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Proactive Manufacturing Strategy for Managing the Multiproduct Production Plan

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Abstract

The case study focuses on a multi-product company in Indonesia that aims to develop a proactive manufacturing strategy to tackle production disruptions caused by process uncertainty. Data from 30 periods are analyzed to evaluate the company's weekly production plan performance, revealing consistent quantity fulfillment but significant discrepancies in the types of products produced compared to the plan. Process uncertainty, especially regarding quality, leads to disruptions such as uneven and inadequate material supplies. Statistical Process Control (SPC) tools, like Pareto analysis, are used to identify priority quality issues, forming the basis for Fault Tree Analysis (FTA) to trace root causes and determine intervention points. Each machine's limited set of valves and pipes poses challenges for thorough cleaning during downtime and quality management outside working hours. Introducing backup valves and pipes per machine can mitigate these issues and improve production efficiency. Companies can implement procurement strategies for pipes and valves to prevent dirty prints in the primary process, ensuring smooth material supply and minimizing disruptions. Although actual production plan achievement hasn't reached 100%, this strategy has the potential to increase product sales by 3.31% by reducing the rejection ratio of dirty prints. Ultimately, proactive procurement of spare pipes and valves is expected to increase production efficiency by 4%, indicating enhanced production schedule stability.

Keywords: *flexible manufacturing strategy, proactive manufacturing strategy, quality management, pareto, fault tree analysis*

Abstrak

Studi kasus menginvestigasi upaya perusahaan multi-produk di Indonesia dalam merumuskan strategi manufaktur proaktif untuk mengatasi gangguan produksi yang disebabkan oleh ketidakpastian proses. Data mengenai isu kualitas produksi dikumpulkan dari laporan perusahaan selama 30 periode. Evaluasi kinerja rencana produksi mingguan perusahaan menunjukkan pemenuhan kuantitas yang konsisten namun menyoroti perbedaan yang signifikan antara jenis produk yang diproduksi secara aktual dibandingkan dengan rencana. Ketidakpastian proses, khususnya terkait dengan kualitas, mengakibatkan gangguan seperti pasokan bahan yang tidak merata dan kurang memadai. Untuk mengidentifikasi masalah kualitas yang prioritas, digunakan alat *Statistical Process Control* (SPC) seperti analisis Pareto sebagai landasan untuk *Fault Tree Analysis* (FTA) guna melacak akar penyebab dan menentukan titik intervensi. Dalam konteks saat ini, setiap mesin hanya memiliki satu set keran dan pipa, yang menghadapi tantangan dalam membersihkan secara menyeluruh selama waktu henti dan manajemen kualitas yang terbatas di luar jam kerja. Pengenalan keran dan pipa cadangan per mesin diharapkan dapat mengatasi masalah tersebut serta meningkatkan efisiensi produksi. Perusahaan dapat menerapkan strategi pengadaan pipa dan keran untuk mencegah pencetakan kotor dalam proses utama, sehingga memastikan pasokan bahan yang lancar dan meminimalkan gangguan. Meskipun pencapaian rencana produksi aktual belum mencapai 100%, strategi ini memiliki potensi untuk meningkatkan penjualan produk sebesar 3,31% dengan mengurangi rasio penolakan cetakan kotor. Pada akhirnya, pengadaan proaktif pipa dan keran cadangan diharapkan dapat meningkatkan efisiensi produksi sebesar 4%, yang menunjukkan peningkatan stabilitas jadwal produksi.

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Kata kunci: strategi manufaktur fleksibel, strategi manufaktur proaktif, manajemen kualitas, pareto, fault tree analysis

Introduction

The main ongoing challenge in the manufacturing field is effectively managing operations to enhance performance within multi-product production systems. Multi-product production planning involves not only determining the quantities of products but also the precise types of products to meet fluctuating demands (Csontos et al., 2022; Georgiadis et al., 2021; Li et al., 2021; Vanzetti et al., 2021). A crucial metric for assessing how well a production system is functioning is the execution of production plans. A company's ability to ensure that the production system operates smoothly is indicated by achieving precise levels of production plan fulfillment (Sun et al., 2020; Woschank et al., 2020). Manufacturing companies are currently concerned about supply chain disruptions, including those affecting supply, production, and demand. Among various disruptions, production disruption is essential in achieving production plans, resulting from process uncertainty related to machine availability, yields, quality, and processing times (Bo et al., 2021; Esmaeili-Najafabadi et al., 2021).

The study examines a multiproduct company in the tissue paper industry implementing the "Just-in-Time" (JIT) principle for material supply management. By analyzing data from 30 recent production periods, the study evaluates the company's weekly production plan performance. Results indicate consistent fulfillment of production plans in terms of quantity but reveal a notable discrepancy in the accuracy of actual product types produced compared to the plan. Process uncertainty, particularly concerning quality, results in disruptions such as uneven and insufficient material supplies. This underscores the potential limitations of the JIT principle's low inventory levels in effectively managing inherent production process uncertainties.

In conditions of material supply chain uncertainty, manufacturing can employ either proactive, reactive, or a combination of both strategies to address the situation(Afifa & Santoso, 2022). The proactive manufacturing strategy is suggested as an approach to initiate a long-term focus on flexibility rather than reacting to uncertainty with inventory-based strategies (Lee & Lee, 2021). Given the gap in achieving multiproduct production plan objectives due to disruptions from process uncertainties, further research is needed to propose proactive manufacturing flexibility strategies for redesigning production processes, particularly for the section that produces the poorest quality in manufacturing. Proactive strategy involves preventive measures before risks occur by taking appropriate actions (Samani et al., 2020). The developed strategy aims to provide readiness in dealing with process uncertainty risks to achieve precise multi-product production plans in terms of both quantity and accuracy of production types.

The issue of production disruptions due to process uncertainty has been investigated in several previous studies. Research over the past five years has shown that the quality of products is a key focus of process uncertainty research, including this study, rather than other factors such as machine availability and processing time, and product outcomes (Febriana & Hasbullah, 2021; Iqbal & Sarkar, 2020; Karim & Nakade, 2019; Kim et al., 2018; Puchkova et al., 2020; Rucitra & Amna, 2021; Sánchez-ramírez et al., 2020; Strohhecker & Größler, 2020; Taleizadeh et al., 2019; Urlu & Erkip, 2020). This research shares similarities with other studies in terms of production type and strategies used. Although previous studies mainly focused on single-product scenarios, research involving multi-product scenarios has also been conducted, as in this study. In this research, a proactive manufacturing strategy proposes a redesign of the quality process using statistical process control (SPC) through Pareto and fault tree analysis (FTA). This study incorporates insights from previous research to include cost analysis (Iqbal & Sarkar, 2020; Urlu & Erkip, 2020). The cost analysis required for implementing the strategy is discussed in this study as input and consideration for management in reviewing the impact of the strategy on the precision of multi-product production plans.

Methodology

A case study of a multi-product company in Indonesia aimed to develop a proactive strategy to address production disruptions caused by process uncertainty. Quality production issue data is gathered through company report documentation studies managed by the quality control department. Data is collected on all types of products from historical data spanning 30 periods. The case study in this research categorizes the available product variants into two main types: banded and pegged. The categorization is based on the type of packaging of the final product. Figure 1 below illustrates the concept and flow of research in developing proactive manufacturing strategies.

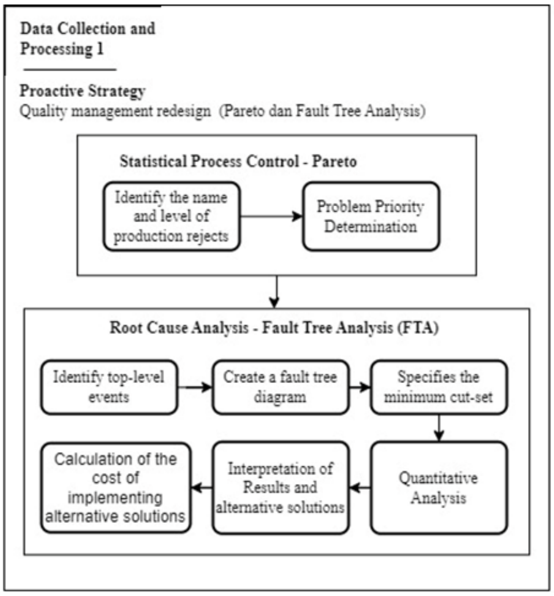

Figure 1. Research Flow for Proactive Manufacturing Strategy

Figure 1 illustrates that the research will commence by identifying priority quality issues using Statistical Process Control (SPC) tools employing Pareto analysis. Quality issues with the top 20% percentage in the Pareto analysis will serve as the basis for constructing the Fault Tree Analysis (FTA) to trace the root causes of the quality issues. In addition to identifying the root causes, this approach aims to determine the appropriate production parts for intervention to prevent poor quality in the resulting products. The boundaries of significance are determined in the initial step where joint analysis should be conducted based on system issues. The subsequent step involves determining the issues for analysis based on the problems identified as top priority in the Pareto analysis.

Data collection and processing in the Fault Tree Analysis (FTA) refer to the procedural approach from previous research (Baig et al., 2013). Fault Tree Analysis (FTA) is a tool in root cause analysis (RCA). The use of this approach is aimed at determining the root causes of the poor product quality supplied in the production flow. Identification of events and conditions leading to the top event in the fault tree is conducted to subsequently explore each branch in sequential detail. Identification of events and conditions leading to events is carried out at the next or lower levels sequentially until the Fault Tree framework is fully explored. Analyzing the entire fault tree based on the combination of contributing events to the top event is performed. The next step involves identifying important dependent failure potentials and adjusting the model accordingly. This requires studying events and discovering dependencies among events that can cause one or more events and conditions to occur simultaneously. Quantitative analysis is conducted as a basis for determining the conditions where the system is most potentially hazardous and to place appropriate actions and recommendations to address these risks. The results and discussions are outlined to further analyze how proactive manufacturing strategies are beneficial when implemented to address production constraints. An analysis is also conducted to assess potential risks that may hinder the implementation of the strategy. Discussions related to the cost description of the strategy and the positive impacts resulting from its implementation are also included.

Results and Discussions

The production process involves primary, printing, and secondary processes, with the secondary process having a short lead time from the preceding process. Analysis indicates an average efficiency of 99.5% in terms of quantity for each period, but poor product type accuracy of 94% due to process uncertainty from material quality. Production control is crucial in multi-product production planning, yet irregular production flow is disrupted due to quality issues and uncertainty factors in material supply (Niu et al., 2021). Proactive strategies offer flexibility in responding to process uncertainty and production disruptions.

Table 1 shows the results of identifying the types of production rejects and their quantities. Production quality data collected from 30 historical periods reveals issues like dirty print, miss registry, line molding, cross m, and cracks in primary printing processes. The source of these problems lies in the primary printing process. Broadly speaking, the quality issues identified so far have been found to occur during the execution of the secondary process. The rejection of dirty prints accounts for 4% of the total production capacity, referring to the data in Table 1. The production output resulting from these quality issues indicates that the production plan for each period can be met in terms of quantity, with an average effectiveness of 100% for each period. However, its performance is poor in terms of the accuracy of the actual products produced compared to the production plan, with an average effectiveness of 94% for each period.

Table 1. Type and level of production quality problems. Primary printing process causes quality problems in secondary process.

Type of Quality Problem (Ball of the entire period)	**Number of Quality Problems** (Ball of the entire period)	**Percentage of quality problems (%)**	**Level of Quality Problems**
Dirty print	2,073	33.26%	1
Miss registry	1,459	23.41%	2
Line mold	970	15.56%	3
Cross mold	932	14.95%	4
Wrinkles	438	7.03%	5
Cracks	360	5.78%	6
Total Number of Quality Problems	**6.231**	**100%**	
Total Production Capacity	**44.431**		

The Pareto analysis identified dirty print as the main issue, accounting for 33.26% of the total, originating from the primary printing process. Challenges in quality control inspections during production were noted due to the nature of the process and the lack of comprehensive inspection methods. Dirty print passing through to the secondary process were attributed to irregular contamination patterns, particularly at the beginning of production runs. Ineffective cleaning processes and the absence of spare equipment exacerbated the issue. The study aims to minimize dirty print occurrences in the primary process by identifying their root causes through Fault Tree Analysis (FTA).

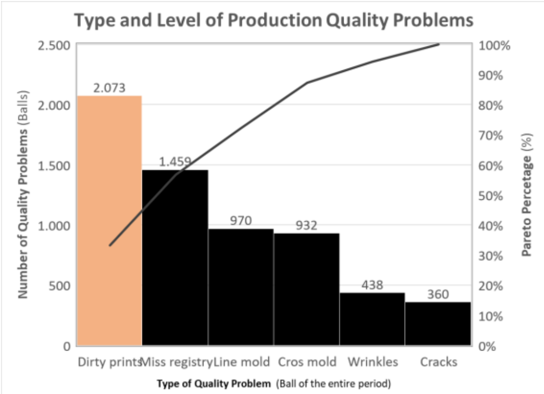

Figure 2. Type and Level of Production Quality Problems. The research focuses on minimizing or reducing the potential for dirty prints occurrence in the primary process and identifying the cause of quality problems through (FTA).

Fault Tree Analysis (FTA) begins with identifying unwanted events to pinpoint system issues. Determining the top-level event refers to Pareto results in indicating the main quality issues occurring in the system. Dirty prints are the selected production quality issue for further analysis in FTA. The Fault Tree diagram in Figure 3 illustrates how the primary quality issues at the top level can manifest in potential networks of problem causes. This diagram is deductive and top-down in nature. The Fault Tree Diagram is constructed with symbols containing descriptions of events in the system and logic gates to explain the relationships between events. The creation of the Fault Tree diagram refers to data on potential causes of dirty print problems.

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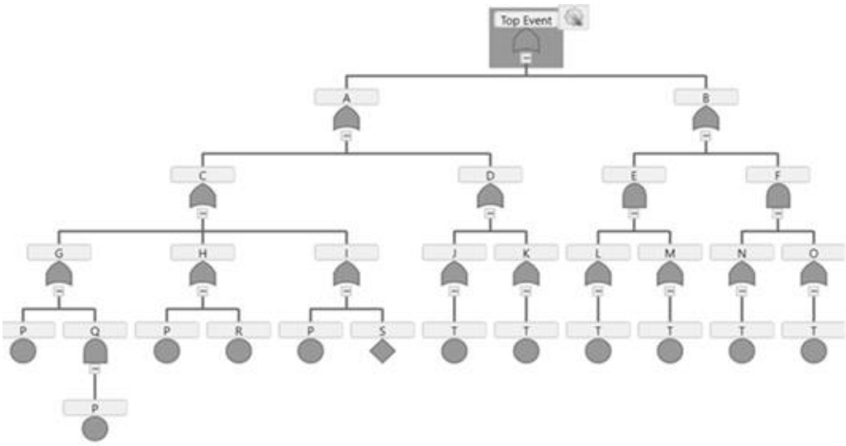

Code	Description
Top Event	Dirty prints
A	Powder waste enters the pipe and valve flow
B	Dirty pipes and valves
C	Powder not completely dissolved
G	Heater temperature insufficiently hot
H	Weak mixer pressure
I	Non-premium quality powder supplier
D	Unclean pipe and valve cleaning
J	Pressure minimizes downtime
K	Cleaning is only done in accessible parts in the machine area
B	Corrosion of valves and pipes
E	Excessive usage
L	Each machine only has 1 valve and pipe
M	Valves and pipes are never replaced
F	Irregular pipe and valve cleaning
N	Cleaning is only done when undissolved powder is detected in the initial process
O	Valves and pipes must be continuously used for production operations
P	No standard study of dissolved powder quality measurement methods and tools
Q	MTC considerations in maintaining machine durability
R	Damaged mixer and needs replacement
S	Price limitations and payment in determining the powder supplier
T	No allocation of spare pipes and valves

Top Event	= A + B
A	= C + D
B	= E + F
C	= G + H + I
D	= J + K
E	= L.M
F	= N.O
G	= P + Q
H	= P + S
I	= P + S
J	= T
K	= T
L	= T
M	= T
N	= T
O	= T
Q	= P

Top Event	= A + B
	= C+D+E+F
Minimum Cut Set	= G + H + I + J + K + LM + NO
	= P + Q + P + R + P + S + T + T+ TT + TT
	= P + P + P + R + P + S + T
	= **P + R + T**

Figure 3. Determination of the Minimum Cut Set of Fault Trees. The T code is identified as the root cause of the problem.

The fault tree analysis depicted in Figure 3 identifies various factors contributing to the occurrence of dirty prints in production. These factors include issues with pipes and valves, inadequate dissolution of powder, insufficiently hot heater temperature, weak mixer pressure, and substandard powder quality from suppliers. Maintenance considerations and management pressure to minimize downtime also play a role. The absence of reserves for valves and pipes, damaged mixers, and the lack of standard method studies further contribute to the problem. The analysis aims to determine the minimal cut set of factors that most significantly impact the occurrence of dirty prints.

The process of finding the minimal cut set involves representing the fault tree as Boolean algebra and then reducing it using Boolean algebra rules. This analysis revealed 5 basic factors coded as P, R, and T, which are the root causes of dirty prints. Quantitative analysis prioritized code T as the main issue, indicating a lack of spare pipe and valve allocation. Alternative solutions were developed, including providing spare pipe and valve stocks for each of the 6 primary machines to eliminate the root causes of the problem.

Fault Tree Analysis (FTA) analysis explains that the fundamental factor that could serve as an alternative solution in formulating a proactive strategy is the lack of allocation for spare pipes and valves. The absence of spare valves and pipes is the selected basic event in the minimal cut set. The current situation involves each machine having only one set of valves and pipes for operational production, leading to challenges in thorough cleaning during downtime and limited quality management outside of working hours. Introducing backup valves and pipes for each machine enables production teams to manage equipment cleanliness beyond usage hours and promptly replace equipment as per new standard operating procedures. This initiative has the potential to reduce downtime from handling dirty prints and increase production output by minimizing rework associated with dirty print issues.

If the company allows room for the implementation of this strategy, it will have a significant impact on preventing dirty prints in the primary process. Procuring spare pipes and valves can be a solution to address issues with dirty pipes and valves that cause dirty prints. Previous research has implemented various spare parts inventory management policies that help companies reduce production downtime due to sudden mechanical failures (Sánchez-ramírez et al., 2020).

The analysis highlights that the presence of dirt on pipes and valves is caused by insoluble powder residue. While procuring pipes and valves is initially considered a proactive strategy for the overall system, within the primary process alone, it is seen as a reactive approach to addressing the issue. The alternative solution is efficient in preventing issues with dirty print quality, but its effectiveness is less dominant in terms of minimal cut set calculations compared to other strategies. However, the company can also explore studying how powder can be maximally dissolved as part of a proactive approach. Overall, procuring pipes is recognized as a valuable proactive strategy within the entire system.

The implementation of the proactive strategy will have potential outcomes as indicated in Table 2. The table shows the potential reduction in reject ratio when the proactive strategy is implemented. Potential impact of implementing the proactive strategy will result in an improvement in achieving the production plan for product types from the previous 94% to 98%. The decrease in reject ratio refers to the rejection data decreasing from 4% to 2.7%, based on the issue of missing dirty print across all production types. The rejection data used for comparison refers to the data and explanation in Table 1. The reduction value of reject due to dirty prints is considered as the production output value. This value will then be estimated to assess the potential impact in terms of achieving production plan.

The implementation of the proactive strategy involves adding 6 sets of spare pipes and valves for each machine, along with 3 pipe cleaning operators per shift. The total cost required for this proactive strategy implementation amounts to Rp 54,529,177.50, which can be utilized as input data for evaluating the potential impact. This cost applies to a 30-period cycle based on historical data, and there is potential for the cost not to increase with appropriate spare part management. This strategy aims to save or reduce material loss resulting from issues with the quality of dirty prints. The cost data serves as periodic evaluation and consideration for management to uphold their commitment to improving production quality by striving to prevent dirty mold occurrences.

The company can focus on implementing a pipe procurement strategy to prevent contamination in the primary process, which causes material supply to be hindered by quality issues detected in the sheeter processing. The implementation of this strategy will be able to overcome the limitations of comprehensive inspection processes during production. This strategy will also help maintain the quality assurance of production from the unavailability of inspection processes after the primary process is completed.

Table 2. Potential Impact of Implementing the Proactive Strategy

Variable	Unit of Measure	**Current Condition** (Before Strategy Implementation)	**Potential Condition** (After Strategy Implementation)
Reject material dirty prints	Percentage per period	4%	2,7%
Pipes and valves	Set per machine	1	2
Achievement of product quantity plan	Percentage per Total Period	94%	98%
Achievement of product type plan	Percentage per Total Period	99,5%	104%
Cost of strategy	Rupiah per Total Period	Rp. 0	Rp. 200.296.710
Sales value	Rupiah per Total Period	Rp. 83.483.880.000	Rp. 86.016.157.440

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Production disruptions are minimal due to reduced or even eliminated uncertainty in the quality process (Niu et al., 2021). The impact of this implementation will provide smooth material supply. The implementation of this proactive strategy will yield positive impacts not only in terms of achieving production targets but also in terms of sales values as shown in Table 3.

Table 3 shows that while the achievement value of the production plan has not reached 100%, in terms of product sales, this strategy has the potential to increase by 3.31% with a sales-to-strategy cost ratio of 49. This value is derived from the decrease in the rejection rate from 4% to 2.7% assuming the elimination of dirty print issues in the production process flow. Based on the description and impact calculation results of the implementation strategy, ultimately, the proactive strategy of procuring backup pipes and valves will result in an increase from 94% to 98% according to the data processing results in Table 2. This indicates that production schedule stability will also increase proportionally with that value. As for resource utilization aspects, the system can still maintain target achievement in production resource utilization.

The proposed strategy shows when the cost needed to restore and prepare the system can provide sales increase and rigidity to the system, affecting the achievement of the production plan. Companies with data-based management can improve performance efficiency by communicating with management about alternative solutions to production disruptions (Del Giudice et al., 2020). Proactive strategies focus on preventing powder removal from contaminating the process, ensuring the root problem is not completely dissolved. This approach is more effective in achieving company objectives and reducing the risk of dirty print.

This research highlights the importance of managing and evaluating measures to provide flexibility to systems facing process uncertainty. By understanding the challenges and opportunities presented by these strategies, companies can develop more effective solutions to address the issues and achieve sustainable improvements in their production processes. The implementation of the strategy on this study has accommodated the production demand rate of 30 historical data.

The study did not conduct calculations and simulations for integrating proactive and reactive strategies in production disruption. The integration of this strategy can accommodate the availability of a production plan at a maximum of 100% with the potential cost of a cheaper strategy but the increase in sales value is higher. The company demonstrated the integration of proactive strategies by procuring pipe and valves reserves and calculating ideal buffer stocks to support production plan achievement. Further research could focus on developing reactive-proactive integration strategies, which could result in smaller costs while ensuring successful production plans. Cost considerations are crucial, but it is essential not to sacrifice quality (Potkány et al., 2021; Stentoft et al., 2021).

Conclusions

The flexibility strategy, which includes proactive manufacturing strategies to address production disruptions due to process uncertainty in material quality, has been formulated. Proactive strategies are built using Statistical Process Control (SPC) and Fault Tree Analysis (FTA). Companies can focus on implementing pipe and valve procurement strategies as an effort to prevent dirty prints in the primary process, which causes material supply to be obstructed by quality issues detected in next processing. The implementation of this strategy will be able to address the constraints of the inspection process's inability to thoroughly examine the ongoing production process.

The impact of this implementation will provide smooth material supply, thus minimizing production disruptions from reduced or lost quality process uncertainties. While the actual achievement value of the production plan has not reached 100%, in terms of product sales, this strategy can potentially increase by 3.31%. This value is obtained from the reduction in the rejection ratio of dirty prints from the previous 4% to

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2.7%, assuming the disappearance of dirty print issues in the production process.

Table 3. Potential Efficiency Level of Proactive Strategy Implementation

Data Variable	Unit	Total Output	Sales/Cost Per Bal	Total Sales/Cost	Note
Actual Production quantity Product type 1	Bal/Total Period	26,137	Rp 2,040,000	Rp 53,319,480,000	Product sales price
Actual Production quantity Product type 2	Bal/Total Period	14,364	Rp 2,100,000	Rp 30,164,400,000	
Actual Number of rejects Product type 1 dirty print	Bal/Total Period	1,339	Rp 2,040,000	Rp 2,732,574,150	Material loss cost
Actual Number of rejects Product type 2 dirty print	Bal/Total Period	733	Rp 2,100,000	Rp 1,539,540,235	
Maximum capacity Product type 1 production quantity after proactive strategy implementation	Bal/Total Period	30,067			Number of bal and sales price of products plus the amount of production lost due to dirting prints rejects
Maximum capacity Product type 2 production quantity after proactive strategy implementation	Bal/Total Period	14,364			
Potential Number of Product type 1 productions after proactive strategy implementation	Bal/Total Period	27,476	Rp 2,040,000	Rp 56,052,054,150	Number of bales and sales price of products plus the amount of production lost due to dirting prints rejects adjusts the maximum production capacity.
Potential Number of Product type 2 productions after proactive strategy implementation	Bal/Total Period	14,364	Rp 2,100,000	Rp 30,164,400,000	
Potential Number of Product type 1 dirting prints rejects after proactive strategy implementation	Bal/Total Period	0	Rp 2,040,000	Rp 0	Material loss cost
Potential Number of Product type 2 dirting prints rejects after proactive strategy implementation	Bal/Total Period	0	Rp 2,100,000	Rp 0	
Proactive Strategy Implementation Cost				**Rp 54,529,178**	Cost of procuring operators and spare pipes and faucets for each machine
Actual Total Sales of Produce				**Rp 83,483,880,000**	All product types before strategy implementation
Potential Total Sales of All Produce				**Rp 86,161,924,973**	Potential impact of proactive strategy implementation. Total potential sales minus strategy implementation cost
Total Sales Increase				**Rp 2,678,044,973**	Implementation of the strategy has a positive impact on saving production costs from material loss costs.
Percentage of Sales Improvement Efficiency Proactive Strategy				**3.21%**	Implementation of the strategy has a positive impact on saving production costs from material loss costs.
Ratio of Sales Increase to Proactive Strategy Implementation Cost				**49**	Comparison of total sales increase with the cost of implementing proactive strategies
Percentage of Output Efficiency (Bal) Proactive Strategy				**3.31%**	Potential Overall Production quantity compared to Actual Overall Production quantity

Based on the description and impact calculations of the implementation strategy, ultimately, the proactive strategy of procuring spare pipes and valves will result in a 4% increase from 94% to 98%. This indicates that production schedule stability will also increase proportionally to this value.

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