

	Production Line					
	Pre-Fabri-cation	**MV Assembling**	**LV Assembling**	**Testing**	**Design Engineeri ng**	**Project Manage-ment**
Apr-18	4536	12432	19824	6720	5528	5024
May-18	4320	11840	18880	6400	5265	4785
Jun-18	2592	7104	11328	3840	3159	2871
Jul-18	4968	13616	21712	7360	6055	5502
Aug-18	3888	10656	16992	5760	4738	4306
Sep-18	4320	11840	18880	6400	5265	4785
Oct-18	4536	12432	19824	6720	5528	5024
Nov-18	4752	13024	20768	7040	5791	5263
Dec-18	4320	11840	18880	6400	5265	4785
Jan-19	4536	12432	19824	6720	5528	5024
Feb-19	3888	10656	16992	5760	4738	4306
Mar-19	4104	11248	17936	6080	5002	4546

The calendar year used in this study refers to the year used by the company in which this research was conducted, from April 1 to March 31.

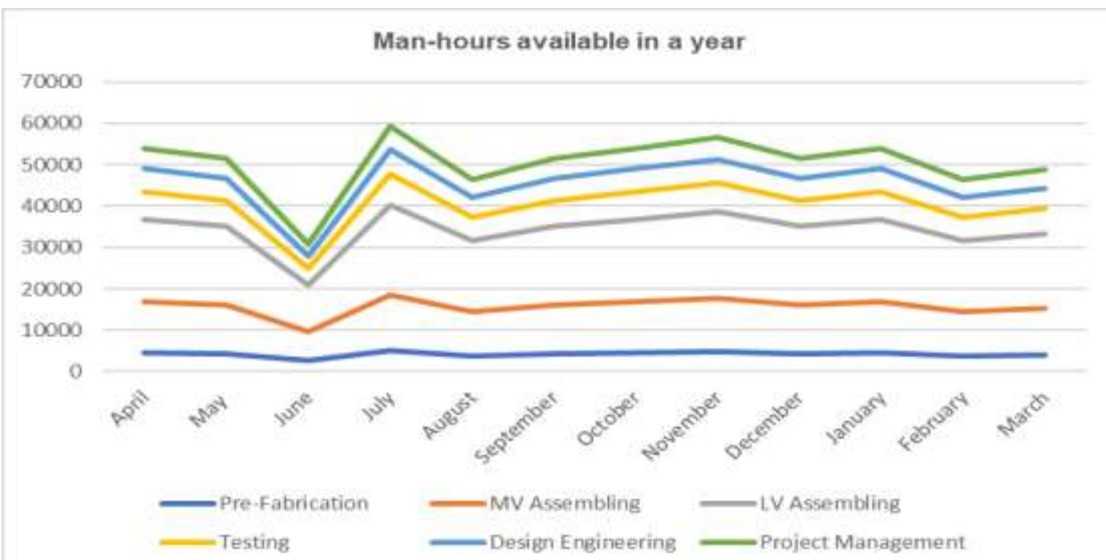

Figure 3. The trend of Man-hours available during the year

5.2.3. Maximum Number Of Each Panel Type Sold

The maximum number of panels per type sold three years ago is a limiter for carrying out production activities. The maximum sales value of each product becomes the value on the right-hand side of the constraint parameter for each product type.

Table 5. It shows the maximum demand for each type of product evaluated during the last three years.

Table 5. Maximum Number of Panels sold per month

No.	Product Type	Quantity
1	Panel A	95
2	Panel B	90
3	Panel C	76
4	Panel D	85
5	Panel E	15

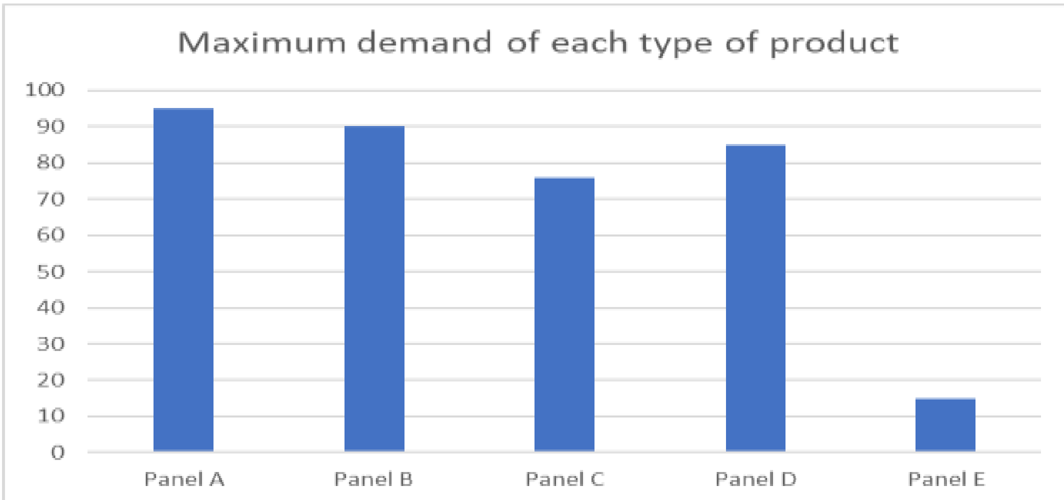

Figure 4. Maximum demand for each type of product

The complete LP formula for April for this research model is as follows. For objective functions (equation 4) and constraints 1 and 2 (equations 5 and 6), both the coefficient and value of the right-hand side are in thousands of rupiahs (KIDR). For example, in the objective function, the Coefficient X_1 is 50,229,690.

The objective function is to maximize profit.

$$Max = 50{,}229.69\,X_1 + 52{,}994.03X_2 + 55{,}486.42\,X_3 + 53{,}961.98\,X_4 + 55{,}612.21\,X_5 \quad (4)$$

<u>**Constraints**</u>

$$19{,}717.58X_1+17{,}976.68X_2+16{,}096.47X_3+18{,}145.16X_4+18{,}446.98X_5 \le 3{,}500{,}000 \quad (5)$$

$$147{,}714.7X_1 + 158{,}670.1X_2 + 168{,}854.9X_3 + 161{,}728.1X_4 + 166{,}927.1X_5 \le 29{,}000{,}000.- \quad (6)$$

$$0\,X_1 + 9.12\,X_2 + 7.12\,X_3 + 14.53\,X_4 + 14.77\,X_5 \le 4{,}536.00 \quad (7)$$

$$48.96\,X_1 + 37.79\,X_2 + 29\,.50\,X_3 + 60.47\,X_4 + 61\,.16\,X_5 \le 12{,}432 \quad (8)$$

$$88.04\,X_1 + 67.10\,X_2 + 52.38\,X_3 + 106.20\,X_4 + 109.32\,X_5 \le 13{,}824 \quad (9)$$

$$15\,X_1 + 15\,X_2 + 15\,X_3 + 15X_4 + 15X_5 \le 6{,}720 \quad (10)$$

$$32\,X_1 + 32\,X_2 + 32\,X_3 + 23\,X_4 + 23\,X_5 \le 5{,}528 \quad (11)$$

$$27\,X_1 + 27X_2 + 27X_3 + 2\,X_4 + 2\,X_5 \le 4{,}536 \quad (12)$$

$$X_1 + 0\,X_2 + 0\,X_3 + 0\,X_4 + 0\,X_5 \le 95 \quad (13)$$

$$0\,X_1 + 1\,X_2 + 0\,X_3 + 0\,X_4 + 0\,X_5 \le 90 \quad (14)$$

$0 X_1 + 0 X_2 + 1 X_3 + 0 X_4 + 0 X_5 \leq 76$ (15)

$0 X_1 + 0 X_2 + 0 X_3 + X_4 + 0 X_5 \leq 85$ (16)

$0 X_1 + 0 X_2 + 0 X_3 + 0 X_4 + X_5 \leq 15$ (17)

$X_1 \geq 0, X_2 \geq 0, X_3 \geq 0, X_4 \geq 0, X_5 \geq 0$ (18)

Optimal Solution Result And Sensitivity Analysis

POM-QM for Windows version 3 provides April's most optimal product combination results, as shown in Table 6.

Table 6 Ranging for Objective Function LP1

No	Variables	Value	Reduced Cost	Original Val	Lower Bound	Upper Bound
1	X_1	31.6253	0	50229.69	50214.58	50483.49
2	X_2	90	0	52994.03	52880.48	Infinity
3	X_3	27.2324	0	55485.42	35391.68	55554.27
4	X_4	18.2154	0	53961.98	49915.07	53963.04
5	X_5	15	0	55612.21	55611.07	Infinity

The Ranging LP1 table for April above shows the optimal solution obtained from the calculation results with the following details:

<u>Objective Function</u>:

- Value is the optimal value of each variable offered by the calculation result system, as many as 31.62 units of panel A (X_1), 90 units of panel B (X_2), 27 units of Panel C (X_3), 18.22 units of panel D (X_4) and 15 units of panel E (X_5), with the maximum profit that can be obtained in April, is KIDR 9,686,114 (nine billion six hundred eighty-six million one hundred fourteen thousand rupiahs). And there are lower-bound and upper-bound values
- Reduced Cost for all variables (X_1.X_2, X_3, X_4, and X_5) equals 0, which shows no reduction in the value of this equation for each of these decision variables.
- The original value is the original value of the coefficient of each variable which in this case is the profit in units of kilo thousand rupiahs = KIDR to be obtained by each product ($X_1 = 50229.69$, $X_2 = 52994.03$, $X_3 = 55485.42$, $X_4 = 53961.98$ and $X_5 = 55612.21$).
- The lower bound is the lowest value of the coefficients of each minimum variable that does not change the optimal solution of the goal function.
  - For product X_1 = 50214.58, which states that if the profit from product X_1 (panel A) is reduced to a value of 50214.58, then there will be no change in the optimal solution of the goal function unless the reduction of profit below the value of 50214.58 then the change in the optimal solution of the value of the destination function will change, as well as,
  - Variable X_2 or panel B, the lowest value of X_2 is = 52880.48 where the original value = 52994.03; the change in profit for product X_2 to 52880.48 will not affect the optimal solution value of the objective function, i.e., profit maximization, similarly,
  - With X_3 or panel product C, which states that the lowest value of the variable X_3 is 35391.68 while the original value is 55485.42, which means that a decrease in the profit value for product X_3

to 35391.68 will not change the optimal solution unless the derived profit value exceeds or is less than 35391.68,

- Furthermore, for variable X_4 or D panel product, the smallest profit value is= 49915.07 where the original value is 53961.98, but a decrease in profit value up to 49915.07 will not change the optimal value of the goal function; the value will change when lowered to a value smaller than 49915.07, last destination function variable is X_5 =with the original value of 55612.21 can only be lowered to 55611.07 so that the optimal solution of the destination function does not change if the profit for this E panel product is lowered by a value smaller than 55611.07 then the optimal solution will change.

- *The upper bound* is the highest value that can be increased for each variable where the increase does not affect the optimal solution of the goal function.
    - The maximum value of the product coefficient X_1 = 50483. 49 means that if the profit from product X_1 (panel A) is increased to a value of 50483. 49 then there will be no change in the optimal solution of the goal function unless the addition of profit exceeds the value of 50483.49; then the change in the optimal solution of the value of the goal function will change,
    - For variable X_2 or panel B, the value of X_2 has an infinite coefficient value (infinity), meaning that whatever value is increased for the coefficient in variable X_2 or panel B product does not affect the optimal solution or, in other words, the maximum profit obtained will not change,
    - Variable X_3 or panel product C states that the highest value of variable X_3 is 55554.27 while the original value is 55485.42, which means that the increase in profit value for product X_3 to 55554.27 will not change the optimal solution unless the profit value increased more or greater from 55554.27,
    - Moreover, for variable X_4 or D panel products, the most significant profit value is = 53963.04, where the original value is 53961.98. However, the increase in profit value up to 53963.04 will not change the optimal value of the goal function; the value will change if increased to a value greater than 53963.04,
    - Furthermore, the last destination function variable is X_5, with the original value 55612.21 having an infinite upper bound value (infinity), which means that whatever value is given to this coefficient will not affect the optimal solution value of the goal function that has been obtained.
- *The upper bound* is the highest value that can be increased for each variable where the increase does not affect the optimal solution of the goal function.

    - The maximum value of the product coefficient X_1 = 50483. 49 means that if the profit from product X_1 (panel A) is increased to 50483. 49 then there will be no change in the optimal solution of the goal function unless the addition of profit exceeds the value of 50483.49; then the change in the optimal solution of the value of the goal function will change,

    - For variable X_2 or panel B, the value of X_2 has an infinite coefficient value (infinity), meaning that whatever value is increased for the coefficient in variable X_2 or panel B product does not affect the optimal solution or, in other words, the maximum profit obtained will not change,

    - Variable X_3 or panel product C states that the highest value of variable X_3 is 55554.27 while the original value is 55485.42, which means that the increase in profit value for product X_3 to 55554.27 will not change the optimal solution unless the profit value increased more or greater from 55554.27,

    - Moreover, for variable X_4 or D panel products, the most significant profit value is = 53963.04, where the original value is 53961.98. However, the increase in profit value up to 53963.04 will not change the optimal value of the goal function; the value will change if increased to a value greater than 53963.04,

- Furthermore, the last destination function variable is X_5, with the original value 55612.21 having an infinite upper bound value (infinity), which means that whatever value is given to this coefficient will not affect the optimal solution value of the goal function that has been obtained.

5.2.4. Post-Optimality Analysis for The Constraints

In linear programming, all model parameters are assumed to be constant; but real-life decisions are always dynamic. The important thing for decision-makers is how much the influence of changes in the following parameters will affect profits,[17] in:

1. Increase or decrease in resources
2. Technology changes,
3. Changes in the raw material budget,

How sensitive the three changes affected the initial data, further analysis of sensitivity to changes that may occur in linear programming models can be seen in the following three sensitivity analyses [17].

The main goal of the management is to know how sensitive the solution is to the original data [20], RHS analysis addresses the effect of a one-unit change in the total number of mandatory constraints since the optimal values or gains are the same. A single-unit change is also called a shadow price [19]. The dual simplex method, as opposed to the primal simplex method, is described in many theorems [9].

Table 7. Ranging for Constraint LP1

No	Constraints	Dual Value	Slack/ Surplus	Original Value	Lower Bound	Upper Bound
1	Production Budget (KIDR)	0	212953	3500000	3287047	Infinity
2	Material Budget (KIDR)	0.2986	0	29000000	27524500	Infinity
3	Machining (Pre-Fab)	0	3035.085	4536	1500.914	Infinity
4	MV Assembly	0	4661.184	12432	7770.816	Infinity
5	LV Customization	29.6176	0	13824	11560.78	15239.86
6	Testing	0	3988.904	6720	2731.096	Infinity
7	Design Engineering	109.9541	0	5528	5219.022	5764.19
8	Project Management	0	938.4119	5024	4085.588	Infinity
9	Maximum Sold Panel A	0	63.3747	95	31.6253	Infinity
10	Maximum Sold Panel B	113.548	0	90	3.7684	138.1527
11	Maximum Sold Panel C	0	48.7676	76	27.2324	Infinity
12	Maximum Sold Panel D	0	66.7846	85	18.2154	Infinity
13	Maximum Sold Panel E	1.144	0	15	0	31.8049

The Ranging for Constraint LP1 on table 7 for April above shows the optimal solution obtained from the calculation results with the following details:

A. Production Budget Constraints

- The dual value is zero.
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of resources of 212953 which means that the Production Budget constraint is not rare because there is a surplus of resources.

- The original value is the value of the right segment of the Production Budget constraint set by the Company at 3.5 billion rupiah

- The lower bound is the lowest value most likely to arrive at 3287047. The optimal solution of the objective function will not change unless the decrease in the value of the resource is smaller than the value of the 3287047.

- Upper Bound is the maximum possible value, so the optimal solution value of the objective function does not change, but in this case, the upper bound value for the Production Budget resource has an infinity value, so any change in value will not affect the final value of the optimal solution.

B. Material Budget Constraints

- The dual value is 0.2986

- Slack / Surplus is an excess or lack of resources; all resources are consumable in this constraint, meaning the Total Material constraint is rare.

- The original value is the value of the right segment of the Production Budget constraint set by the Company at 29 billion rupiah

- The lower bound is the lowest value that is most likely to arrive at the value of the optimal solution 27524500 of the objective function will not change unless the decrease in the value of the resource is smaller than the value of the 27524500, so the material expenditure budget is at least 27,524,500.

- Upper Bound is the maximum possible value, so the optimal solution value of the goal function does not change, but in this case, the upper bound value for material budget resources has an infinity value, so any change in value will not affect the optimal solution value.

C. Machining Constraints (Pre-fabrication)

- The dual value is zero

- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of 3035,085 which means that in Machining (Pre-fabrication), constraints are not a rare obstacle because there is a surplus of resources.

- The original value is the value of the proper field constraint of the Machining (pre-fabricated) production line, available at 4536 hours.

- The lower bound is the lowest possible value, whereby until at a value of 1500.914, the optimal solution of the objective function will not change unless the decrease in the value of the resource is smaller than the value of 1500.914.

- The upper bound is the maximum possible value, so the optimal solution value of the goal function does not change. However, in this case, the upper bound value for the production capacity resource "Machining (pre-fabrication) has an infinite value (infinity), so any change in value will not affect the optimal solution of the goal function.

D. MV Assembly Constraints

- The dual value is zero.

- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of 4661,184 which means that the MV Assembly constraint is not a rare obstacle because there is a surplus of resources.
- The original value is the value of the proper field constraint of the MV Assembly production line, which is available at 12436 hours people
- The lower bound is the lowest possible value, whereby until at the value of 7770.816, the optimal solution of the goal function will not change unless the decrease in the value of the resource is smaller than the value of 7770.816.
- Upper Bound is the maximum possible value, so the optimal solution value of the destination function does not change. However, in this case, the upper bound value for the MV Assembly production capacity resource has an infinity value, so any change in value will not affect the optimal solution of the destination function.

E. LV Customization Constraints

- The dual value is 29.6176
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of 4661,184 which means that the LV Customization strain is not a rare obstacle because there is a surplus of resources.
- The original value is the value of the proper field constraint of the LV Customization production line, which is available for 13824 hours of people.
- The lower bound is the lowest possible value, whereby until at the value of 11560.78, the optimal solution of the objective function will not change unless the decrease in the value of the resource is smaller than the value of 11560.78.
- Upper Bound is the maximum value possible, so the optimal solution value of the destination function does not change. However, in this case, the upper bound value for LV Customization production capacity resources has a value of 15239.86, so the maximum change in value will not affect the optimal solution of the destination function if the value of the right segment of this constraint is not more than 15239.86.

F. Testing Constraints

- The dual value is zero.
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of 3988,904 which means that in Testing constraints, it is not a rare obstacle because there is a surplus of resources.
- The original value is the value of the proper field constraint of the Testing production line, which is available for 6720 hours of people.
- The lower bound is the lowest value, most likely whereby arriving at a value of 2731.096, the optimal solution of the objective function will not change unless the decrease in the value of that resource is smaller than the value of 2731.096.
- The upper bound is the maximum possible value, so the optimal solution value of the goal function does not change, but in this case, the upper bound value for the Testing production capacity resource has an infinite value, so the maximum change in value will not affect the optimal solution of the goal function.

G. Design Engineering Constraints

- The dual value is 109.9541
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of resources of 0 which means that the Design Engineering constraint is a rare obstacle because there is no surplus of resources.
- The original value is the value of the proper field constraint of the Design Engineering production line, which is available at 5528 hours people.
- The lower bound is the lowest possible value, whereby until at the value of 5219.022, the optimal solution of the objective function will not change unless the decrease in the value of the resource is smaller than the value of 5219.022.
- Upper Bound is the maximum value possible, so the optimal solution value of the destination function does not change. However, in this case, the upper bound value for the production capacity resource of Design Engineering has a value of 5764.19, so the maximum change in value will not affect the optimal solution of the destination function if the value of the right segment of this constraint is maximum 5764.19.

H. Project Management Constraints

- The dual Value is zero.
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of 938.4119 which means that Project Management constraints are not a rare obstacle because there is a surplus of resources.
- The Original Value is the value of the proper field constraint of the Testing production line, which is available for 5024 hours.
- The lower bound is the lowest possible value, whereby until at a value of 4085,588, the optimal solution of the goal function will not change unless the decrease in the value of the resource is smaller than the value of 4085,588.
- Upper Bound is the maximum possible value, so the optimal solution value of the objective function does not change, but in this case, the upper bound value for Project Management's production capacity resources has an infinite value, so the maximum change in value will not affect the optimal solution of the goal function.

I. Constraint on the Number of Panels A Sold Maximum

- The dual Value in this constraint is zero.
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of resources of 63.3747 which means that the Number of Panels sold Maximum is not a rare obstacle because there is a surplus of resources.
- The original value is the value of the correct field constraint Number of Panel A sold The Maximum available is 95 units of Panel A product.
- The lower bound is the lowest possible value, whereby until at the value of 31.6253, the optimal solution of the goal function will not change unless the decrease in the value of the resource is smaller than the value of 31.6253.

- The upper bound is the maximum possible value, so the optimal solution value of the goal function does not change, but in this case, the upper bound value for the maximum sale of Panel A has an infinite value, so the maximum change in value will not affect the optimal solution of the destination function.

J. Constraint on the Number of Panels B Sold Maximum

- The dual value in this constraint is 113,548
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of resources of 0 which means that the maximum Number of Panel B sold is a rare obstacle because there is no limitation in sales volume in the type of Panel B product.
- The Original Value is the value of the correct field constraint Number of Panel B sold the maximum available is 90 Units of Panel B products.
- The lower bound is the lowest possible value, where until at a value of 3.7684, the optimal solution of the goal function will not change unless the decrease in the value of the resource is smaller than the value of 3.7684.
- Upper Bound is the maximum possible value, so the optimal solution value of the destination function does not change, but in this case, the upper bound value for the maximum sale of panel B has a value of 138.1527, so the maximum change in that value will not affect the optimal solution of the destination function as long as the maximum value is 138.1527.

K. Constraints on the Number of C Panels Sold Maximum

- The dual value in this constraint is zero.
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of resources of 48.7676 which means that in the constraint, the number of C Panels sold is not a rare obstacle because there is a surplus of resources.
- The original value is the value of the correct field constraint Number of Panel C Sold, The Maximum available is 76 units of panel C products.
- The lower bound is the lowest possible value, whereby until at the value of 27.2324, the optimal solution of the destination function will not change unless the decrease in the value of the resource is smaller than the value of 27.2324.
- Upper Bound is the maximum possible value, so the optimal solution value of the destination function does not change, but in this case, the upper bound value for the maximum C panel sales has an infinite value, so the maximum change in value will not affect the optimal solution of the destination function.

L. Constraint on the Number of D Panels sold Maximum.

- The dual value in this constraint is zero.
- Slack /Surplus is an excess or lack of resources; in this constraint, there is an excess of 66.7846 which means that the constraint Number of Panels sold is not a rare obstacle because there is a surplus resource.
- The Original Value is the value of the correct field constraint number of Panel D sold. The Maximum available is 85 units of Panel D product.

- The lower bound is the lowest possible value, whereby at a value of 18.2154, the optimal solution of the objective function will not change unless the decrease in the value of the resource is smaller than the value of 18.2154.
- Upper Bound is the maximum possible value, so the optimal solution value of the goal function does not change, but in this case, the upper bound value for the maximum D panel sales has an infinite value, so the maximum change in value will not affect the optimal solution of the goal function.

M. Constraints on the Number of E Panels Sold Maximum

- The dual value in this contour is 1.144
- Slack / Surplus is an excess or lack of resources; in this constraint, there is an excess of resources of 0 which means the constraint Number of Maximum B Panels sold is a rare obstacle because there is no limitation in sales volume in the type of panel E product.
- The original value is the Value of the correct field constraint Number of Panel E sold The Maximum available is 15 units of panel product E
- The lower bound is the lowest possible value whereby arriving at a value of 0, the optimal solution of the goal function will not change.
- Upper Bound is the maximum possible value, so the optimal solution value of the destination function does not change, but in this case, the upper bound value for the maximum E panel sales has a value of 31.8049, so the maximum change in that value will not affect the optimal solution of the destination function as long as the maximum value is 31.8049.

Data processing in the LP model for production planning uses POM QM software for Windows version 3 to find the optimum amount and combination of the type of product and gain maximum profit, as shown in Table 7, as a result of 12 linear programming models. Each month has a linear programming formula so that each formula produces an output of a certain number of products and the maximum amount of profit that can be generated.

Table 8. Optimum Result of 12 Months of LP Models

Quarter	Period	Panel A X1(unit)	Panel B X2(unit)	Panel C X3(unit)	Panel D X4(unit)	Panel E X5(unit)	Profit (KIDR)
Q1	April	32	90	27	18	15	9.686.114
	May	0	71	60	31	15	9.627.084
	June	0	20	76	0	0	5.280.817
Q2	July	95	35	21	37	0	9.750.001
	August	0	46	76	22	15	8.642.772
	September	0	71	60	31	15	9.627.084
Q3	October	32	90	27	18	15	9.686.114
	November	72	90	5	5	15	9.742.991
	December	0	71	60	31	15	9.627.084
Q4	January	32	90	27	18	15	9.686.114
	February	0	46	76	22	15	8.642.772
	March	0	49	76	28	15	9.186.870
	Total	**262**	**768**	**591**	**261**	**150**	**109,185,817**

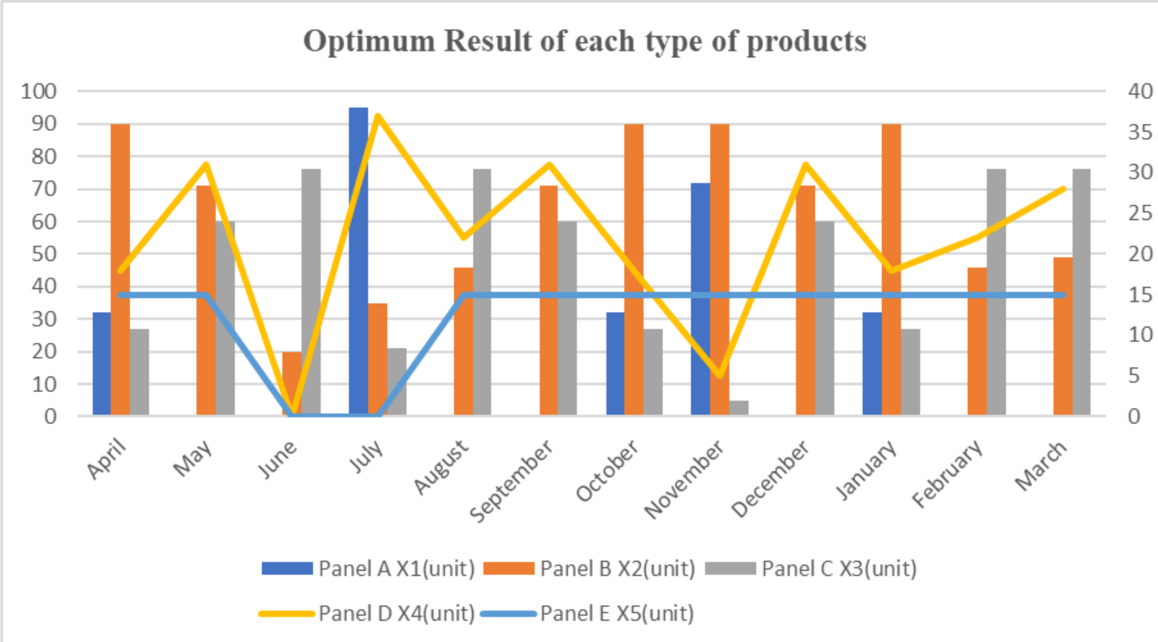

Figure 5. The number and type of products to be produced per month [15]

Based on this LP calculation, the number of panels can be produced per year: 1). Two hundred sixty-two units of Panel type A, 2). Seven hundred sixty-eight units of Panel Type B, 3). Five hundred ninety-one units of Panel Type C, 4) Two hundred and sixty-one units of Panel Type D, and 5). One hundred fifty units Panel Type E, with overall profit KIDR 109.185.817

However, there are 235 working days in the year; by the target of eight panels per day, there will be 235 x 8 = 1880 panels per year.

CONCLUSIONS

The linear programming model formulated herein under the objective function to generate the maximum profit was found to be KIDR 109,185,817 per year, which consists of 1). Two hundred sixty-two units of Panel type A, 2). Seven hundred sixty-eight units of Panel Type B, 3). Five hundred ninety-one units of Panel Type C, 4) Two hundred and sixty-one units of Panel Type D, and 5). One hundred fifty units Panel Type E, with overall profit KIDR 109.185.817, 2032 (262+768+591+261+150) units of panels. However, the number of target panels to be produced, defined by the company, was eight per day. It means that the maximum number of panels that can be produced in 235 working days is 1880 switchboards per year.

There is still a slot in the available production capacity to obtain an additional number of panels that can produce one hundred and fifty-two panels (2032-1880=152) within the year. Moreover, the additional profit that can be obtained is KIDR 53733.2 X 152 = KIDR 8,167,443.

This production planning model can be one of the solutions to problems that usually occur in the manufacturing world in general, which is similar to the Objective of this research and becomes a reference for master production planning.

The lower bound value can be arranged as the new resources budget to optimize the budget spending by the company since the more spending budget is prepared, the more overhead cost will happen.

The number and combination of products produced by this linear programming model can be used as a reference in calculating the material requirement planning model as a master production schedule (MPS) to optimize the procurement of raw materials effectively and efficiently.

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