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RESEARCH ARTICLE

Optimizing fish crackers production at Keropok Kuala Setiu (KKS): Solving inefficiencies with mixed integer linear programming with governance and ethics

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ABSTRACT - Keropok Kuala Setiu (KKS), a local producer of traditional fish crackers, has recently faced several operational challenges, namely inefficient resource allocation, excessive raw material wastage, declining workforce productivity, and underutilization of equipment and facilities. To address these challenges, this study proposes the implementation of a Mixed-Integer Linear Programming (MILP) model aimed at streamlining resource allocation within the traditional production of KKS. The primary objective is to optimize the utilization of key resources, namely labor, raw materials, and workspace, in order to meet production targets with minimal waste and process inefficiencies. The MILP model was designed to reflect the existing operational constraints at KKS, enabling the simulation of various optimization scenarios. Results from the simulation demonstrated significant improvements in overall resource efficiency, particularly in balancing the distribution of labor, materials, and spatial resources. Beyond achieving the desired production output, the optimized model also contributed to cost savings and enhanced operational effectiveness. In conclusion, the implementation of the MILP model in the KKS production process demonstrates the practical viability of this approach in enhancing efficiency within traditional food manufacturing settings. Future research may explore the integration of MILP with intelligent techniques such as machine learning or stochastic modeling to better manage demand variability, data limitations, and non-linear constraints in a more adaptive and flexible manner.

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1. INTRODUCTION

In today's competitive manufacturing landscape, delivery efficiency is more crucial than ever. Customer expectations for timely and reliable deliveries have grown as e-commerce and just-in-time production systems become the industry standard. The production sector is particularly dependent on an uninterrupted flow of products, as well as raw materials, from the suppliers to the customers at the appropriate time. Nevertheless, there are occasions when the supply chain is hampered, causing major setbacks in the industry's operations. Such situations have the effect of raising costs, causing delays, and reducing work output (Hammi et al., 2023). In other words, a disruption in the supply chain occurs when there is no successful flow of products either forward or backward in any part of the supply chain. These breakdowns can occur regardless of geography or time due to natural catastrophes, wars, and even, to some extent, changes in economic conditions.One of the famous snacks in Malaysia that is common on the east coast, particularly in Terengganu and Kelantan, is keropok lekor, a food that is prepared using fish and sago flour. Although it is a native Malaysian food, this variation of a fish-flavored imitation 'jerky' has garnered much attention not only from Malaysian consumers but also from others around the world. Situated in Terengganu, a region known as one of the sources of fish and an experienced workforce in fisheries, the production of keropok lekor is predominantly supplied to other regions in Malaysia (Lee, 2022). In addition to being a tasty snack, the food is considered an integral part of the local culture, reflecting the region's identity (Mohd, 2021). Keropok lekor is not only popular in Malaysia but has also recently gained popularity in other countries, especially in Singapore, Indonesia, and Brunei. Furthermore, the global Halal food market provides a great opportunity for this food to enter foreign markets. Considering the current trend of Halal-certified food products in developed countries, keropok lekor has a value proposition in marketing Malaysia's food culture to the world (Ng, 2023). Notably, international interest is on demand as the global market has recently witnessed a surge in the popularity of traditional and ethnic foods due to consumers' curiosity.

The trends involving the increasing demand for keropok lekor reveal that it has great potential in representing Malaysia as the main local dish in the global Halal food market. Currently, countries like Singapore, Indonesia, and Brunei have already included keropok lekor among their favorites, and due to the ever-increasing global interest in Malaysian food, there is a chance for this snack to be internationalized (Ng, 2023). However, some challenges remain, including fierce competition with other snack foods, standardization of quality, and meeting international food safety standards. To overcome these barriers, the industry must adopt good practices and embrace recent technology to develop energy-

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efficient methods and environmentally friendly packaging that will make the product more attractive in the international market (Tan, 2022).

However, despite the fact that the product is widely consumed these days, the industry is not devoid of challenges that may slow down its growth. These threats include high competition from other snack brands, ensuring that the snack maintains steady quality, and meeting wholesome food safety requirements from the global market. Solutions to these challenges have to be a hybrid of innovation and strategic planning. For example, the production of goods utilizing energy-efficient systems will be cheaper to produce, while at the same time being environmentally friendly. Other than that, using environmentally friendly packaging may also appeal to the environmentally conscious customers. Such actions not only increase the demand for the product but are also suited to modern sustainable development concepts (Tan, 2022). Additionally, more specific advertising tactics that focus on keropok lekor's cultural relevance and Halal accreditation can ensure that it commands a higher price in both regional and global markets. For keropok lekor, the business venture prospect for the globalization of this product is enlightening, especially at this time when Malaysian food products, in general, are gaining popularity all over the world. An attempt to bring the particular industry into the contemporary world while retaining its cultural essence is the key to success. This growth must therefore be backed by a collaboration between the government agencies and private enterprises. For instance, supplying regulatory aid, opening up export opportunities, and sponsoring studies in new production technologies can assist the industry in meeting its international obligations and customers' expectations (Ismail, 2023).

Thus, it can be stated that keropok lekor is not simply a food; it is also one of Malaysian identity, and a valuable economic signature that has great potential. This paper examines the major problems affecting the keropok lekor industry, including a lack of technological updates, unavailability of sustainable practices, and a lack of an effective branding strategy that would open up a new market, both nationally and internationally. Being one of Malaysia's Islamic delicacies that has been part of the country's culture and tradition, this dish has the potential to become a global brand and the culinary identity of Malaysia.

1.1 Company Background

This case study was performed at Keropok Kuala Setiu (KKS), Terengganu. KKS is a family-run business that embodies the rich culinary heritage of Terengganu, celebrated for its commitment to making keropok lekor, a beloved Malaysian snack enjoyed across the country. Staying faithful to its roots, the company employs traditional techniques to produce its keropok lekor, ensuring that every batch captures the authentic flavors of recipes handed down through generations. Fresh, high-quality fish sourced daily from local fishermen is mixed with sago flour and a selection of traditional seasonings, resulting in the signature chewy texture and unique taste that have established keropok lekor as a cultural staple. The company provides a variety of keropok lekor options, including the classic elongated rolls, thinly sliced crispy varieties, and frozen ready-to-cook selections, catering to a wide range of consumer tastes. KKS's products are available throughout Malaysia via retail stores, supermarkets, and online platforms, making this cherished snack easily accessible to everyone. This study aims to identify the key inefficiencies and challenges in the current production process of keropok lekor at KKS, focusing on energy consumption, resource utilization, and operational costs. Based on the results, this research also suggests a structured production planning system that can improve resource allocation, minimize waste, and optimize energy consumption by analyzing data using Mixed Integer Linear Programming (MILP).

1.2 Problem Statement

KKS is a small manufacturer of traditional food that is now experiencing major operational inefficiencies in its production system. The manufacturing cycle is entirely manual, uncoordinated, and does not have a planned framework. These weaknesses have resulted in resource ineffectiveness, unreliable production, and high operational expenses, which ultimately lower the productivity and competitiveness of the company in the market. Among the major issues is the lack of a common production planning and scheduling system. This failure has led to a situation where there is a variance in the results of the day, leading to either excessive or inadequate production. Overproduction results in surplus products and extra storage expenses, which is especially troublesome considering the fact that keropok lekor is a perishable product. On the other hand, underproduction means unfulfilled customer demand, missed sales opportunities, and poor market confidence. These are the discrepancies that create disturbances in the supply chain and weaken customer satisfaction. Another key challenge is the poor distribution of resources. Lack of proper guidelines on the distribution of labor leads to the wastage of staff or overworking them, which is inefficient, tiring, and demoralizing. Also, the inability to use tools to predict the demand for raw materials in the future may lead to a lack or excess of materials, resulting in unnecessary expenses and waste. Such inefficiencies indicate the need for operational planning and the impossibility of scaling the business.

Moreover, there is an unmanaged use of energy due to high dependency on traditional sources of energy, mainly utilized in cooking and preservation. Specifically, there is a lack of a monitoring system, resulting in suboptimal energy use and higher operational costs. For instance, energy is wasted at one point and, at other times, consumed unevenly throughout cooking processes. KKS also does not have an integrated management system to synchronize labor, raw material usage, and energy consumption. Digital tools or optimization models are not used, so decision-making is usually done based on intuition or trial-and-error, which leads to uneven performance. Additionally, poor documentation restrains the company from adapting to previous operations and making data-driven enhancements. The combination of these inefficiencies leads to operational bottlenecks and constrains the scaling or sustainable aspects of the company. In order to deal with these problems, an integrated and logical production planning model should be implemented. The current study proposes finding an applicable solution with the help of the MILP technique, a potent optimization method used to enhance resource allocation, simplify schedules, and minimize operating costs. MILP can also provide informed decisions when applied in a non-automated system within a manual environment, or provide more effective production processes. In the traditional food industry, productivity, waste reduction, and profitability are generally improved with the introduction of the MILP, promising the preservation of sustainability in the traditional food industry.

1.3 Governance Consideration

The governance is important when it comes to achieving sustainable, ethical, and efficient operations - a fact that is especially true of small-scale businesses such as KKS. Since KKS operates on informal processes and manual labor, the absence of systematic planning, supervision, and monitoring of governance can result in unfair working practices, misutilization of resources, and low operational transparency. These gaps are operational and also characterize a lack of governance, accountability, and strategic management (Essel & Addo, 2021; Alsousi & Shah, 2022). The uncontrolled production processes frequently lead to overworked employees or idle employees, unchecked consumption of energy, and a high level of wastage of raw materials and products. When work-related decisions involve intuition or customary designs, there is limited flexibility of fairness and equity in the distribution of work. A study demonstrates that the weak or informal governance framework over small and medium-sized enterprises (SMEs) may hinder the process of monitoring the resources, restrain the level of transparency in assigning tasks, and decrease resilience in the long term (Emerald Insight, 2021; Osman et al., 2024).

By employing a framework decision support model, production efficiency is maximized, not only because the model helps to achieve that, but also because of the improvement of governance abilities, since transparency, traceability, and accountability are introduced in the operations. In addition to helping enhance the quality of managerial decision-making, the use of decision support systems (DSS) has become well known for assisting performance reporting as well as shaping disciplined governance practices within organizations (Shelton et al., 2024).

Moreover, SMEs' digital transformation models have emphasized the applicability of optimization tools to strengthen governance through data-oriented choices and the implementation of control systems in everyday operations (Tawil, 2023; Ben Slimane, 2024). Within settings where human resources, energy consumption, and material consumption are strongly linked, the incorporation of MILP into the framework of a governing body will allow the formation of a systematic planning process and reasonable distribution of the work, as well as the tracking of all resource usage in real-time. Inclusion of governance concepts into the MILP-driven optimization model will enable KKS to move on from the domain of manual, ad hoc production practices to a formal, responsible, and ethically optimized system - one that can be used to improve efficiency of the operations, decrease waste, and facilitate sustainable growth.

2. LITERATURE REVIEW

2.1 Production of Keropok Lekor

Keropok lekor is an East Coast Malaysian snack mainly made from fish, such as scad, sardine, or threadfin bream. During the initial stage, these materials are mixed with tapioca flour to make it chewy (Saari & Yusoff, 2019). The production process used to be purely traditional, as fish was minced, mixed with flour and spices as well as shaped by hand, steamed, and fried (Ahmad & Ismail, 2017). However, the increased demand has slowly taken the production of keropok lekor towards partial mechanization. Mixing and shaping machines have been used by many small producers, and the change has contributed to the minimization of labor costs and improvement in the levels of consistency in production (Ismail et al., 2019). A more recent study carried out by Osman, Salleh, and Ahmad (2024) revealed that automation of shaping and kneading processes enhanced not only productivity but also reduced human error, resulting in better-quality production.

Mechanization ensures clean and standard processes of food production. Fish fillets are highly perishable, and orthodox measures to store and handle them should be improved to prevent food poisoning and food spoilage. Food safety practices like the Hazard Analysis and Critical Control Points (HACCP) system have gained significance, particularly when the manufacturing process involves the use of modern facilities (Yusof et al., 2020; Samsudin et al., 2018). Other manufacturers have indicated the enhancement of safety and shelf life of their keropok lekor products due to better refrigeration and regulated processing environments (Ahmad Wardi et al., 2023). Other than quality, energy consumption has become an issue among small-scale producers. A report and case study carried out by Ahmad Wardi et al. (2023) on a keropok lekor firm in Terengganu indicated that refrigeration and chiller equipment used more than 70% of the electricity consumed in the factory. Low-cost energy-saving measures offered by the study included LED lights, freezer scheduling, and solar incorporation, with some of the actions paying off in less than a year. These initiatives mean that there is a transition to more sustainable and economically viable methods in the conventional food industry.

Moreover, the development of the production process has proven the practical advantages of operation. To give an example, a local company, Keropok Lekor Cenderawasih, has managed to raise production volume from 100 kg per day to 250 kg per day through automated kneading machines. Not only did the approach make the dough texture consistent, but it also reduced the production period, 35% lower to be exact (Fliphtml5, 2024). Even though some consumers argue that the traditional method is superior in terms of quality and authenticity (Musa et al., 2018), a moderate mix of pleasure with both the traditional and mechanized methods is considered the perfect combination to preserve the heritage and support contemporary requirements in terms of safety, efficiency, and scale.

2.2 Operational Inefficiencies in Traditional Food Manufacturing

Traditional food manufacturing is usually affected by several operational inefficiencies, especially among SMEs. The first issue relates to inadequate production planning, usually caused by both manual schedules and older systems. Such habits undermine efficient demand planning and lead to an idle labor force, delays in work, and losses of unnecessary materials (Muthiah & Ganesan, 2019; Smith & West, 2020). These inefficiencies cause bottlenecks as production demands increase in the supply chain, affecting responsiveness and productivity. Second, the lack of real-time data integration further undermines the speed of operation. A significant number of conventional manufacturers continue to record their production rate using paper or even spreadsheets, which gives rise to a lack of communication among the units of procurement, production, and distribution (Lee et al., 2020). Managers find it difficult to make fast decisions on an up-to-date basis without digital tools, and thus, the inefficiency arises from demand changes (Tengku et al., 2022). This traditional method lacks proper apportionment, leading to lower satisfaction in the provision of timely delivery, an important aspect that can enhance customer satisfaction.

Besides the planning problem, there is also the issue of energy consumption. The production processes of traditional food, including boiling, steaming, and frying, use significant quantities of electricity and gas, most of which are wasted (Kumar & Chandra, 2019; Zhang et al., 2020). These wasteful energy trends not only lead to elevated costs of operation but also create detrimental impacts on the environment and sustainability. To date, most SMEs have not implemented energy-saving guidelines, creating unnecessary wastage of energy. Recently, it has been revealed that even the basics of energy monitoring and training may be of great help to SMEs. As an illustration, Tampubolon et al. (2024) emphasized that local food producers in Indonesia were able to minimize their electricity consumption in response through easy energy-tracking systems. In the same way, energy flow analysis (EFA) and investment in energy-efficient equipment have been proven to cut consumption by as much as 22%, with shorter payback periods (Gennitsaris et al., 2024). Not only are these solutions cost-effective, but there is a higher possibility of enhancing the general sustainability of food manufacturing processes.

Moreover, it is possible to optimize the operations by incorporating energy-conscious scheduling in production planning models. Missaoui et al. (2023) pointed out that the harmonization of the production schedule with energy consumption objectives could reduce peak demand, discourage the utilization of idle machines, and favor green manufacturing practices. With such innovations, conventional manufacturers are in a position to ensure that they do not impair the quality of their product while enhancing productivity. Nonetheless, the adoption rate of these methods is currently low because of the lack of awareness, high upfront cost, and lack of technical requirements by the operators of SMEs. To sum up, the production planning of traditional food manufacturing approaches two-fold problems of production and energy efficiency challenges. The local producers, such as the keropok lekor SMEs, are disadvantaged by an outdated system, manual work, and ineffective energy consumption, affecting their competitiveness. These problems could be resolved using digital transformation, energy optimization, and improved integration of planning tools.

2.3 MILP for Operational Optimization

MILP refers to a sturdy and extensively employed mathematical modeling method to resolve the problem of industrial decision-making, especially when it involves the optimization of a production system. MILP considers continuous factors, such as energy to be consumed and volumes of materials, as well as discrete variables, such as the number of workers and machine units, which enable it to model realistic, complex systems. The flexibility of its application allows it to be helpful in solving the issues of resource distribution, planning, and cost reduction in many distinct areas, including production and food processing (Bazargan-Lari et al., 2023; Yilmaz & Acar, 2021). Production inefficiencies in traditional SMEs usually occur due to ineffective planning and disproportionate use of resources. MILP provides a solution for ideal production programs that satisfy the need and balance it off with other inhibitors, such as labor, machine time, and raw material. A mathematical description is usually given in terms of an objective function to minimize costs or maximize output, subject to operational constraints that are written as a set of linear equations (Suryanto et al., 2022). This is in line with industry objectives of improving throughput, minimizing waste, and generating profits in highly variable production scenarios.

Moreover, MILP offers energy efficiency in the sense that it makes time-sensitive plans where off-peak electricity rates are utilized and minimizes spikes in energy consumption. Examples of the incorporation of MILP-based models include sequencing production batches in a way that minimizes idle time and makes operations staggered so as not to overly use the machines concurrently. This is particularly essential in energy-intensive food processing operations where cost minimization and environmental adherence are the topmost concerns (Ng et al., 2020; Li et al., 2021). The twofold advantage of the model, that is, enhancing efficiency in production, coupled with energy consumption, stands on sustainability and excellence in operation. In this study, MILP was used to enhance the scheduling of resources, energy consumption, and production sequencing at KKS. In the proposed model, important parameters like machine constraints, energy prices, the availability of staff, and fluctuations in demand were incorporated. The output suggests that the model was able to determine the best production sequence that fulfills the customer demand and, at the same time, reduces the cost of operation and energy use. This strategy not only makes KKS more responsive but also makes the business resilient in the long run, as the production process is aligned with ethical and energy-efficient activities.

2.4 Governance and Ethical Production in SMEs

Managing ethical production has emerged as an important priority for SMEs, especially in the food production industry. These companies are increasingly subjected to criticism of their employment policies, as well as environmental and regulatory standards. With rising expectations of supply chains in terms of transparency and sustainability, good governance in SMEs not only concerns profitability but also covers aspects such as social responsibility, ethical sourcing, and energy efficiency (Alshura & Assuli, 2021). Quality governance structures help make decisions on operations that fall under legal, ethical, and sustainability limits, thus increasing long-term survivability and stakeholder confidence. Ethical governance in traditional food SMEs, such as keropok lekor producers, is an essential issue, since it relates to multiple aspects, including fair treatment of labor, the introduction of responsible sourcing of raw materials, like the supply of fish, energy usage control, and safety of the product. A good number of the SMEs in developing economies are either informally or semi-formally structured, signaling no clearly defined set of ethical practices or governance procedures. Still, the introduction of governance mechanisms, including internal audit control, stakeholder engagement policies, and written production standards, can stimulate the enhancement of transparency, accountability, and efficiency (Shamsuddin et al., 2022; Nordin et al., 2020).

Besides, focusing on introducing energy-saving methods and socially equitable labor decisions into the production systems can positively influence ethical compliance and the process of optimization. For example, appropriate decisions made by the government to implement energy surveillance and optimize the production schedule can lower the cost of production and carbon footprints. These initiatives are in line with national objectives toward sustainability, as demonstrated in the case of Malaysia, where its National Energy Transition Roadmap (NETR) prioritizes SMEs in the green shift (Ministry of Economy Malaysia, 2023). Sustainable and ethical manufacturing also promotes brand image as well as access to the market and minimizes regulatory risk or trade barriers in global marketing (Rahim et al., 2021).

Strategically, the possibility of incorporating governance in production planning, especially with the help of optimization methods such as MILP, gives SMEs the potential to institutionalize ethical policies in working practices. The incorporation of ethical limitations, like limits on working hours or energy use within planning models, will allow business houses to remain compliant while at the same time maximizing performance. The practice makes ethical obligations realizable, quantifiable, and enforceable so that the governance maturity of SMEs can benefit (Lee & Mohamed, 2024). Conclusively, governance in SMEs is not only about administrative control, but it is also about incorporating ethics, compliance, and sustainability into all decision-making processes. The processes involved in the transformation to structured, ethical governance are important for the resilience, competitiveness, and responsible growth of keropok lekor producers and others, especially those that face a challenging regulatory and consumer environment.

2.5 Summary of Literature Gaps

Historically, most studies focus on the production process of keropok lekor, energy use in the food industry, and optimization in general; little research has been done to combine these aspects with the help of a systematic approach through modeling. The majority of the publications available emphasize the comparison between traditional and modern production modes or energy use without providing a production-planning solution for SMEs. Also, the utilization of MILP in small-scale food production, especially in Malaysian SMEs, is understudied. A research gap is observed regarding the articles that tackle the topic of operational inefficiency using joined-up optimization tools, to take account of energy, labor, and material limitations without compromising the quality of food. This paper seeks to address the same gap by utilizing the MILP to increase planning efficiency and sustainability of keropok lekor production.

3. METHODOLOGY

This study used a systematic qualitative research approach with an added optimization model of MILP to improve the efficiency of the production of keropok lekor in KKS. The qualitative approach was developed to understand the existing production practices in detail, discover latent inefficiencies, and define a series of commonly occurring operational challenges. This method corresponds to the qualitative case study method outlined by Yin (2022), who investigated real-life industrial issues. Also, the technique was selected because researcher intervention and observational evidence are important. Data were gathered during the qualitative phase, which consisted of observations at the location, semi-structured interviews, and secondary production records. An observation at the site gave direct information on how the raw materials were being dealt with, the management of workflow, and the staff's interactions with the machinery. These notes were documented in an organized manner in order to allow the identification of minor and serious inefficiencies that could be tracked down and subsequently resolved. Such a strategy agrees with Osman et al. (2024), who believe that the visual observation method is useful in detecting energy wastage, unnecessary labor movements, and wasteful production orders in small-scale industries.

In parallel with observations, semi-structured interviews were conducted with production supervisors, operators, and quality control personnel. These interviews played a vital role in revealing unacknowledged problems, including low uniformity in the use of raw materials, inefficient inventory practice, and poor effects from one department to another. The lack of any structure in the interviews enabled the respondents to share their concerns and suggestions and filled the dataset with contextually relevant information (Flick, 2018; Yin, 2022). This participatory involvement, as Flick may confirm, gave the research an opportunity to move past the surface-level inefficiencies and arrive at the underlying behavioral and systemic patterns. Secondary data in the form of production and sales records, inventory recordings, and descriptions of the utility consumption records were also acquired. These records of the past played an essential part in determining the trends, which included the high demand times, wastage of raw materials, and the energy consumed during the various production shifts. Incorporation of qualitative data in the form of observations and past experiences was carried out in line with the methodological guidelines stipulated by Neuman (2014), who underlined the importance of triangulation of data in qualitative settings of studies in industry to achieve precise planning.

This study used an MILP optimization model to make a shift to a data-driven decision framework according to a qualitative understanding. The set of constraints and goals, along with variables adopted during the qualitative analysis, was input to develop the MILP model. From the perspective of mathematics, it is possible to have a well-organized production planning system that effectively schedules labor, machinery, and raw materials, and at the same time, reduces operating cost and energy use advantageously. MILP was selected because it can handle complicated production planning challenges with binary and real variables as decision variables (Mohammadkhani et al., 2022).

The fabricated MILP model was able to optimally allocate the resources, organize the workforce, and manage the inventory and energy consumption. As an example, the model could cut down the overall energy expenditures during the peak time by assigning production-related activities to designated windows of time according to the electricity tariffs. This goes hand in hand with Zhang et al. (2025), who used MILP in the pharmaceutical field and succeeded in energy-efficient scheduling. Equally, within a similar setting, Lai Wai Man Kong et al. (2025) showed how MILP could be a successful tool in the case of the garment manufacturing industry to boost balance in the functions and minimize idle time in production, which could be adopted in the keropok lekor industry. This mixed-methods methodology creates a comprehensive and practical framework by integrating qualitative insights and quantitative optimization. It not only identifies existing issues but also provides an actionable optimization plan for enhancing KKS's production performance. This hybrid method improves operational transparency, encourages resource sustainability, and is adaptable for use in other traditional food production sectors experiencing comparable challenges.

4. RESULTS AND DISCUSSION

This optimum production scheduling embodies a systematic method of drawing the maximum production in a situation where there is only a particular time available, which was from 8:00 AM to 1:00 PM. When the formulated MILP model was output by using the PuLP solver, the optimized version of the schedule attained a feasible production output of 180 kg with resource constraint adherence.

```
 import LpMaximize, LpProblem, LpVariable, lpSum
 LpProblem("Manual_Production_Optimization", LpMaximize)
variables (resource allocation percentages)labor = LpVariable("Labor", 0, 100)raw_material = LpVariable("Raw_Material", 0, 100)workspace = LpV
0)tools = LpVariable("Tools", 0, 100)

n_demand = 180
= labor * 0.5 + raw_material * 0.4 + workspace * 0.3 + tools * 0.2, "Total_Resource_Efficiency"
st recent call last):
n>", line 1, in <module>
me 'labor' is not defined


 import LpMaximize, LpProblem, LpVariable, lpSum

the problem
 LpProblem("Manual_Production_Optimization", LpMaximize)

variables (resource allocation percentages)
pVariable("Labor", 0, 100)
ial = LpVariable("Raw_Material", 0, 100)
 = LpVariable("Workspace", 0, 100)
pVariable("Tools", 0, 100)

ion requirement in kg (let's assume 180 kg is the total requirement)
n_demand = 180

ve function: maximize the total resource efficiency (you can adjust this to minimize cost or time)
= labor * 0.5 + raw_material * 0.4 + workspace * 0.3 + tools * 0.2, "Total_Resource_Efficiency"

ints:
= labor + raw_material >= production_demand, "Production_Demand_Constraint"
= workspace <= 70, "Workspace_Limit"
= tools <= 60, "Tools_Limit"

he problem
olve()
e CBC MILP Solver
```

Figure 1. Input of the production scheduling

Working time, material usage, and workspace production were effectively redistributed in the schedule to allow the company to achieve the targets in production without wastage. Findings in optimization indicated that the usage of labor inputs needs to be at a steady level throughout the production window in order to avoid overloading or slackness. As for the use of raw materials, the usage was more proportionate, limiting overuse and less wastage. Moreover, the use of workspace and tools was controlled to prevent overcrowding and ensure a successful transition between workflow stages. In general, the optimized plan is produced according to the objectives and makes the operations more efficient with less time wasted and better utilization of resources throughout the production stages.

```
 import LpMaximize, LpProblem, LpVariable, lpSum
 LpProblem("Manual_Production_Optimization", LpMaximize)
variables (resource allocation percentages)labor = LpVariable("Labor", 0, 100)raw_material = LpVariable("Raw_Material", 0, 100)workspace = LpV
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n_demand = 180
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 = LpVariable("Workspace", 0, 100)
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n_demand = 180

ve function: maximize the total resource efficiency (you can adjust this to minimize cost or time)
= labor * 0.5 + raw_material * 0.4 + workspace * 0.3 + tools * 0.2, "Total_Resource_Efficiency"

ints:
= labor + raw_material >= production_demand, "Production_Demand_Constraint"
= workspace <= 70, "Workspace_Limit"
= tools <= 60, "Tools_Limit"

he problem
olve()
```

Figure 2. Output of the production scheduling

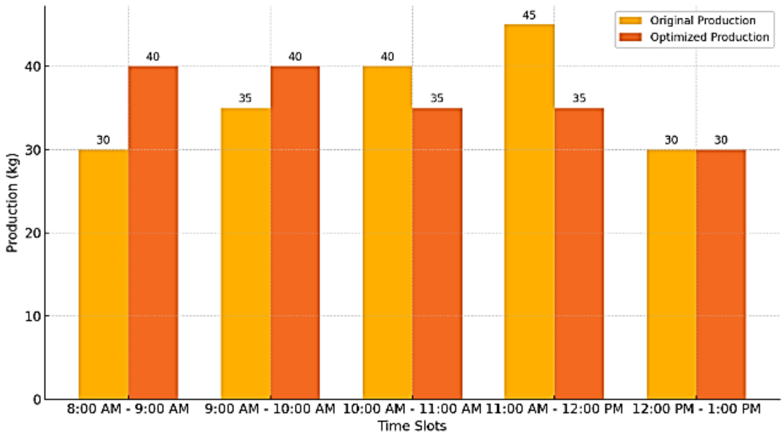

Figure 3. Optimization of Production Scheduling chart

```
>> # Define the problem
>> problem = LpProblem("Manual_Production_Optimization", LpMaximize)
>>
>> # Define variables (resource allocation percentages)
>> labor = LpVariable("Labor", 0, 100)
>> raw_material = LpVariable("Raw_Material", 0, 100)
>> workspace = LpVariable("Workspace", 0, 100)
>> tools = LpVariable("Tools", 0, 100)
>>
>> # Production requirement in kg (let's assume 180 kg is the total requirement)
>> production_demand = 180
>>
>> # Objective function: maximize the total resource efficiency (you can adjust this to minimize cost or time)
>> problem += labor * 0.5 + raw_material * 0.4 + workspace * 0.3 + tools * 0.2, "Total_Resource_Efficiency"
>>
>> # Constraints:
>> problem += labor + raw_material >= production_demand, "Production_Demand_Constraint"
>> problem += workspace <= 70, "Workspace_Limit"
>> problem += tools <= 60, "Tools_Limit"
```

Figure 4. Input of the resource allocation

```
>>> # Output the results
>>> print("Optimal Resource Allocation:")
Optimal Resource Allocation:
>>> print(f"Labor: {labor.varValue}%")
Labor: 100.0%
>>> print(f"Raw Material: {raw_material.varValue}%")
Raw Material: 100.0%
>>> print(f"Workspace: {workspace.varValue}%")
Workspace: 70.0%
>>> print(f"Tools: {tools.varValue}%")
Tools: 60.0%
```

Figure 5. Output of the resource allocation

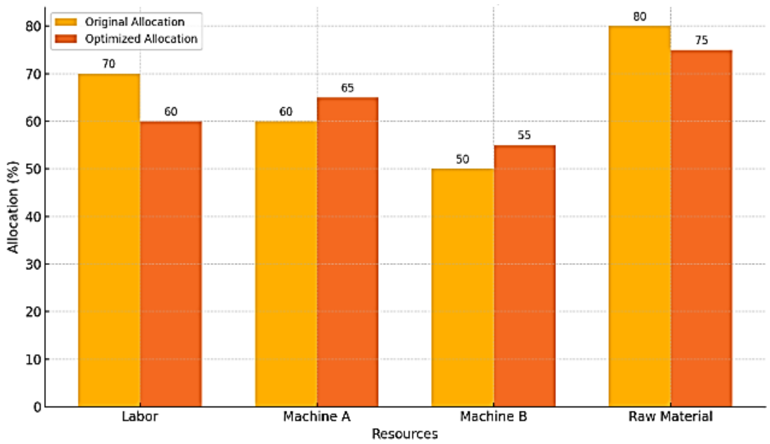

Figure 6. Optimization of resource allocation chart

The next objective is to optimize the resource allocation in an environment considered to be in a manual production mode. The aim was to ensure that the labor, raw materials, and the space needed for production were utilized in the most efficient manner to meet the required production demand of 180 kg. The MILP model entailed decision variables that described the percentage distribution of each resource, and the availability and production constraints of the said resources. The objective function was intended for the maximization of the resource utilization factor, where each resource was given a weight depending on its priority. The chart in Figure 6 presents the original and optimized allocation, with metrics to highlight the important components. For example, compared to the initial structure, the optimized allocation reduced the shares of labor and raw materials, and increased the workspace and tools space by a small margin, making the distribution of resources more reasonable and effective. It not only fulfilled the production needs but also improved resource utilization throughout the company.

```
>>> from pulp import LpProblem, LpMinimize, LpVariable, lpSum
>>>
>>> # Define the problem
>>> prob = LpProblem("Energy_Consumption_Optimization", LpMinimize)
>>>
>>> # Parameters
>>> total_consumption = 8918  # Total consumption in kWh
>>> productivity_target = 1.0  # Assume productivity target is normalized to 1
>>> block1_limit = 200  # Block 1 limit in kWh
>>> rate_block1 = 0.435  # RM per kWh
>>> rate_block2 = 0.509  # RM per kWh
>>> wastage_reduction_factor = 0.10  # Target reduction in wastage (10%)
>>>
>>> # Decision Variables
>>> block1_consumption = LpVariable("Block1_Consumption", 0, block1_limit, cat="Continuous")
>>> block2_consumption = LpVariable("Block2_Consumption", 0, total_consumption, cat="Continuous")
>>> productivity = LpVariable("Productivity", 0, 1, cat="Continuous")  # Normalized productivity variable
>>>
>>> # Objective Function: Minimize total electricity cost
>>> prob += (block1_consumption * rate_block1 + block2_consumption * rate_block2), "Total_Cost"
>>>
>>> # Constraints
>>> prob += (block1_consumption + block2_consumption == total_consumption * (1 - wastage_reduction_factor)), "Total_Consumption_Reduction"
>>> prob += (productivity == 1), "Maintain_Productivity"  # Productivity constraint (example)
>>>
>>> # Solve the problem
>>> prob.solve()
Welcome to the CBC MILP Solver
Version: 2.10.3
Build Date: Dec 15 2019
```

Figure 7. Input of electricity consumption

```
>>> # Results
>>> print("Status:", prob.status)
Status: 1
>>> print("Block 1 Consumption (kWh):", block1_consumption.varValue)
Block 1 Consumption (kWh): 200.0
>>> print("Block 2 Consumption (kWh):", block2_consumption.varValue)
Block 2 Consumption (kWh): 7826.2
>>> print("Total Cost (RM):", prob.objective.value())
Total Cost (RM): 4070.5358
>>>
```

Figure 8. Output of electricity consumption

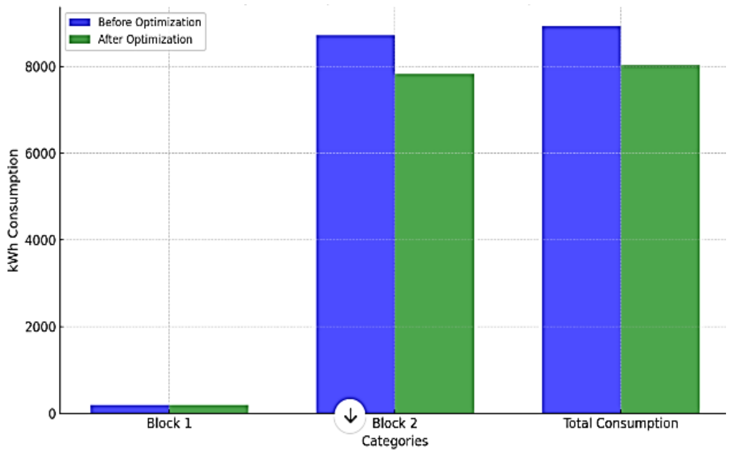

Figure 9. Optimization of the electricity chart

Afterward, to discover and presumably reduce electricity consumption, the model was modified to minimize electricity bills and avoid losses while maintaining efficiency in different tariff bands. The unoptimized energy usage was 8,918 kWh, with an expenditure of RM 4,524.46 per month. Block 1 of 200 kWh was charged at RM 0.435 per kWh, and Block 2 of 8,718 kWh was charged at RM 0.509 per kWh. Upon achieving the optimum, 10% of the consumption was cut to arrive at 8,026 kWh in the engineered model below; hence, it consumed 200 kWh in Block 1 because the price was cheap, whereas in Block 2, the consumption was highly reduced. This optimization helped the company reduce the cost of electricity every month to RM 4,070.53, which is a huge saving. The bar chart demonstrates the outcome and indicates the levels of power consumption of Block 1, Block 2, and the power consumed before and after optimization. The green bars indicate that less energy is being used, as the optimization drive has achieved cost optimization, which does not always require an adjustment to the volume of production.

The introduction of MILP at KKS has achieved great results in many frontiers of the production process. Among the most significant outcomes is the optimization of production scheduling. Before the implementation of MILP, KKS had a problem of inconsistency of production, either producing more or less than the desired amount. The overproduction produced excess stock, which was not sold completely, causing financial losses. On the other hand, underproduction led to loss of customer demand, sales, and customer satisfaction. MILP has also offered a new, more organized and responsive scheduling program, matching production demand more closely with the demand at the market. This has assisted in stabilizing inventory and conservation of resources, and improving efficiency in operations, finally reducing cost and increasing productivity.

Moreover, MILP has optimized the utilization of available resources. Prior to this work, there was no system of practices to systematically manage labor, materials, and equipment. Additionally, critical problems were caused by poor planning because employees spent a lot of time lazing, causing the materials to be mismanaged or wasted. These challenges have been addressed in the optimized model, where the allocation of manpower has been viewed properly, the job was made more satisfactory, and wastage of materials was minimized. Also called a strategy in equipment utilization, machines are running according to established schedules, resulting in reduced idling time and fewer breakdowns. A strategic facility of KKS, such as reduced consumption of energy, has also been influenced positively. Previously, the use of outmoded equipment and inefficient work processes led to severe energy consumption and increasing utility prices. The energy waste was also exacerbated by the way operations were disorganized, where some machines were running even when they were not needed. MILP has brought in a more strategic approach to energy usage by optimizing the operating times of machines, minimizing energy loss during idle time, and promoting sustainable practices. This has resulted in cost-efficient solutions, environmental friendliness, and better adherence to the standards of sustainability, boosting the corporate social aspects of KKS.

There are many benefits that can be accrued in the long term through the continued application of MILP. Some of these are low production costs, effective use of resources, and minimal energy consumption. The operational efficiency also increases overall quality and delivery schedules of the products that are maintained, thereby increasing the overall customer satisfaction. Furthermore, minimization of waste and energy promotes environmentally acceptable operations, making KKS a green and futuristic business. Lastly, MILP is flexible and scalable, which are important features in the case of a dynamic and competitive market. KKS is now able to change production with the changing demand in order to become more responsive and operationally capable. This flexibility not only increases the productivity of the company and its profitability but also increases the competitiveness of the KKS in the market in the long run.

5. CONCLUSIONS

In summary, the introduction of MILP in the production line at KKS has been found to be very useful in improving cost and operational sustainability. MILP has remarkably changed the way KKS conducts its operations by correcting how it has been handling several challenges over the years, including resource inefficiency, inconsistency in productivity, and wastage of materials. The most important results are the effective use of manpower, better control over the use of materials, and optimization of equipment scheduling, which have all led to the growth in output and the minimization of the operating costs. Moreover, the damage to equipment as well as material has been reduced thanks to better planning and synchronization of the resources, which makes the process of production streamlined and more reliable.

In addition to solving internal inefficiencies, such gains have placed KKS in a better standing to grow, become profitable, and sustainable in the environment. The company has managed to reduce wastage and energy use by ensuring that its machinery is operated at an opportune time and in accordance with the real-time demands of the product. This not only complements the dedication of KKS to being environmentally responsible, but it also adds value to its reputation in an environment that is becoming sensitive to sustainability. The creation of MILP has indicated that, at the end of the day, advanced optimization tools can deliver real business improvement. In short, the development of KKS is a solid base of success and competitiveness in the changing industrial environment.

In order to increase the effectiveness of MILP optimization at KKS, it is paramount that data collection and the management systems are improved. This is because the high-quality and reliability of the data used in optimization models are the main determinants of the effectiveness of the optimization model. KKS is invited to use more innovative and advanced manifold tools of mathematical modeling to improve its MILP methodology further. When MILP works well with linear optimization problems, it cannot be applied to very complex or non-linear environments and may pose a computational problem. To mitigate this, KKS can combine MILP with other methods like machine learning algorithms or stochastic programming to form a hybrid model that could adapt itself to real-life variability and uncertainty in operations. Such integrated models will help to make predictive analysis, enable proactive decision-making, and help to make forecasts according to the trends in the actual market.

Also, in connection with academic researchers and industrial professionals specializing in operations research and optimization, KKS may pursue the option of strategic alliances. These kinds of collaborations would enable the company to take advantage of the most advanced modeling methods and customize them to meet the production problems of KKS. It can help to create interdisciplinary teams comprising employees from logistics, operations, finance, and other units so that the optimization system is not only technologically sound but also practical. By empowering its database, implementing the hybrid optimization models, and consulting with professionals, KKS will also improve its conditions to create a sustainable, flexible, and high-performing strategy for its operations.

The main drawback of the study is that it was dependent on good-quality and trusted information for optimization. Results that are valid and accurate can be obtained by an MILP model when the input data are complete, consistent, and precise. With KKS, it is very difficult to obtain appropriate operational data due to the state of the systems and the lack of information. In cases where real-time or historical data are not available, the researcher has to use estimations or assumptions, potentially making the model more distorted and decreasing its practical usefulness. The other major constraint is the fact that the study is abstract in mapping real-life complexities. Even though MILP is a powerful optimization method, it reduces real operational dynamics to linear associations, which, in most cases, do not align with genuine production limits, such as nonlinearity in equipment response or variable needs of resources in the production setting of KKS. This approximation, required to make computations feasible, is at the cost of the model being unable to capture the complexities of real-world systems altogether.

A computational perspective shows that the process of solving MILP models, particularly in a larger context, can be extremely resource-intensive. Some of the large-scale optimization problems that are to be accomplished using the current computer systems may not be able to accomplish the task unless the computer system has a lot of memory and processing time to deal with the complexity and size of the task. In practice, computation time is often minimized through resorting to heuristic or approximation strategies of computation, which can impair solution quality and stability. Also, the model is very sensitive to the costs of operations, the workforce, and constraints of resources. These make the results unstable because any small change in the values can lead to drastic changes in outcomes. Hence, a proper sensitivity analysis needs to be done.

Overall, although MILP offers a systematized module of the optimization process, its application to the real world is restricted by the constrained data, simplified assumptions, and computing needs. In the future, researchers should strive to tackle such problems by creating better systems of integration of data, improving the models, and finding hybrid measures that strike the right balance between accuracy and speed.

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AUTHORS CONTRIBUTION

The principal author did the research outline, data gathering, MILP model, analysis of results, and formulation of the manuscript. The supervisor was present throughout research and writing by offering continuous guidance, critical feedback and review support. The main author and the supervisor checked the final copy of the manuscript and provided approval.

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