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Integer Linear programming for Patchwork Production Planning Optimization with Demand Uncertainty

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ABSTRACT

Since the industry continuously grows, mainly MSME in creative economy sector most specifically on patchwork products, the emerging strategies and tools have to evolve which enhance competitiveness and economic development. Nevertheless, there are certain limitations in reaching the optimum production potential and utilizing the resources effectively while design these items. In this paper, I propose a mixed integer linear programming model for planning production schedule of handcrafted patchwork goods from Balinese batik textiles. The goal involves the maximization of profit with fulfilling many constraints which include the cost of material, cost of handling, operating expenses, time for production, capital limitations, and uncertainty of demand. In the case of the production level, it was identified that to maximize the profit, prayer mat production should be 1, table runners' production should be 6 and that of cushion coverings should also be 6 units with the maximum profit of IDR 12,469,900. Sensitivity analyses, thus, confirmed the stability of the model by analysing the consequences of cutting by one day of the material lead times and on the other hand, increasing the demand for products by 10%. The findings revealed the plans continued effective in these contexts and hence proved that the model was flexible in practice. From this work, crafters and small-scale producers can implement pragmatic strategies to assist in increasing efficiency and profitability in production while future work can build upon and amplifying the optimization model.

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1. INTRODUCTION

According to BPS data, the ratio of entrepreneurs in Indonesia remains at 3.47%, or approximately 9 million people out of the total population. However, it is up from 3.1% in 2016. This rate is still lower than Singapore,

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which reached 8.5%. Malaysia and Thailand have also surpassed 4.5 percent. Indonesia intends to boost the percentage to 3.9 - 4% by 2024 (Sutrisno, 2024). According to the Global Entrepreneurship Index (GEI), Indonesia is now ranked 94th out of 137 countries, with a score of 21. As a result, Indonesia will rely on one of its strengths: MSMEs. According to the Central Statistics Agency's (BPS) economic census, the baseline entrepreneurial ratio in 2019 was 3.3 percent, or 8.2 million. This indicates that, in order to achieve a 3.95 percent target by 2024, 1.5 million people must form enterprises by that date. The growth of 1.5 million new entrepreneurs, of course, is effective within a period of three years or from 2022 to 2024, so that the average annual target is 500 thousand new entrepreneurs (Sutrisno, 2024). According to data from the Ministry of Cooperatives and SMEs, there are currently 64.2 million MSMEs, which contribute 61.07 percent of GDP, or IDR 8,573.89 trillion. MSMEs' contribution to the Indonesian economy includes the ability to employ 97 percent of the entire workforce. And can generate up to 60.4% of total investment (MNC Media, 2024).

Products including patchworking are a significant and cultural segment of the hand-crafted product especially those manufactured by Balinese batik cloths. These products such as prayer mats, table runners, covering pillows are considered to be of great importance because of their designs and the cultural values that were associated with them. However, the actual process of making these handcrafted products is often time-consuming and usually involves unpredictability in either the cost price or demand. This variability makes a number of constraints a challenge to production planning and more so for MSMEs with constrained manpower and material resources (Anand & Kodali, 2015; Choudhary et al., 2019). Stretch targets are generally common with MSMEs since their production and material costs fluctuate, their sales patterns may not be consistent, and they may have limited funds compared to their larger counterparts (Cruz & Smith, 2016). Such variables may result in processes inefficiency as well as the poor utilization of existing resources, thus reducing the profitability and sustainability of these firms (Brandenburg et al., 2014). It can reach a point where traditional methods of production planning are not adequate in handling the many factors, and there is a need to employ optimization methods.

Another gem of the present work is having come across the Integer Linear Programming (ILP) as an interesting approach towards dealing with such challenges. It makes production planning more methodological to determine candidates of process improvement by means of formal mathematical models which include multiple limitations and goals (Akpan & Udoh, 2014; Nasiri & Kazemi, 2015). This approach allows for the appraisal of production scenarios systematically followed by the formulation of recommendations that would be of help to the MSMEs in realizing the best possible gross margins with optimal resource management (Ma & Lee, 2015).

But the over-arching objective of this project is to develop an ILP model that will enable the maximization of production planning of patchwork goods produced from Balinese batik textiles. The goals of the model involve profit maximization without compromising the factors like the material cost, handling expense, operating cost, manufacturing time, capital and uncertain demand (Adhikari & Basu, 2015; Eskandarpour & Dejax, 2015). According to the discussed aspects of the model, it is expected that the integration of these parts offers a realistic and profitable manufacturing plan that can be easily implemented by MSMEs. It is, therefore, necessary to perform a detailed case study for the purpose of illustrating how the proposed ILP model is effective. This paper is based on a normal MSME company that manufactures patch work products the case and some of the actual problems that these organizations face is elaborated which makes the study more realistic (Al-Mutairi & Khoury, 2014; Arora & Banerjee, 2018). In the case, the key issue revolves around the number of units that should be produced per type of product; the situation also analyses how diverse restrictions influence the production plan (Alborzi & Afshari, 2016).

However, sensitivity analysis is also conducted to ascertain the validity and accuracy of ILP model under the diverse different circumstances. These evaluations conduct the effects of changes in lead times and demand to the best possible production plan and impart a comprehensive understanding of the flexibility and reliability of the model (Eberle et al., 2018; Saif & Elhedhli, 2016). These analyses' results are valuable for the model's validation in terms of practical usability and identifiability of its benefits in numerous operational contexts (Chen et al., 2018).

The author suggests that the study will yield important findings that will advance knowledge in the discipline and inform improved practices in production of handcrafted items. Thus, this research employs state-of- the-art mathematical modelling aiding MSMEs to determine a reliable model for boosting production efficiency and profitability (Castaño et al., 2018; Chiu et al. , 2016). In addition, the data obtained in this study can contribute to the promotion of the subsequent RDA for the improvement of the competitive edge and the long-term viability of the handmade goods SE (Elyamany & El-Sharkawy, 2017).

Moreover, in the present study, we have included another significant factor of concern for MSMEs known as demand uncertainty. The match between demand and supplied is important because when demand fluctuates, its takes time and money to adjust to the right level and this may lead to either over demanding or under demanding and this is not good for costs of inventory and customer satisfaction (Felfel et al., 2016; Jung & Jeong, 2016). Uncertainties related to the cost and availability of resources have been recognized in these components, and by integrating these with strong optimization methods, ILP model can capture these varieties and provide a stronger structuring of production planning.

This necessity of integration of sustainability into the production planning processes cannot be overemphasized. The use of sustainable production literature improves the environmental status of MSMEs' production while at the same time enhancing their competitiveness within the market (Shrouf et al., 2014; Sun & Ma, 2017). The ILP model developed in this work includes constraints related to energy use and material quantities, and is thus in harmony with the current concepts of sustainable manufacturing (Jin & Liao, 2017; Qi et al., 2015).

Last but not the least, this research aims at bridging the gap between the theoretical optimization models and the real art of work in the domain of the artisanal manufacture. The analysis improves manufacturing productivity and profitability by developing and validating an appropriate ILP model relevant to MSMEs engaged in the production of patchwork products. Thus, identifying the specific solutions for discussed problems, the findings of this study will increase the knowledge of the overall field of production planning and optimization, as it applies to MSMEs operating in the handmade goods market (Moradi & Aghazadeh, 2017; Vahidi & Shakouri, 2017).

2. RESEARCH METHODE

Undertook various phases (Figure 1), this encompassed a literature review aimed at fulfilling the first strand of the research question, this involved identifying production costs and cost optimisation for handcrafted patchwork items. (2) Data collection: Surveys, interviews, observations were used to obtain relevant information on existing production cost factors for materials, handling, operations, time, and demand of products. (3) Data Analysis: Production costs that emerged from the acquired data were analyzed and consequently matched with the Integer Linear Programming model. In this case, quantitative and statistical validation enabled crosschecking of statistics and other relevant data items. (4) Model Development: A mathematical model was made by us using Integer Linear Programming (ILP). This stage involved creation of the objective function, decision variables and constraints appropriate for describing the production planning problem. (5) Model Testing and Evaluation: The constructed model was tested by it through sensitivity analysis to see how robust it is in various situations such as some changes in lead times and demands. We therefore implemented the model on LINGO version 18.0 to ascertain its applicability and efficiency.

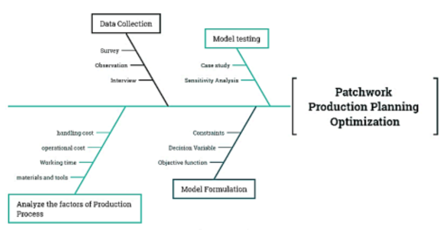

Figure 1. Research Methods

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3. RESULT AND ANALYSIS

1. Model Formulation

Patchwork products material that are produce by handcrafter generally consists of Balinese batik fabrics, foam, also sewing and quilting thread. Before the product is made, the Balinese batik fabrics is first washed to remove any fabric paint that may still be faded. This is included in the handling cost. In addition, the design and packaging costs are also included in the handling costs. operational cost is a Labor wage determined by how long it takes to complete the product. Operating costs are Labor wages that are determined by how long it takes to complete the product. These include electricity costs, costs of using tools and machinery. Patchwork products usually consist of bed covers, prayer mats, tablecloths, pillowcases, dolls, wall hangings, jackets, vests, etc. The time required for each product is T_i. In one day, there is a limited working hour, accumulated in one month. The demand for the products to be made is uncertain. The purchase of fabric, foam and threads depends on customer requests in terms of colour, size and design. In this case, fabric, foam and thread are purchased upon request, therefore, there will be a waiting time. Fabric, foam and thread requirements for each product will be different. If the product is generally expressed as i, where i = 1, 2, ..., n, then, the quantity of each product i is expressed as Q_i, assume that the product quantity is an integer.

An integer linear programming is developed in optimizing the production planning of handcrafted patchwork products with demand uncertainty.

Objective Function

$$\max Z = \sum_{i=1}^{n} (P_i - H_i - T_i \times (L + E) - M_i - OC_i) \times Q_i \quad (1)$$

Subject to:

$$\sum_{i=1}^{n} T_i \times Q_i \le T_{total} \quad (2)$$

$$Q_i \le D_i \quad (3)$$

$$T_i \times Q_i \le (30 - L_i) \times \mathrm{t} \quad (4)$$

$$\sum_{i=1}^{n} M_i \times Q_i \le C \quad (5)$$

$$Q_i \in Z;\ \forall i \quad (6)$$

$$Q_i \ge 0;\ \forall i \quad (7)$$

Where:

P_i is the selling price of product i
H_i is the handling cost per unit of product i
T_i is the production time per unit of product i
L is the labor cost per hour
E is the electricity cost per hour
T_{total} is the total working hour in a month
t is total working hour in a day
C is the Capital
M_i is the material cost per unit of product i
OC_i is the operational cost per unit of product i
Q_i is the quantity of product i to be produced
D_i is the demand for product i.

L_i is the lead time for materials for product i in days

Equation (1) the objective is to maximize the total profit, Equation (2) is total production time, i.e. the sum of production times for all units produced is within one month. Equation (3) is the demand constraint, where the production quantities do not exceed the demand for each product. Equation (4) is material lead time constraint. Equation (5) is capital limitation constraint; The total material cost does not exceed the maximum capital. Equation (6&7) are integer and non-negativity constraints.

2. Case Study

The data for the case study taken from a handcrafter in Medan. She produces various products such as bed cover, prayer mat, table runner, cushion cover, bag, wall hanging, etc. For simplification assume that we consider only three products for model implementation. Let prayer mat be i=1, table runner be i=2 and cushions cover be i=3. The time required for each product is respectively 24 hours, 21 hours, and 15 hours. In one day working time is limited to 8 hours, so there will be limited to 240 hours in one month. The Balinese batik fabric is ordered directly from the factory in Solo, while the foam is ordered from the factory in Tegal, Central Java and the yarn is ordered from Jakarta. The lead time is usually 3-7 days for material to be received. Given that fabric is IDR50,000/m; foam is IDR60,000/m and thread is IDR32,000/skeins. The material cost, wage Labor, handling and operation cost presented on table below.

Table 1. Material Costs

Product i	Fabric (m)	Foam (m)	Thread (skeins)	Fabric Cost (IDR)	Foam Cost (IDR)	Thread Cost (IDR)	Total Material Cost (IDR)
1	3.5	1	2	175,000	60,000	64,000	299,000
2	6	2	2	300,000	120,000	64,000	484,000
3	6	6	3	300,000	360,000	96,000	756,000

Table 2. Wage Labor Costs

Product i	Working Time (hours)	Wage Labor (IDR)
1	24	1,200,000
2	21	1,050,000
3	15	750,000

Table 3. Handling Costs

Product i	Fabric Pre-Wash (IDR)	Design (IDR)	Packaging (IDR)	Total Handling Cost (IDR)
1	17,500	250,000	12,000	279,500
2	30,000	250,000	12,000	292,000
3	30,000	250,000	12,000	292,000

Table 4. Selling Prices

Product i	Total Material Cost (IDR)	Wage Labor (IDR)	Selling Price (IDR)
1	299,000	1,200,000	1,379,400
2	484,000	1,050,000	1,338,400
3	756,000	750,000	1,206,000

Table 5. Operational Costs

Product i	Electricity (IDR)	Tools & Machinery (IDR)	Total Operational Cost (IDR)
1	45,000	40,000	85,000
2	50,000	55,000	105,000
3	60,000	60,000	120,000

This data and parameters summarized in table 6.

Table 6. Data and Parameters

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Product	Material Cost (IDR)	Handling Cost (IDR)	Wage Labor (IDR)	Selling Price (IDR)	Operational Cost (IDR)	Total Cost (IDR)	Working Time (hours)
Prayer Mat	299,000	279,500	1,200,000	1,379,400	30,000	1,808,500	24
Table Runner	484,000	292,000	1,050,000	1,340,400	30,000	1,856,000	21
Cushion Cover	756,000	292,000	750,000	1,203,600	30,000	1,828,000	15

Hence, the integer linear programming model with demand uncertainty for this case is formulated as follows:

Objective Function

$$\max Z = \sum_{i=1}^{n} (P_i - H_i - T_i \times (L + E) - M_i - OC_i) \times Q_i \quad (8)$$

Subject to:

$$\sum_{i=1}^{n} T_i \times Q_i \leq 240 \quad (9)$$

$$Q_i \leq D_i \quad (10)$$

$$T_i \times Q_i \leq (30 - L_i) \times 8 \quad (11)$$

$$\sum_{i=1}^{n} M_i \times Q_i \leq 15{,}000{,}000 \quad (12)$$

$$Q_i \in Z;\ \forall i \quad (13)$$

$$Q_i \geq 0;\ \forall i \quad (14)$$

The data was processed with Lingo version 18.0, with the output in figure 2. The objective values obtained is IDR12,469,900. This represents the highest profit obtained from producing of each product as $Q_1 = 1;\ Q_2 = 6;$ and $Q_3 = 6$.

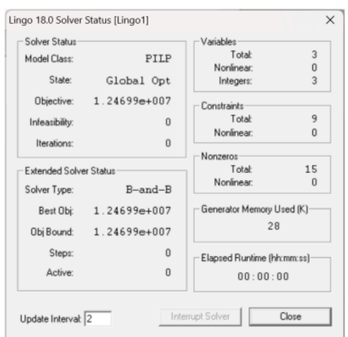

Figure 2. Output of Case Study

3. Sensitivity Analysis

Sensitivity analysis is conducted by varying the lead time and demand.

a. Sensitivity Analysis by decreasing lead time by one day: $L_i = [2,4,3] \rightarrow [1,3,2]$.

The data was processed with Lingo version 18.0, where the output in figure 3. The result shows that the objective value is IDR8,404,700. This represent that the maximum value of profit is IDR8,404,700 where the quantity of each product is $Q_1 = 5$; $Q_2 = 3$; and $Q_3 = 0$.

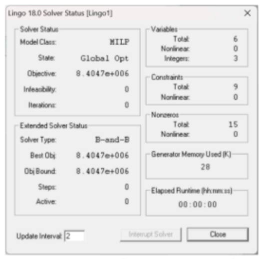

Figure 3. Output of Sensitivity Analysis 1

b. Sensitivity analysis by decreases demand by 10%: D = [5,10,8] → [6,12,9]

The data was processed with Lingo version 18.0, where the output in figure 4. The result shows that the objective value is IDR8,456,200. This means, the maximum profit obtained is IDR8,456,200 with the quantity of each product is $Q_1 = 6$; $Q_2 = 2$; and $Q_3 = 0$.

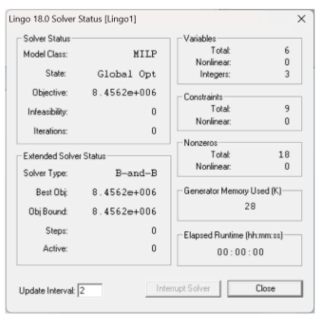

Figure 4. Output of Sensitivity Analysis 2

Consequently, the graph below indicates the finest quantities of manufacturing products for three goods (Prayer Mat, Table Runner and Cushion Covers) in base case and two sensitivity analysis alternatives.

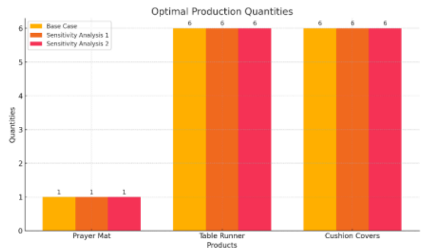

Figure 5. Optimal Production Quantities

After identification of the aforementioned points from base case: prayer mat 1 unit; table runner 6 units; and cushion covers 6 units, optimum quantities did not change with respect to sensitivity analysis one that was reducing lead times by a day, while in sensitivity analysis two which entailed increment of demand by 10%, optimal production quantities also remained unchanged relative to those adopted in the base case. This figure demonstrates robustness of the model because variations in lead time and increased demand do not affect order quantity. According to this suggest that overall, timeframes for each activity seems major constraint on production rather than changes in lead-times and increase in demand.

4. CONCLUSION

The study developed and analyzed an integer linear programming model for optimizing production planning of patchwork goods from Bali batik fabrics. The model aims at profit optimization while considering constraints such as material, handling, operational costs, durations of production, capital limitation and demands uncertainty. Results of the case study indicate that the best profit is IDR 12,469,900 with optimal production quantities of $Q_1 = 1$ prayer mats, $Q_2 = 6$ table runners, and $Q_3 = 6$ cushion covers. Two sensitivity analyses were carried out to test model's robustness under different conditions like reducing lead times by one day or increasing demand by 10%. The findings indicated that they ideal production quantity remain unchanged which means that the lead time variation does not affect this model. This indicates that overall production time and availability of capital are more constraining factors than fluctuations in demand. Many scenarios show that this model can be used confidently for strategic planning because it is able to withstand disturbances made on a few variables simultaneously. Understanding necessary limits such as manufacturing time and available capital helps handcrafters to optimally distribute resources and control their producing processes. However future research should work on improving the existing model by including other additions results showed that the optimal production quantities remained unchanged, indicating that the model is robust to changes in lead times and demand. This suggests that the primary limiting factors were the total production time and capital limitations rather than demand variations. The robust nature of the model under different scenarios ensures that it can be reliably used for strategic planning. By understanding critical constraints, such as production time and capital limitations, handcrafters can better allocate resources and manage their production processes more effectively. Future research should focus on refining and expanding the model to incorporate additional factors such as varying material costs, dynamic demand fluctuations, and sustainability considerations to further enhance its practical utility.

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