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REDUCING CHANGEOVER TIME IN INJECTION MOLDING: A LEAN APPROACH

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ABSTRACT

Overall Equipment Effectiveness (OEE) and production efficiency are two of the measures that influence mold changeover time. In the context of mold changeover time reduction, these two measures are highly influenced in the manufacturing industry. Through this study, the main aim is to reduce the mold changeover time and increase process efficiency with the application of Single-Minute Exchange of Die (SMED), waste analysis, and Eliminate-Combine-Rearrange-Simplify (ECRS). The main focus of this study is to identify and eliminate non-value-adding activities from the changeover process. Therefore, this study had done a time-and-motion study and a process breakdown analysis in order to identify the factors that are critically influenced. While the SMED and waste analysis are dealing with the internal and external setup, ECRS will help to streamline the process by improving efficiency and effectiveness. Therefore, this study will discuss the impact of lean manufacturing tools such as SMED, waste analysis, and ECRS on the process and operational efficiency improvement. Also, it discussed how these tools can be practiced in the industrial context.

Keywords: Lean Manufacturing, Mold Changeover, Production Efficiency, SMED, Time Reduction

1. Introduction

One of the most common challenges faced by manufacturing organizations in terms of efficiency and productivity is to optimize the production process area where the OEE is critically impacted by mold changeover time. Non-value-adding activities in the process affect the production flow of the organizations, making it a strategic imperative to enhance competition and profit.

Mold changing in a final product (output) manufacturing plant is one of the critical areas of concern. Delays in the process due to prolonged changeovers can hinder production flow. OEE causes a drop in the competitiveness and profits of the company. Such a slow-down effect is of greater severity as more non-value-adding activities happen during the prolonged changeover time making it a challenging activity for many businesses. Hence, organizations have to get the most out of their resources and activities by perfecting their operations.

This study contains a description of the current mold-changing processes in the final production's production line. It provides a detailed understanding of the utilization of molds, operational durations, the identification of bottlenecks, problem areas, and production efficiency. The goal is to demonstrate where improvements can be made. Additionally, it provides a comprehensive understanding of how the entire operation can be much more productive.

1.1 Research Objectives and Scope

The issue that has been subjected to a detailed scientific analysis in this research is the lack of a standard process for mold changeover. As a consequence, it takes longer changeover time than the standard time. The main task now is to bring down the present mold changeover time from 8 hours to 6 hours. To accomplish this, the study begins with an analysis of the current process and then ends with the in-depth study results that are the basis for the strategies proposed for improvement. The listed sub-objectives are:

1. Identify the bottlenecks and non-value-adding activities in the process.
2. Perform the SMED technique to separate the internal activities from external activities and eliminate the downtime to its lowest level.
3. Reduce the changeover time by two hours.
4. Develop a standard set of activities for the changeover process.

In fact, the present research study is aimed at a specific matter, which is to bring up the necessary information that how the changeover process can be improved to the full extent of OEE and production efficiency.

2. Literature Review

The concept of lean was developed in Japan which represents the Toyota Production System (TPS). Lean management is a way of thinking and a set of principles to create value addition to the customer by eliminating waste [17]. Modern manufacturing organizations are being adopted lean management to improve the quality of the operations and functioning of the process [21].

Implementing lean manufacturing provides a powerful framework to optimize the manufacturing process in the highly competitive manufacturing industry [20]. It demonstrates lean manufacturing principles leading to a significant change over time reduction by streamlining the changeover process [4,14,15].

In the dynamic manufacturing environment, reducing mold changeover time is a crucial task [19]. The period between the last good product generated from the previous production order and the first good product generated from the new production order through the machine [10,11,12]. This process consumes significant time and resources without adding value, causing production slowdowns in production facilities [10].

The quick changeover option is particularly facilitating smoother production by mitigating peak loads, preventing equipment overload, and enhancing efficiency [13,19]. From the different techniques available within lean manufacturing, the SMED technique mainly describes changeover time reduction [20].

The concept of SMED is an important technique designed within lean manufacturing to reduce changeover time by eliminating non-value-added activities from the changeover process [5]. As Dave [9] defined, the SMED technique aims to reduce machine changeover time to a single-digit minute range following a five-step structured approach.

The initial step of the SMED technique is identifying each individual activity and the associated time of each activity. Each activity should be categorized as either internal or external. Internal and external activities can be categorized when the machine is stopped and activities that can be completed while the machine is running respectively. By converting internal activities into external activities, the remaining activities are optimized as the next stage of streamlining the changeover process while reducing time consumption. A standardized procedure should be established for the optimized changeover process as stated by [18].

Apart from the SMED Application, autonomation and multiskilled labor have proven effective implementation in mold changeover [2]. The importance of autonomation is that the worker can intervene with the process when they find an issue when the process stops and during the investigation processes [1,6,7].

The integration of machines, materials, processes, production, and information in molding technology in the manufacturing industry involved simple computer-aided simulation engineering. With the help of developing autonomation technologies, currently, it can be represented virtually [3,8].

The concept of multi-skilled labor is essential to increase efficiency and intervene and deal with any kind of abnormalities to continue the process where they utilize their specific skills across multiple areas of specialization [8,15,16].

3. Methodology

3.1 Data Sources

The study encompasses a qualitative approach, allowing for an in-depth investigation of the mold changeover process. The multi-method qualitative design enables data collection through various methods, which can be used for related data analysis procedures. The study was conducted in a manufacturing plant focusing on the mold changeover process of a primary mold injection machine that used different molds. The aim of this study is to streamline and standardize this process to significantly reduce changeover time.

Qualitative techniques were used to collect data including both primary and secondary data collection methods. Unstructured observations with employees and focused group interviews with managers were employed as primary data collection methods to understand the changeover process. Other than that, physical observations were done through site visits. Additionally, CCTV footage and other digital materials were used to examine the workflow and identify areas for improvement, classifying these as secondary data collection methods.

3.2 Data Analysis

The collected data was analyzed using the SMED technique which is suitable for reducing changeover time in lean manufacturing. The analysis process included monitoring the current changeover process to record activities and time spent, combining observed activities for integrated steps, classifying activities into internal and external based on SMED, converting internal activities to external to reduce changeover time, and optimizing activities using the ECRS method. The following explanations are used before stepping into the SMEDD technique.

- Brainstorming

One of the main concerns in the traditional format setup is the need for clarity between internal and external activities. Therefore, clarifying and identifying the operations and their actual times is crucial. Organizing a

STEPS INVOLVED IN THE CURRENT CHANGEOVER PROCESS					
Day 01		Day 02		Day 03	
Step	Description	Step	Description	Step	Description
Cleaning the floor		put gloves and safety helmet		put on helmet & gloves	
Remove water tubes	black-hydrolic oil	close the machine door		spray green	
remove hot runner	Remove the hot runner and two black tubes (two black - hydrolic oil tubes were connected to it)	Adjust the machine	Prepare the machine before removing the mould (using control panel).	remove water tubes	blue colour tubes
spray for rusting of the machine	ambersil green mould protection	spraying the green		close the door	
close the machine		removing the water tubes (blue)		adjust the machine	
		remove the hot runner		vaccum the inside of the machine	this is to remove the rust inside the mould (they said there was a gap between pause of production and mould change over) therefore they pressure wash the inside of the machine to remove the rust .
open machine		vacuuming the machie floor		close the door	during this process the doors are constantly closed and opend because the water which comes out is of high pressure
spray again	ambersil green mould protection	close the door other side	to furthur vacum inside without spreading all over	open the door	
keeping aside the hot runner and the two black tubes connected to it in the shelf		opening the door		remove the hydrolic line	the hydrolic line on top of the machine is removed using a spanner
vacuuming inside of the machine	removing the water from inside of the machine using high pressure vaccum tubes	close the door		remove the hot runner	take hot runner away and put it on the shelf

Figure 1: Baseline Worksheet.

brainstorming session can help detect the real problems and weak points in the current mold changeover process through observations, pre-interviews, the CCTV recordings. Identifying these breakpoints makes it easier to launch and work on the real project.

- Setup baseline worksheet

In the baseline worksheet, the previously mentioned steps and processes of the current procedure will be recorded (Figure 1). Here, all internal and external activities are documented including the actions performed by operators before the machines start and machines rest. The baseline worksheet will help us to determine whether an activity is an internal activity or an external activity. Since the setup baseline worksheet encompasses the detailed documentation of the current changeover times, operators, and activities, it will facilitate the next procedure which is to apply SMED application (Figure 2).

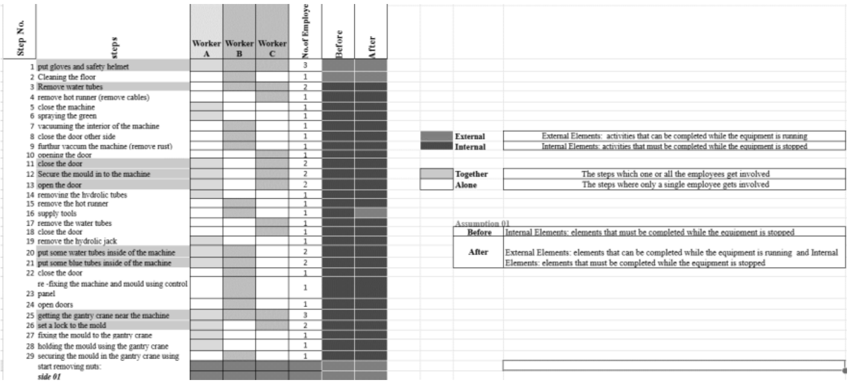

Figure 2: Worker Classification and Waste Analysis.

As a result of the brainstorming process, each activity will be allocated to one of three categories. The sole purpose of brainstorming is to eliminate non-value-adding activities and identify internal activities (Figure 2).

1. Necessary activity required during production.
2. Necessary activity that could be carried out while the assembly line is working (before or after the format changeover).
3. Redundant and unnecessary activities that could be eliminated.

Moreover, to identify the redundant activities, the ECRS tool is used.

- Process flow definition and waste analysis

Now that the internal and external activities have been properly identified the next step is to eliminate waste. To do this, a waste analysis is performed, highlighting the non-value-adding activities. The waste analysis process breaks down the entire process into small steps and analyzes them to eliminate waste. By applying this waste analysis, we could determine waste prevalent areas, and over-processing areas in the changeover process.

As a result, through this identification, we could detect the specific starting and ending points of the process which could help generate insights and implement countermeasures to optimize the changeover process.

- Implementation of the SMED technique in the changeover phase

Implementing the SMED technique consists of 5 main areas,

1. Identify the current changeover process
2. Register the changeover
3. Classify activities into external and internal
4. Convert internal activities into external activities
5. Develop a plan to streamline activities

Therefore, prior to implementing the SMED, here are some of the basic principles of the SMED Application.

1. Internal activities: These are activities that can only be performed when the machine is stopped.
2. External activities: These are the activities that can be performed when the machine is still running/processing.
3. Streamline: Develop ECRS.

Accordingly, the data analysis methods are tailored to align with the steps of SMED, encompassing the following.

1. Identify the current changeover process: This analysis began with observing data from the changeover process during field visits. We recorded all the activities, noting the time spent on each activity and the number of workers involved in each activity.
2. Register the changeover: In this step, consolidate the activities observed during field visits to create an integrated framework for analysis using SMED. We finalized the integrated activities, including the time taken for each activity, the number of employees involved in each activity, and other relevant details.
3. Classify activities into external and internal: In this step, it categorizes the activities involved in the changeover process into internal and external setup activities based on SMED principles. By separating activities in this manner, we identified opportunities for reducing setup time.
4. Convert internal activities into external activities: The main focus in this step was to convert identified internal activities into external activities that can be performed while the machine is running but are currently performed internally. The goal here is to perform as many activities as possible while the machine is still running. By converting internal activities into external activities, the overall changeover time can be considerably reduced, leading to increased productivity in the manufacturing process and helping to establish standardization.
5. Develop a plan to streamline activities: In this phase, our aim is to streamline the activities involved in the changeover process by

employing the ECRS technique. We will primarily focus on internal activities, which are currently contributing to longer changeover times. However, we will also consider recommendations for optimizing external activities. Through this analysis, we aim to identify opportunities to reduce the changeover time in alignment with SMED's objectives.

As a supportive role for SMED, developing Standard Operating Procedures (SOP) provides a comprehensive understanding of how important training employees is in dividing roles and responsibilities.

3.4 Validation

By analyzing collected data using SMED, and ECRS, we aimed to implement suggested improvements in the actual working environment. These changes are introduced after a discussion session with the parties responsible for the project to ensure the proper alignment. The purpose of this part is to highlight the practical applicability and acceptability of this model in a real-world industrial environment. As we intend to test these improvements to assess their effectiveness under real operating conditions, this validation process will play a crucial role in the entire project. The detailed explanation of the validation process is further discussed in the discussion.

4. **Results and Discussion**

The project goal of reduce the time needed for changeover using subsequential steps, allowing us to evaluate its impact on the process setup during the implementation and optimization phase.

The ECRS analysis demonstrated that the application of SMED reduced the changeover time (Figure 3 - 2.41 hours). This reduction also

Step No.	Steps	Current Situation: Internal Duration (minutes)	Current Situation: External Duration (minutes)	Classification (Current): Internal Activity	Classification (Current): External Activity	Improvement Proposal: Internal Duration	Improvement Proposal: External Duration	Eliminate
137	fixing the machine	00:04:00		1		00:04:00		
138	start production	00:03:00		1		00:03:00		
	Total	**08:04:00**	**00:02:00**	**136**	**2**	**4:32:10**	**0:53:30**	**19**
	Calculations (in minutes)	**484/60**	**2/60**			**272.1/60**	**53.3/60**	
	As percentage %	**99.59%**	**0.41%**	**99%**	**1%**	**84%**	**16%**	**40%**

Illustrates
In the current process, it spend 8.6 hrs to finish
For analysing, activities caterigozied into internal and external. Activities that can be completed while the equipment is running called external and activities that must be
The process spend 8 hrs and 4 minutes from total time for internal activities and it is 99% as
The process spend 2 minutes from total time for external activities and it is 1% as percentage.
According to classification there are 136 activies identify as internal and only 02
Based on the improvement proposal internal activities able to reduce into 84% i.e 4 hours
Based on the improvement proposal external activities increase into 16% but time reduce into
In ECRS analysis, certain activities are eliminate, cobime, re-arrnage and simply for the

Current Total Time = 8.06 Hrs
Proposed Total Time = 5.25 Hrs (05:25:40)
Remaining Time = 2.41 Hrs

Total Production Time = 7 Min
(Per product)

Reducing planned downtime will be benefited by additional 2.41 hours a
items will be produced

Figure 3: ECRS Analysis.

increased overall equipment efficiency by allowing an additional production increment. (Figure 3 - Reducing planned downtime by 2.41 hours and producing an additional 23 items). Therefore, the changeover time reduction enhanced production efficiency while eliminating non-value-adding activities.

As a result of implementing the ECRS method, organizations can eliminate non-value-adding activities from their operational processes. The application of ECRS to the mold changeover process eliminated waste and enhanced productivity, easily increasing OEE (Figure 3). The application of ECRS to mold changeover influenced time reduction and led to better solution recommendation procedures.

As a graphical illustration of how the SMED, waste analysis, and ECRS impacted the process of externalizing activities to reduce mold changeover time increase production efficiency, and eliminate waste, the Gantt chart below serves as a better demonstration. The impact on the process flow as a result of externalization can be easily detected through this chart.

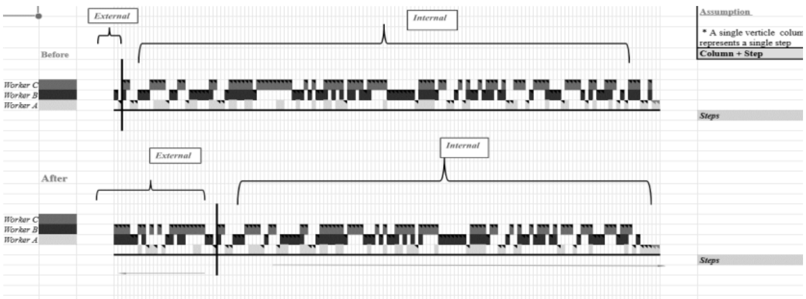

Figure 4: Gantt Chart.

Apart from this, for the process to be more effective and efficient it recommended a layout plan for a better movement management of the stocks, and raw materials and the reduction of labor movement throughout the process of mold changeover.

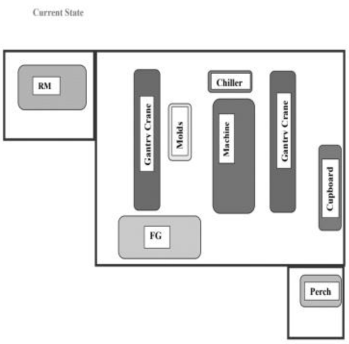

Figure 5: Current State.

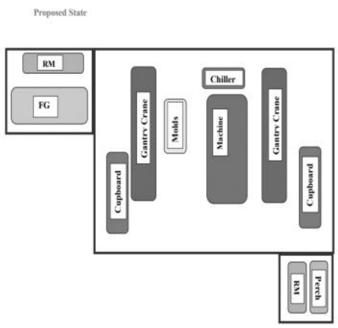

Figure 6: Proposed State.

1.1. Validation

As indicated in the methodology, we successfully validated the improvement suggestions as the final part of this project. After analyzing and finalizing the recommendations, we presented them to key stakeholders involved in the mold changeover process to gather feedback. A total of nine participants attended the discussion session, including the factory manager, the project coordinator, two engineers responsible for implementing the proposed layout plan, the supervisor of the changeover process, and our team. The session received positive feedback with several suggestions for further implementation.

In particular, engineers agreed with the proposed layout changes and have already begun implementing one of our key recommendations: extending the gantry crane rails to their full length, which they had not previously considered. Furthermore, they have begun creating SOPs and are in the process of fully implementing the SMED and ECRS improvement proposals. The following figures illustrate how we categorized the improvement proposals into two phases, based on implementation time and budget considerations.

Step No.	Steps	ECRS Analysis: Eliminate	Combine	Re-arrange	Simplify	Improvement Proposal
2	Cleaning the floor	1				If the employees in the previous shift could clean up the premise prior to there closure then, the employees in the up coming shift wont need to clean again.
3	Remove water tubes		1			change the path of movement (3,17,21)
5	close the machine	1				unnecessary motion - on employee side
6	spraying the green			1		Currently only a single emplyee sparys green for the both sides of the mould, but if we could combine this step and let two employees spray green together at once; the time could be reduced in half.
7	vacuuming the interior of the machine		1			change the path of movement (combine with 7,9)
8	close the door other side	1				unnecessary motion - on employee side
9	furthur vaccum the machine (remove rust)		1			change the path of movement (combine with 7,9)
10	opening the door	1				unnecessary motion - on employee side
17	remove the water tubes		1			change the path of movement (3,17,21)
20	open machine door another side	1				unnecessary motion - on employee side
21	put some water tubes inside of the machine		1			change the path of movement (3,17,21)
32	remove hydrolic tubes			1		Re-arrange the steps (32,33)
33	swiping the tubes using rags			1		Re-arrange the steps (32,33)
54	Tea time			1		follow the standard time shedule
55	cleaning the tie bar	1				unnecessary motion (duplication of work step 55 and 59)
59	cleaning the tie bar			1		unnecessary motion (duplication of work step 55 and 59)
83	remove water tubes	1				unnecessary motion
87	using the gantry crane keeping aside the iron plate				1	placing the iron plate on the gantry crane and not detaching it always
89	vacum the floor	1				eliminate and re-arrange steps 89 &126
90	lunch break			1		follow the standard time shedule
105	swiping the mould using the rags			1		segregate the task between two employees for time reduction and efficiency increments
110	Tea break			1		follow the standard time shedule
126	clean overall floor			1		eliminate and re-arrange steps 89 &126

Figure 7: Phase I.

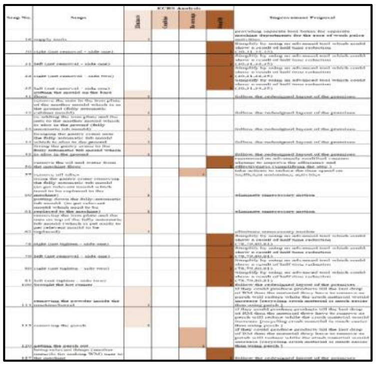

Figure 8: Phase II.

The improvement proposals outlined in Phase I are relatively easy to implement and require minimal time compared to Phase II suggestions. Phase I suggests it does not necessitate a significant budget or extensive time investment. Currently, several phase II proposals are being prepared for physical implementation.

In summary, we validated these recommendations through an expert panel of employees in the injection molding plant receiving valuable feedback and opinion-based validation of the model. In addition, some recommendations are already being implemented physically.

1.2. Limitations of the Discussion

Despite proposing the standardization of the changeover process, there are several limitations that must be acknowledged. The proposed changes to the changeover process for molding machines have limitations as they are tailored to a specific process, and they cannot be directly applied to other molding machines. Other than that, research findings are limited to the current operation of a particular organization. Therefore, it may require adjustments for generalization to different plants or industries due to differences in machinery, worker skills, and production conditions.

5. Conclusion and Implications

This study has demonstrated the application of SMED along with other lean manufacturing including waste analysis, and ECRS in order to reduce mold changeover time and enhance operational efficiency. It is a crucial fact in order to effectively minimize downtime and enhance overall efficiency with the identification of each step and categorize them into external and internal activities. Furthermore, establishing well-structured standardized procedures not only streamlines processes but also improves productivity while improving competitiveness within the manufacturing industry.

Even if it may vary the efficient usage of lean practices across different manufacturing environments, it encourages manufacturing organizations to adopt the SMED technique to integrate their lean practices while creating a standardized and efficient changeover process. However, this approach is not only reducing the required time for the changeover but also the operational excellence and culture of continuous improvement.

5.1 Future Recommendations

For further implications for this, the following recommendations can be considered to shape future directions.

1. Use of Visual Management Techniques
    - 1.1 Shadow boards
    - 1.2 Color coding tubes and their connecting portals
    - 1.3 Magnetic bases to hold removed tubes
    - 1.4 Customized manifold assembly line system
    - 1.5 Andon light system

2. Skill Enhancement
    - 2.1 Embedding the employees with the necessary skills such as technical and problem-solving.
    - 2.2 Show them key skills and competency analysis

Key Skills & Competencies

Instructions:
1. Fill in the name of the team.
2. Enter the skills that are required for the team and briefly describe each skill.
3. Rate the skill importance on a scale from 1 to 5 based on the 1st table on the right-hand side.
4. Rate the skill level required on a scale from 1 to 5 based on the 2nd table on the right-hand side.

TEAM	

SKILL/COMPETENCY	Skill Description	Skill Importance	Skill Level Required
Technical skills			
Machine Operation	Proficiency in operating washing machines and understanding their specific requirements.	3	
Mold Handling	Ability to handle, clean, and maintain molds safely and efficiently.	4	
Tool Usage:	Knowledge of the correct use of tools and equipment involved in the changeover process.		
Troubleshooting	Ability to diagnose and troubleshoot problems that may arise during the changeover process.		
soft skills			
Problem-Solving	The ability to identify and solve problems effectively.		
Time Management	The ability to manage time efficiently and prioritize tasks.		
Teamwork	The ability to work collaboratively with others and contribute to a team effort.		
Attention to Detail	The ability to pay close attention to detail and ensure accuracy in tasks.		

Skill Importance Levels	
Rating	Meaning
1	**Not Important**: Peripheral to the job role; a 'nice-to-have' but not essential.
2	**Of Minor Importance**: Occasionally useful, but not central; enhances some tasks.
3	**Moderately Important**: Regularly used; expected for the role.
4	**Very Important**: Frequently used; absence hinders performance; defining for the role.
5	**Critically Important**: Indispensable for primary responsibilities; must-have for the job.

Skill Level Requirements	
Rating	Meaning
1	**Novice**: Limited understanding of the skill. Requires significant guidance and is in the early stages of learning.
2	**Basic**: Has foundational knowledge but lacks hands-on experience. Can perform simple tasks with some assistance.
3	**Competent**: Comfortable with the skill. Can perform tasks independently but may require occasional guidance for complex
4	**Proficient**: Strong understanding with extensive hands-on experience. Can handle complex tasks and resolve issues effectively.
5	**Expert**: Mastery of the skill. Recognized as a go-to person for challenges and can guide or train others.

Figure 9: Competency Analysis.

As shown in Figure 9, it will provide a comprehensive detailed analysis of the skill levels of each employee.

3. Use of Lean Manufacturing Tools
   - 3.1 Creating task-batches
   - 3.2 Task deviation
   - 3.3 Time allocation for each task
   - 3.4 Creating insider intervals

By considering these recommendations, any organization can foster a culture of continuous improvement and improve overall operational efficiency. Integrating visual management techniques provides clarity on the production floor and skills development initiatives enable employees to adapt to challenges and contribute to problem-solving efforts. In addition, the use of lean manufacturing tools, streamlines processes reduces waste, and optimizes resource allocation. Collectively, these strategies can pave the way for sustainable growth, improved productivity, and a more engaged workforce.

In conclusion, the findings of this study highlight how effectively lean manufacturing principles are used in optimizing changeover processes. Implementing continuous improvement by developing comprehensive training programs based on lean methods, exploring advanced technologies, and conducting regular changeover practice assessments can enhance their competitiveness while gaining significant efficiency and reducing waste.

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