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Optimization of Floor Ceramic Production Profit using Simplex Method and Sensitivity Analysis

Tedjo Sukmono[1], Demas Bani Alfan[2]
[1,2]Muhammadiyah University of Sidoarjo, Indonesia

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ABSTRACT

Objective: *This study aims to find the optimal production strategy by considering these limitations.* ***Method:*** *Simplex method based on linear programming using LINGO software is applied to determine the best production combination.* ***Results:*** *The results of the analysis show that to obtain optimal profits of Rp680,963,542, the company needs to produce 14,815 m² of 60×60 granite, 21,297 m² of 60×60 ceramic, and 8,334 m² of 60×120 ceramic. This figure is 3% higher or equivalent to IDR 21,103,292 compared to the initial profit of IDR 659,860,250. Sensitivity analysis shows that all selected production variables have a reduced cost of zero, indicating that production conditions are optimal. A price change to the lower bound could potentially decrease revenue by 5% to Rp625,515,731, while an increase in price to the upper bound could increase revenue by 13% to Rp745,599,549. This result shows that there is flexibility in adjusting prices to maximize profits.* ***Novelty:*** *The problem of optimization in achieving maximum profit due to limited machine capacity and production targets is a challenge for ceramic companies.*

INTRODUCTION

The ceramic tile industry is one of the major manufacturing sectors in Indonesia with a national production capacity of 510 million m² per year, of which 87% is marketed domestically. Indonesia is ranked 9th in the world's ceramic tile producers, with production technology equivalent to developed countries such as Italy and Spain. Production or in Indonesian production is an activity related to the production of a product, either in the form of a physical (tangible product) or in the form of a service (intangible product) [1]. In this business, maximizing profits requires a strategy that considers limited resources. Overproduction can trigger stock buildup, while underproduction can lead to lost sales opportunities. Therefore, optimization methods such as *simplex* are a good choice as they are able to handle problems with three or more variables efficiently. The outputs of the traditional method and the LP model were compared. The comparison revealed that with 22% less production, 39% more profit could be made if the selection of goods and production quantities were properly calculated [3].

Previous research in the leather industry sector shows that optimization using *linear programming* can increase profits by 39% even though production is reduced. This study is different because it combines manual calculations, LINGO software, and sensitivity analysis to determine the best production strategy in the ceramic industry. With limited raw material inventory and production capacity, companies must ensure that they can maximize these limitations to get maximum profit [4]. If there are three or more variables, algebra is more complex than graphics, and Gauss-Jordan requires caution. Simplex is more appropriate to solve problems with three or more variables because it is easier and simpler to work with [5]. linear programming such as the simplex method can be one solution [6]. This method allows companies to optimize profits, resource allocation, especially raw materials and labor, to achieve optimal profits. Sensitivity analysis is also important to obtain optimization results in different situations and how changes in certain parameters will affect production decisions [7].

RESEARCH METHOD

The research was conducted for six months at a ceramic company in the Ngoro industrial area, Mojokerto. The research process includes problem identification, production data collection, *linear programming* model formulation, calculation with *simplex* method, validation using LINGO, and sensitivity analysis.

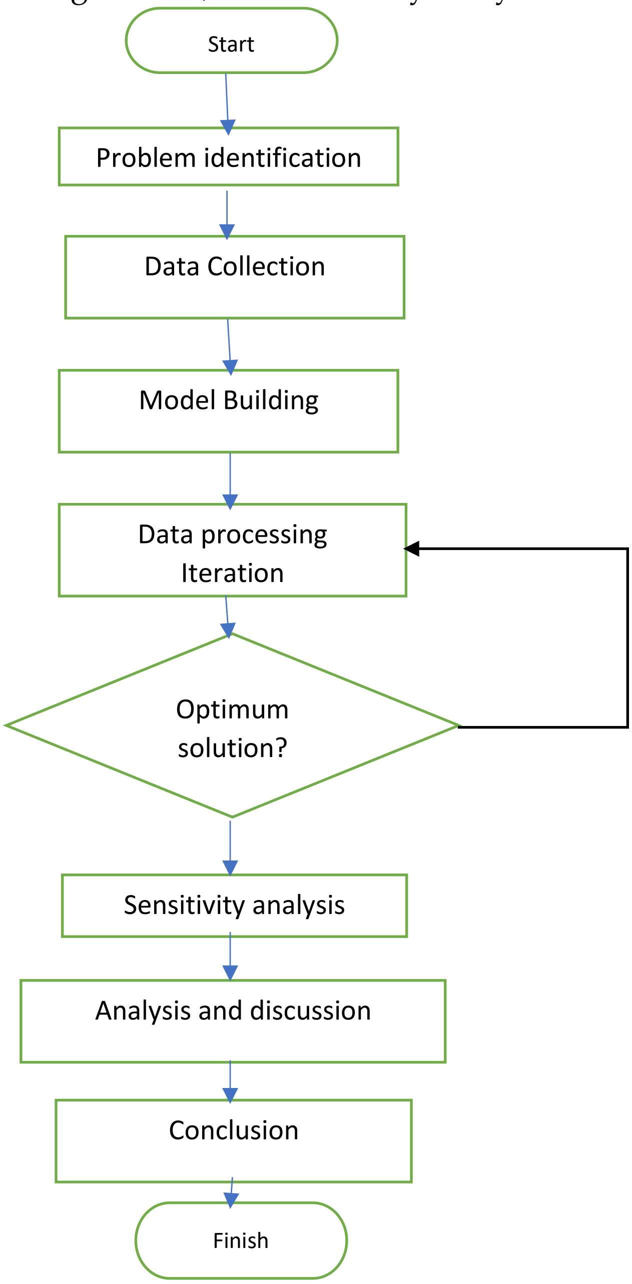

Figure 1. Simplex Flow Chart.

Linear Programming

Linear programming is a technique used to solve optimization problems [8]. This method is designed to formulate and solve mathematical problems involving linear relationships between variables, with the goal of finding a solution that optimizes a given objective function. Some key concepts in that context include objective function, constraint function, and decision variables, which are essential elements in formulating and solving optimization problems [9].

1. Decision variables are values that will be chosen or taken after a decision is made in a context [4]. In this case, the decision variables are expressed in values to be determined in the form of X1, X2, X3, X4,......., Xn
2. An *objective function* is a mathematical expression designed to be optimized in the context of a mathematical problem or linear programming. In linear programming, the objective function guides in finding the optimal value for the decision variables, taking into account the constraints imposed on the system. The objective function is usually presented by using the letter Z to maximize and the letter C to minimize [9]. The ceramic profit optimization formula is as follows [10]:

$$\text{Max/Min} = C1X1 + C2X2 + C3X3 + CnXn \qquad (1)$$

Source: [11]

Description:
Cn : Coefficient of objective value.
Xn : Decision variable.

3. Limiting Function is a mathematical presentation of capacity constraints including the optimal allocation of available capacity to various activities in the form of equations or inequalities [12]. The formula in the constraint function is as follows [12]:

$$A11X1 + A12X2 + A13X3 + \ldots + A1nXn \ (\leq, =, \geq)\ Bn \qquad (2)$$

Source: [12]

Description:
A1n : Coefficient of constraint value.
Bn : Right segment value.

The simplex method is a systematic approach that starts from a basic possible solution until it reaches an optimal basic solution through a series of iterations [13]. This process is carried out iteratively with the aim of achieving the optimum solution to optimization problems involving variables and constraints. The iterations of the simplex method allow for step-by-step improvement towards the optimum solution, making it an effective tool for handling complex problems in linear programming and optimization. Set up the equation in the table:

Table 1. Compilation of Equations.

Base variable	Z	X1	X2	Xn.....	S1	S2	Sn	NK
Z	1	C1	C2	Cn	0	0	0	0
S1	0	A11	A12	A1n	1	0	0	B1
S2	0	A21			0	1	0	B2
Sn	0	Am1	Am2	Amn			1	Bn

Here are the steps in solving linear programming [11]:

1. Convert the linear programming problem with constraints into a mathematical form.
2. Compilation of equations in the table.
3. Determining the key column by selecting the smallest negative$zj - cj$.
4. Determining the key row by finding the index of each bar and selecting the positive index value with the smallest number.
5. Determines the key number by finding the value that belongs to the key column and key row.
6. Convert the values in the key row by dividing by the key number.
7. Change the values other than the key row.
8. In the maximizing case, the simplex table is declared optimal if$zj - cj \geq 0$ for all j values. If the table is not optimal then iterate by repeating step 3.

Sensitivity Analysis

The process of examining changes in the objective function coefficients and constraints in a mathematical model [14]. The aim is to determine the limits to which such changes can occur without affecting the optimal solution of the problem. Sensitivity analysis provides insight into the robustness of the optimal solution to parameter fluctuations, enabling better decision-making in the face of changing conditions or variables in an optimization context. Sensitivity analysis is an evaluation that aims to understand the changes that may occur during the production stage [15]. The main objective is to identify the extent to which certain variations or modifications can affect the final outcome in the production process. By conducting a sensitivity analysis, it can be revealed how changes in certain parameters can impact the overall performance. This helps companies or organizations to make more informed decisions and understand the level of uncertainty associated with production factors. It can be concluded that sensitivity analysis is an important process in the evaluation of mathematical models, focusing on changes in the coefficients of the objective function and constraints. The aim is to identify limits to the extent to which changes can occur without affecting the optimal solution. In the context of production, sensitivity analysis provides insight into the impact of parameter fluctuations on the final outcome, enabling better decision-making in the face of changing conditions. Overall, sensitivity analysis becomes an important tool for understanding the robustness of optimal solutions and managing uncertainty in decision-making, The formula in the constraint function is as follows [16].

Ĉn = CBV B-1an - cn ....(3)

Source: [16]

Description:
CBV : Base variable coefficient
$B^{-1}an$: Inverse matrix of non-base variable coefficient
Cn : Non-base variable coefficient

Lingo

Lingo is a simple but effective software for performing linear and non-linear optimization [17]. Lingo is a software for finding solutions in linear programming. As an older generation of lindo, lingo provides an effective tool for solving linear programming problems optimally [18]. Overall, lingo is a simple yet effective software for linear and non-linear optimization. With its speed in calculating and complex problem solving capabilities, lingo becomes a very useful tool. Not only that, lingo is also able to handle linear programming well, making it an effective and optimal solution. As an older generation of lindo, lingo remains a reliable choice for analysis and problem solving in a variety of contexts.

Research steps

1. Data Collection The following is the daily ceramic production data at the company, as follows:

Table 2. Production Data.

No	Machine	Product						Capacity/day
		60 x 60 Granite	60 x 60 Ceramic	30 x 60 Granite	30 x 60 Ceramic	50x 50 Granite	60x120 Granite	
1	Milling	11	8	11	8	11	8	400 .000
2	Press	7	7	7	7	6	5	300.000.
3	Burn 1	9	9	9	9	8	9	400.000
4	Layying	3	3	3	3	2	2	125.000
5	Burn 2	9	9	9	9	8	9	400.000
6	Polish & cutting	4	0	6	0	7	0	125.400
Profit (rp)		16.667	15.625	15.625	14.063	9.000	12.153	

Table 3. Company Profit.

No.	Product	Volume (M2)	Value (rp)	Total (rp)
1	60 x 60 Granite	11966	16.667	199.428.000
2	60 x 60 Ceramic	5939	15.625	92,797,500
3	30 x 60 Granite	8391	15.625	131,107,500
4	30 x 60 Ceramic	6680	14.063	131,107,500
5	50x 50 Granite	9143	9.000	82,282,500
6	60x120 Granite	4962	12.153	60,305,000
	Total			659,860,250

2. The objective function used is profit maximization based on six decision variables:

a. X1: Granite 60×60
b. X2: Ceramic 60×60
c. X3: Granite 30×60

d. X4: Ceramic 30×60
e. X5: Granite 50×50
f. X6: Ceramic 60×120

3. Function Production constraints are based on the capacity of six main machines, such as milling, press, burn, laying, second burn, and polishing & cutting.
a. Limitation of milling machine 11x1 + 8x2 + 11x3 + 8x4 + 11x5 + 8x6 ≤ 400,000
b. Press machine limitation 7x1 + 7x2 + 7x3 + 7x4 + 6x5 + 5x6 ≤ 300,000
c. Burn machine 1 limitation 9x1 + 9x2 + 9x3 + 9x4 + 8x5 + 9x6 ≤ 400,000
d. Limit layying machine 3x1 + 3x2 + 3x3 + 3x4 + 2x5 + 2x6 ≤ 125,000
e. Burn 2 machine limitation 9x1 + 9x2 + 9x3 + 9x4 + 8x5 + 9x6 ≤ 400,000
f. Polish and cutting machine limit 4x1 + 0x2 + 6x3 + 0x4 + 7x5 + 0x6 ≤ 125,400

RESULTS AND DISCUSSION

The simplex method both manually and using LINGO produces the optimal production combination: 14,815 m² granite 60×60, 21,297 m² ceramic 60×60, and 8,334 m² ceramic 60×120. This result indicates that not all types of ceramics need to be produced in equal proportion; rather, prioritizing certain product variants can lead to higher profitability. By concentrating production on these three product categories, the company is able to allocate resources more efficiently while still meeting market demands. This strategic focus also reduces unnecessary machine usage for less profitable products, ensuring that capacity constraints are respected.

The optimal strategy provides a profit of IDR 680,963,542, which represents an increase of 3% compared to the initial condition of IDR 659,860,250. Although the percentage increase may appear modest, the absolute increase of over IDR 21 million demonstrates the tangible benefit of applying optimization techniques in production planning. This finding reinforces the importance of quantitative methods such as linear programming in industries where margins are tight and production decisions directly affect financial outcomes. Moreover, it provides evidence that mathematical modeling can help reduce managerial uncertainty and support data-driven decision-making.

Sensitivity analysis shows that price changes within the lower to upper bound range do not change the optimal production mix. This stability indicates that the solution obtained is robust and reliable even under fluctuating market conditions. For companies operating in highly dynamic industries, such robustness is essential to avoid frequent adjustments that may disrupt production flow. Maintaining the same optimal production mix also simplifies planning and ensures consistency in output, which is advantageous for both inventory management and customer satisfaction.

A decrease in price to the lower bound decreases revenue to Rp625,515,731, while an increase in price to the upper bound increases revenue to Rp745,599,549. These results demonstrate the elasticity of profit relative to market prices. Management can use this information to anticipate different market scenarios and prepare contingency strategies, such as promotional efforts or product differentiation, to mitigate losses in the case of declining prices. Conversely, when prices are favorable, the company can capitalize on higher margins without having to change the production allocation.

The analysis also highlights the role of resource constraints, particularly machine capacity, in shaping the production strategy. Each machine, from milling to polishing, imposes limits that must be carefully considered in the optimization model. If production planners ignore these constraints, overutilization could occur, resulting in inefficiencies or equipment breakdowns. By incorporating these constraints into the model, the company ensures that the solution is not only profitable but also feasible from an operational standpoint. This demonstrates how optimization bridges the gap between theoretical profit maximization and practical manufacturing realities.

Overall, the combination of simplex method and sensitivity analysis provides a comprehensive framework for decision-making in the ceramic industry. While the simplex method identifies the optimal product mix for maximizing profit, sensitivity analysis validates the resilience of the solution against changes in external factors. Together, these tools empower companies to design more adaptive and profitable strategies in the face of resource limitations and market uncertainties. Future implementations can expand the model by including additional variables such as labor costs, energy consumption, or raw material fluctuations to achieve even more precise optimization.

CONCLUSION

Fundamental Finding : The simplex method manually and using LINGO produces the optimal production combination: 14,815 m² granite 60×60, 21,297 m² ceramic 60×60, and 8,334 m² ceramic 60×120. This strategy provides a profit of IDR 680,963,542 or an increase of 3% from the initial condition. Sensitivity analysis shows that price changes within the lower to upper bound range do not change the optimal production mix. **Implication :** This result shows that there is flexibility in adjusting prices to maximize profits. Companies are advised to use this method on an ongoing basis for production planning, so that resource utilization is maximized. Sensitivity analysis provides insight into the robustness of the optimal solution to parameter fluctuations, enabling better decision-making in the face of changing conditions or variables in an optimization context. **Limitation :** With limited raw material inventory and production capacity, companies must ensure that they can maximize these limitations to get maximum profit. Overproduction can trigger stock buildup, while underproduction can lead to lost sales opportunities. Function production constraints are based on the capacity of six main machines, such as milling, press, burn, laying, second burn, and polishing & cutting. **Future Research :** Further research can use other optimization methods to compare their effectiveness. This study is different because it combines manual calculations, LINGO software, and sensitivity analysis to determine the best production strategy. Future research can integrate nonlinear programming or multi-objective optimization to expand the scope of decision-making in the ceramic industry.

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***Tedjo Sukmono (Corresponding Author)**
Muhammadiyah University of Sidoarjo, Indonesia
Email: thedjoss@umsida.ac.id

Demas Bani Alfan
Muhammadiyah University of Sidoarjo, Indonesia