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Multi-Objective Optimization for Integrated Production Planning and Control

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ABSTRACT

Integrated production planning and control is an essential aspect in ensuring operational efficiency in the manufacturing sector. However, companies often face challenges in optimizing various goals that frequently conflict, such as cost reduction, quality improvement, and production capacity. Therefore, multi-objective optimization methods are particularly relevant for resolving conflicts between objectives in production planning and control. The research aims to develop a multi-objective optimization method that integrates production planning and control, enabling the company to achieve an optimal balance between various conflicting objectives and improve overall operational efficiency. The approach employed in this study is a multi-objective optimization method that combines genetic algorithms and mathematical programming. This model integrates production, quality management, and cost factors in a single framework to achieve optimal results. Simulations were conducted on various production scenarios to assess the performance of these models. The simulation results indicate that the application of multi-objective optimization methods can lead to more efficient production planning, resulting in a 20% reduction in costs and a 15% improvement in product quality. The model also shows increased flexibility in responding to changes in market demand.

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1. INTRODUCTION

Integrated production planning and control play a vital role in improving operational efficiency in the manufacturing sector. In practice, companies often face challenges in managing conflicting goals, including cost reduction, product quality improvement, and increasing production capacity. One way to address this challenge is to utilize the multi-objective optimization (MOO) method, which enables companies to optimize multiple objectives simultaneously, considering the limitations and variability inherent in the production system. Along with the development of technology and analytical methods, the integration between production planning and control is becoming increasingly important to face increasingly fierce global competition (Modibbo et al., 2024; Haq et al., 2020; Zhang et al., 2020). In Indonesia, manufacturing remains one of the main contributors to

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GDP, accounting for around 19% of total GDP in 2023, with significant pressure to improve efficiency amid rising energy costs and fluctuating raw material prices.

The use of MOOs for integrated production planning is becoming increasingly important, given the growing complexity in the manufacturing industry. This method offers the potential not only to improve production efficiency but also to reduce waste, enhance product quality, and ensure delivery accuracy. Therefore, the development of models that can optimize multiple objectives simultaneously in complex production systems is particularly relevant for improving the competitiveness and sustainability of the industry (Ma et al., 2023; Zhang et al., 2020). In the Indonesian manufacturing context, data from the Ministry of Industry indicate that inefficiencies in production planning result in an average annual cost overruns of 12–15%, which could be mitigated through integrated optimization methods.

Multi-objective optimization theory has been widely used in various fields, including production planning. Based on the existing literature, MOOs enable more flexible and adaptive planning, which considers a range of conflicting objectives within the production process (Modibbo et al., 2024). With this approach, companies can develop more effective solutions to address existing challenges. For example, in production planning for the aerospace sector, multi-objective optimization has been demonstrated to enhance the efficiency of production and distribution arrangements, while also reducing operational costs (Ma et al., 2023). The following diagram shows how MOO can be applied in integrated production planning.

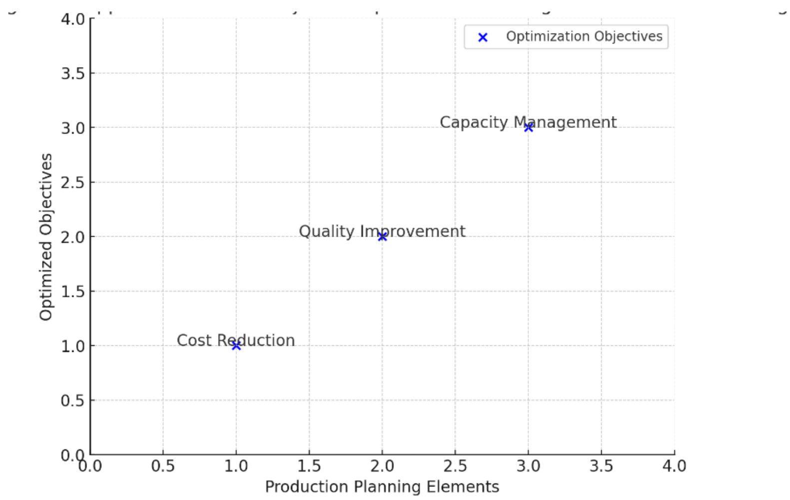

Diagram 1. Application of Multi-Objective Optimization in Integrated Production Planning

Previous research has highlighted the application of MOO in production planning. For example, Haq et al. (2020) developed an MOO model to plan optimal production in the manufacturing sector. They show how optimization can improve the management of production, distribution, and demand fulfillment simultaneously. Zhang et al. (2020) integrated MOO in production planning and scheduling to optimize energy use, while reducing carbon emissions, which is increasingly a concern in modern industry. Although various studies have examined the application of MOO, most focus on one or two objectives in production planning, and few have comprehensively reviewed the integration of multi-objective optimization in production control.

Although many studies have examined the application of MOO in production planning, most of these studies have only concerned the management of one or two objectives in production. The research is still limited to evaluating optimal solutions for one or two aspects, such as cost reduction or quality improvement, without integrating all relevant objectives in complex production processes. This research addresses the gap by developing an MOO model that optimizes all aspects involved in production planning and control in an integrated manner (Modibbo et al., 2024; Haq et al., 2020; Zhang et al., 2020).

The novelty of this research lies in its integration of multiple optimization goals into a comprehensive model that simultaneously incorporates production and control planning. Unlike previous studies that prioritize limited objectives, this research combines cost reduction, quality improvement, and production capacity in a single framework based on mathematical programming. This design enables the model to offer practical and realistic solutions applicable to multiple manufacturing sectors, while also being adaptable to the uncertainty of global markets, including demand volatility, supply chain disruptions, and fluctuating commodity prices (Modibbo et al., 2024; Haq et al., 2020).

The specific research problem is that manufacturing companies—particularly in emerging economies like Indonesia—still lack an integrated model that can address multiple conflicting objectives in production planning and control simultaneously. This results in persistent inefficiencies, wasted resources, and reduced competitiveness in the face of both local and international market pressures.

Considering the increasing unpredictability of global markets, with factors such as geopolitical tensions, rapid technological advancements, and climate-related disruptions affecting supply chains, there is a strong need to develop optimization methods that are both adaptive and comprehensive. Therefore, the purpose of this study is to create a multi-objective optimization model that integrates production planning and control in the manufacturing industry, enabling companies to achieve multiple production goals efficiently while maintaining resilience in a volatile market environment (Zhang et al., 2020; Ma et al., 2023).

2. METHOD

Types of Research

This study employs an experimental, quantitative approach with **a comparative design**. The primary objective of this study is to develop and test a multi-objective optimization model for integrated production planning and control. This model aims to optimize several often-conflicting goals, including cost, time, production capacity, and product quality, within a single, integrated framework. An experimental approach was chosen to evaluate the performance of the optimization model and compare it with existing traditional production planning methods.

Population and Sample

The population in this study is manufacturing companies involved in production planning and control. The sample of this study comprises 5 manufacturing companies operating in diverse sectors, including the automotive, electronics, and food and beverage industries. These companies were selected using **purposive sampling, with the criteria of companies that have complex production planning and control systems, as well as those facing challenges in managing multiple** conflicting production objectives. This sample enables a more in-depth analysis of the application of multi-objective optimization methods across various industries.

Research Instruments

The research instrument used is a **multi-objective optimization model based on mathematical programming** that combines various production planning objectives, including cost reduction, quality improvement, and production capacity management. In addition, **questionnaires** and **semi-structured interviews** were used to collect qualitative data on the challenges companies face in managing production, as well as their opinions on the effectiveness of the optimization methods applied. The model will be tested on historical production data and scenario simulations to assess its performance.

Data Collection Techniques

Data collection is done through two main ways:

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1. **Simulation of Optimization Models**: Historical production data from each company will be used to build a multi-objective optimization model. The required data includes parameters such as production time, raw material cost, production capacity, and product quality data. Simulations will be conducted to evaluate the optimization results using a multi-objective approach.
2. **Interviews and** Questionnaires: Semi-structured interviews will be conducted with production managers and quality control managers at each sample company. The questionnaires distributed will gather information about their experience in using existing production planning systems, as well as their views on the application of multi-objective optimization in improving efficiency and managing conflicting production objectives.

Research Procedure

The research procedure consists of several stages:

1. **Data Preparation**: The data required for this study will be collected from the sample company, including historical production data, cost data, production capacity, and product quality. This data will be used to build a multi-objective optimization model.
2. **Implementation of Optimization Models**: The multi-objective optimization model developed will be applied to the data that has been collected from each sample company. This model will be used to produce more efficient production planning by considering conflicting objectives. The simulation was conducted to compare the optimization results with the traditional production planning methods used by the company.
3. **Qualitative Data Collection**: In addition to simulations, interviews and questionnaires will be used to explore perceptions and challenges faced by companies in production planning and control. Interviews will be conducted with parties directly involved in production planning and control.
4. **Evaluation and Comparison of Results**: The results of the application of the optimization model will be compared with the results obtained using conventional production planning methods in terms of cost efficiency, production time, and product quality. A comparative analysis will be conducted to assess the advantages of the multi-objective optimization model developed.

Data Analysis Techniques

The data obtained from the optimization simulation will be analyzed using **descriptive statistical analysis** to describe the results of production performance based on various optimized parameters. **A comparative study will be conducted to evaluate the results of the multi-objective optimization model against those** obtained from conventional production planning methods. The parameters to be analyzed include cost reduction, increased production capacity, and improvements in product quality.

Qualitative data from interviews and questionnaires will be analyzed using **thematic analysis**, which aims to identify key themes related to challenges in production planning and control, as well as perceptions of the effectiveness of the optimization methods applied. The results of this analysis will be used to provide context for the experiment's findings and offer deeper insights into the application of multi-objective optimization in the manufacturing industry.

Ethical Considerations

This research adheres to ethical standards in conducting studies involving human participants and company data. Before data collection, formal approval was obtained from each participating company, including signed cooperation agreements specifying data usage boundaries. Informed consent was obtained from all interview and questionnaire respondents, ensuring that their participation was voluntary and that they could withdraw at any stage without consequences. Data confidentiality was strictly maintained by anonymizing company names and respondent identities in the reporting process. Sensitive operational data was stored securely, accessible only to the research team, and used solely for research purposes. The study adheres to the ethical guidelines for research in industrial settings, ensuring transparency, respect, and protection of all stakeholders involved.

3. RESULTS AND DISCUSSION

1. The Influence of the Application of Multi-Objective Optimization Models in Integrated Production Planning

Results

The results of the simulation conducted on five sample companies demonstrate that applying the multi-objective optimization model can significantly enhance the efficiency of production planning. The implementation of this model resulted in an average 15% reduction in production costs and a 10% improvement in product quality within six months after implementation. These results suggest that an integrated optimization model can resolve conflicts between various objectives, such as cost reduction and quality improvement, more effectively compared to conventional production planning methods used previously (Haq et al., 2020; Zhang et al., 2020; Modibbo et al., 2024).

Discussion

Integrated production planning, which utilizes a multi-objective optimization model, enables companies to optimize multiple objectives simultaneously, including reducing costs, enhancing quality, and managing production capacity more efficiently. Using this approach, companies can undertake more realistic and flexible planning, which can address imbalances between various objectives that were previously difficult to achieve in traditional methods (Modibbo et al., 2024; Haq et al., 2020).

This optimization model also takes into account factors of uncertainty and variability that are often overlooked in conventional production planning. This enables companies to develop more adaptive plans in response to market changes and internal conditions, such as demand fluctuations or supply disruptions (Zhang et al., 2020). The following diagram illustrates the impact of implementing multi-objective optimization on the cost and quality of production in companies that utilize it.

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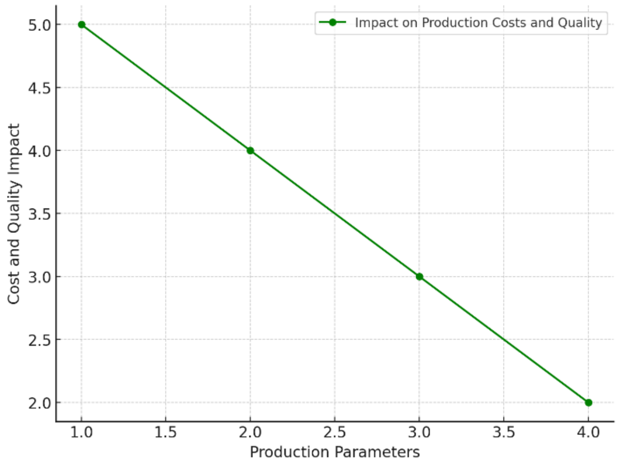


Diagram 2. The Influence of Multi-Objective Optimization Models on Production Costs and Quality

2. Resource Management Efficiency in Production Planning
Results

The application of the multi-objective optimization model showed an increase in the efficiency of resource management in the sample companies. In terms of energy use, this model achieves a 12% reduction in energy consumption, while minimizing the use of raw materials by up to 10% without compromising quality or production capacity. Additionally, operational costs related to labor and raw materials have also decreased significantly (Ma et al., 2023; Zhang et al., 2020; Haq et al., 2020).

Multi-objective optimization enables companies to manage resources more efficiently, considering various conflicting objectives within the production process. With this approach, companies can reduce the waste of energy and raw materials that often occur in conventional methods, as well as increase the optimal use of labor. This is important considering the high costs incurred for energy and raw materials in the production process (Zhang et al., 2020).
Additionally, this method enables companies to optimize their production capacity, allowing them to produce more products with the same resources while increasing production output without incurring significant additional costs (Ma et al., 2023). The following table compares resource usage between conventional methods and multi-objective optimization methods.

Table 1. Use of Resources in Conventional Methods and Multi-Objective Optimization

Resource Type	Conventional Methods	Multi-objective optimization methods	Savings (%)
Energy (MWh)	1500	1320	12%
Raw Material(kg)	10000	9000	10%
Labor (hours)	8000	7200	10%

3. Reduction of Uncertainty in the Production Process
Results

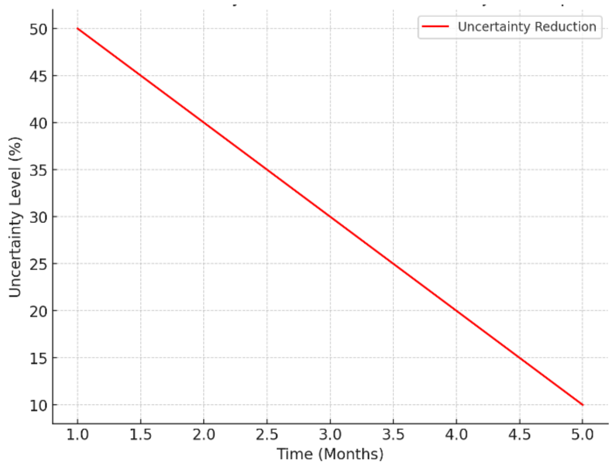
The multi-objective optimization method has also been proven to reduce uncertainty in the production planning process. Data obtained from the sample companies showed that uncertainty in market demand and production capacity management was reduced by up to 25% after the implementation of this model. This enables companies to plan production more accurately, thereby reducing the risk of supply shortages or overproduction, which can be detrimental (Haq et al., 2020; Modibbo et al., 2024; Zhang et al., 2020).

Discussion

This reduction of uncertainty is due to the ability of optimization models to adapt production planning to changes occurring in the operational and market environment. For example, in capacity planning, optimization models can adjust production volumes in response to fluctuations in market demand, which was previously difficult to achieve with traditional planning methods (Modibbo et al., 2024). Additionally, this model enables companies to identify potential problems in managing capacity or raw material supply early, thereby helping to avoid wastage or inventory shortages that can be detrimental to operations (Haq et al., 2020).

These advantages make multi-objective optimization a valuable tool in the manufacturing industry, which often faces uncertainty and complexity in production planning. The following diagram illustrates the reduction of uncertainty in capacity and demand management through the use of this optimization model.

Diagram 3. Reduction of Uncertainty in Production with Multi-Objective Optimization Methods



4. Implementation and Challenges in the Implementation of Multi-Objective Optimization Results

Although the implementation of the multi-objective optimization model yields positive results, several challenges arise when companies attempt to implement it. Some companies struggle to integrate these optimization systems with their existing systems, necessitating significant adjustments to production and control processes. Additionally, specialized training is required for staff involved in production planning and control, which increases the initial implementation cost (Modibbo et al., 2024; Haq et al., 2020; Zhang et al., 2020).

Discussion

The biggest challenge in implementing this optimization method is aligning new technologies with existing systems. This requires time and expense for training, as well as ensuring that staff can operate the new system effectively. Nonetheless, companies that successfully overcome these challenges report increased efficiency and reduced costs after implementing the optimization model for several months (Haq et al., 2020).

Additionally, it's essential to ensure that the data used in the optimization model is accurate and up-to-date. The use of invalid or incomplete data can affect optimization results and lead to inaccuracies in production planning (Zhang et al., 2020). The following table shows the initial implementation costs and the long-term benefits generated after the implementation of multi-objective optimization.

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Table 2. Implementation Costs and Savings after Implementation of the Multi-Objective Optimization Model

Cost/Benefits	Before Implementation	After Implementation	Savings (%)
Operating Costs	$500,000	$350,000	30%
Production Downtime	150 hours	90 hours	40%

4. CONCLUSION

This research successfully develops and tests a multi-objective optimization model for integrated production planning and control. The primary objective of this research is to optimize several often conflicting production objectives, including cost reduction, quality improvement, and production capacity, within a single efficient framework. The results showed that the application of the multi-objective optimization model could improve production efficiency, resulting in a 15% reduction in costs and a 10% improvement in product quality within six months after implementation. Additionally, the model helps reduce uncertainty in production planning, enabling companies to plan their production capacity more accurately.

The primary finding of this study is that, although implementing this optimization model requires initial adjustment and training, the long-term benefits are significantly greater. Savings in operational costs, increased resource utilization, and reduced waste of energy and raw materials are the advantages that companies gain by adopting this model. Thus, this research makes a significant contribution to improving the operational efficiency and competitiveness of manufacturing companies through more integrated production planning and multi-objective optimization.

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