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Industry 4.0-Enabled SMED Implementation for Improving Pipe Extrusion Efficiency: A Case Study

Dewan Hafiz Nabil
Department of Industrial Engineering and Management
Khulna University of Engineering & Technology, KUET-9203, Bangladesh
nabil.kuet@gmail.com , nabil@akijpipes.com

Shamsunnahar Khanam
Department of Industrial Engineering and Management
Khulna University of Engineering & Technology, KUET-9203, Bangladesh
tripte.kuet@gmail.com

Sifat Ajmeer Haque
Department of Industrial and Production Engineering
Jashore University of Science and Technology
sifatajmeer@gmail.com

Abstract

Efficient equipment utilization is critical in the competitive plastics industry, where prolonged setup and changeover times, particularly in die-changing processes, impede productivity and delay order fulfillment, leading to customer dissatisfaction. This study addresses these challenges by implementing Single Minute Exchange of Die (SMED), a key Industry 4.0 methodology, to optimize setup processes in pipe extrusion. SMED systematically identifies and segregates internal (machine-stopped) and external (machine-running) setup activities, aiming to minimize overall setup time. By streamlining workflows and adopting best practices, SMED demonstrates substantial benefits in pipe manufacturing, which often requires frequent die changes. A case study revealed that the initial die setup process required 50 minutes and six workers. Through SMED implementation, this time was reduced to 20 minutes - a 60% improvement. Learning curve analysis further validated this reduction, illustrating how consistent practice and process refinement achieved the target setup time efficiently. These improvements resulted in a 40% productivity gain and annual cost savings of 518,400 taka (4,320 USD). This research highlights the transformative potential of Industry 4.0 tools like SMED in optimizing setup times, enhancing productivity, reducing bottlenecks, and maximizing equipment utilization, thereby significantly improving operational efficiency and competitiveness in the pipe extrusion industry.

Keywords:
SMED, Industry 4.0, Smart Manufacturing, Setup Optimization, Productivity Improvement

1.0 Introduction

Single Minute Exchange of Die (SMED) is an Industry 4.0 enabled lean manufacturing tool designed to minimize setup time in production processes. In the context of pipe extrusion, SMED involves optimizing the changeover process between different die configurations, reducing the time required to switch from producing one pipe size or type to another. By minimizing setup time, SMED can significantly improve production efficiency, reduce costs, and enhance overall competitiveness. (Ohno 1988). The concept of SMED was pioneered by Taiichi Ohno, a key figure in the Toyota Production System. It is rooted in the principles of lean manufacturing, which emphasize eliminating waste and maximizing value in production processes. SMED has been widely adopted in various industries, including automotive, electronics, and food processing, to improve productivity and reduce costs (Womack & Jones 1990).

Although SMED's positive impacts have been extensively studied and successfully implemented in various manufacturing sectors (Bhuiyan & Baghel, 2005), its specific application in the pipe extrusion industry remains relatively limited and largely unexplored (Nablus, 2014). There is a lack of empirical research exploring the specific challenges and opportunities associated with implementing SMED in this context.. This research aims to address this gap by providing a comprehensive case study of SMED implementation in a pipe extrusion facility, offering insights into the potential benefits and challenges of SMED in this industry, and providing guidance for manufacturers seeking to improve their productivity and competitiveness. The research questions guiding this study are:

1. What are the current challenges and inefficiencies in the setup process of a pipe extrusion facility?
2. How can SMED be effectively implemented to reduce setup time, cost and improve productivity in pipe extrusion?
3. What are the potential benefits and costs associated with implementing SMED in a pipe extrusion facility?

To address the research questions, a case study methodology was adopted. A specific pipe extrusion facility was selected as the case study site. Data was collected through time study and interviews, observations, and analysis of existing production records. The data collected was then analyzed to identify the current setup process, its inefficiencies, and the potential areas for improvement through SMED implementation. The findings of this study will offer valuable insights into the specific challenges and opportunities associated with SMED in this context, as well as the potential benefits in terms of reduced setup time, cost, improved productivity, and enhanced competitiveness.
The remainder of this paper is organized as follows: Section 2 provides a brief overview of previous work. Section 3 provides the problem statement for the case study. Section 4 presents the methodologies of the study. Section 5 discusses the application of SMED for the company specific case. Section 6 conducts numerical analysis and the potential benefits of SMED implementation in pipe extrusion. Finally, Section 7 & 8 sums up the result and concludes the paper by summarizing the key findings and recommendations.

2. Literature Review

This section delves into the core concepts of lean manufacturing, with a particular focus on the Single Minute Exchange of Dies (SMED) and its implementation in industrial settings. SMED is a specialized technique designed to minimize the setup time required for the changeover of production equipment, such as the dies used in pipe extrusion. By streamlining these changeover processes, SMED aims to reduce the overall time a machine or process is unavailable for production (Malindzakova et al. 2021). This research investigates the application of SMED within the framework of lean manufacturing, a philosophy that emphasizes the elimination of waste and the maximization of value throughout production processes. The analysis will distinguish between internal setup activities, which must be performed while the machine is stopped, and external setup activities, which can be carried out while the machine is still running.

This distinction is crucial for identifying opportunities to convert internal setup tasks to external ones, thereby minimizing machine downtime and optimizing production flow. Rother & Shook (2003) introduced the concept of production process analysis, a tool that can be used to identify and eliminate waste in the setup process. It provides a visual representation of the entire production flow, enabling a systematic analysis of setup activities and their impact on overall lead times. The review will also explore the concept of Kaizen, a Japanese term for “continuous improvement,” which is central to the ongoing efforts to refine and enhance the efficiency of setup processes (Pellegrini, Shetty, & Manzione 2012). Additionally, the research will examine the impact of SMED on production bottlenecks – constraints that limit the overall throughput of a manufacturing process. By addressing these key terms and their practical implications, this literature review provides a comprehensive foundation for understanding the role and benefits of SMED in optimizing pipe extrusion processes.

Previous works on SMED implementation in various industries have demonstrated its effectiveness in reducing setup times and improving productivity (McCarthy & Rich, 2004). These studies provide valuable insights into the challenges and opportunities associated with implementing SMED in different manufacturing contexts. Some relevant works include Shigeo Shingo's (1985) book, which provides a detailed methodology for implementing SMED in manufacturing settings. As a method, SMED involves a systematic approach to analyzing and reducing setup time, aiming to convert as many internal setup tasks to external as possible, while simplifying and standardizing the remaining steps (Singh, Singh, & Singh 2018). In the plastic injection molding industry, Cakmakci and Demirel-Ortabas (2019) demonstrated the use of process capability analysis for attribute data to measure the performance of SMED improvements. Their study highlighted the effectiveness of SMED in improving quantitative and qualitative characteristics in the production process. McCarthy and Rich (2004) provide a comprehensive guide to implementing Total Productive Maintenance (TPM), a lean manufacturing methodology that complements SMED.

It highlights the importance of equipment reliability and operator involvement in achieving optimal setup times. Bhuiyan and Baghel (2005) review various applications of SMED across different manufacturing industries, including automotive, electronics, and food processing. It highlights the diverse benefits of SMED, such as reduced lead times, improved quality, and increased production flexibility. In the electronics industry, SMED has been applied to optimize setup processes for printed circuit board assembly, resulting in increased responsiveness and accelerated delivery times (Trovinger & Bohn, 2005). Liker (2004) explores the management principles behind the Toyota Production System, which includes SMED as a key element. It emphasizes the importance of continuous improvement, employee empowerment, and customer focus in achieving sustainable success. Godina et al. (2018) analyze 70 publications on SMED from 2007 to 2018, categorizing them by industry, research method, and publication type. The review finds that the majority of publications are case studies (72.8%), with the automotive industry being the most frequently studied (21.6%). The authors conclude that SMED research has been increasing in recent years and that case studies are the most common method for examining SMED implementation.

In addition to these general works on SMED, there have also been several studies specifically examining the implementation of SMED in the pipe extrusion industry. SMED has proven effective in the plastic extrusion industry, significantly reducing setup times and boosting productivity, as evidenced by studies (Arroyo-Huayta et al. 2021). Martínez, Najera, and Diez (2024) further emphasize the broader benefits of SMED, showing its potential to reduce workplace accidents, defects, and machine breakdowns through a comprehensive approach that includes process analysis, task structuring, and leveraging employee expertise. Mulla, Bhatwadekar, and Pandit (2014) conducted a study on a semi-automatic Vertical Boring Machine (VBM) in a pump manufacturing industry in Maharashtra, India, and successfully reduced changeover time by employing the SMED technique. Mendhe (2017) implemented SMED in a bandsaw cutting machine, achieving 75% reduction in setup time and 8% improvement in Overall Equipment Effectiveness (OEE). Haddad and Shaheen (2021) conducted a study on improving the Overall Equipment Effectiveness (OEE) of an extrusion machine using a lean manufacturing approach, specifically the Single Minute Exchange of Die (SMED) technique.

Their research focused on a leading Palestinian aluminum and profiles company, where they implemented SMED through experimental procedures on the extrusion line processes. The successful implementation of SMED resulted in an increase of OEE by 3.26% as a consequence of the increase of machine availability by 4.86%. These related works provide a theoretical and practical foundation for understanding and implementing SMED in various manufacturing contexts. While the specific challenges and opportunities may vary across industries, the underlying principles of SMED remain relevant for optimizing setup times and improving overall productivity (Godina et al. 2018). SMED implementation is an ongoing process that requires continuous evaluation and refinement to maintain and improve efficiency.

3.0 Problem Statement

In the competitive pipe extrusion industry, frequent product changeovers necessitate efficient die change processes to maintain productivity and cater to diverse market demands. However, many facilities face challenges with prolonged setup times, hindering their ability to respond quickly to customer orders and optimize production efficiency. These delays often stem from a lack of standardized procedures, optimized workflows, and proper resource utilization, resulting in significant downtime, production losses, and increased operational costs. This study addresses the problem of excessive die changeover times in a pipe extrusion facility, with the aim to identify the root causes of these inefficiencies and implement targeted solutions to streamline the setup process. By employing SMED methodology, a proven lean manufacturing technique, this research seeks to minimize machine downtime, reduce costs associated with labor and lost production, and improve the overall productivity of the pipe extrusion process.

4.0 Research Methodology

This study employed a mixed-methods research methodology, combining quantitative and qualitative data collection and analysis techniques to comprehensively investigate the problem of excessive die changeover times in the pipe extrusion facility. The research design involved a multi-stage approach, beginning with an initial assessment of the current die changeover process, followed by the implementation of the SMED technique, and concluding with a post-implementation evaluation to measure the effectiveness of the intervention.

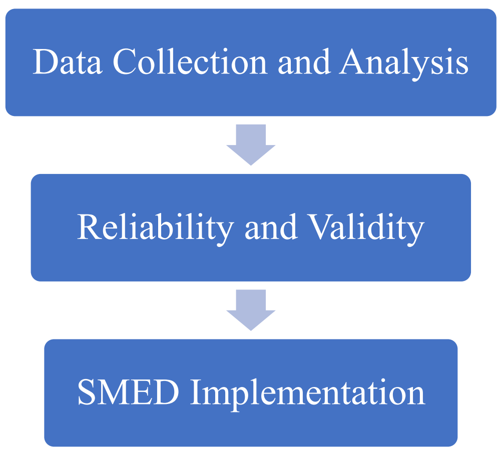

Figure 1. Research Methodology

This multifaceted approach allowed for a thorough examination of the research problem and facilitated the development of targeted solutions to optimize the die changeover process.

4.1 Data Collection and Analysis:

In the first step, primary data on die changeover times was collected directly from the production floor using the time study method. This involved observing and recording the time taken for each step in the die changeover process. Additionally, information on minimum employee hourly wages was gathered through interviews with key human resource personnel at the facility. Secondary data, including production records and process documentation, was also collected to supplement the primary data and provide a deeper understanding of the existing setup process. Following the implementation of SMED in third step, further data collection was conducted to assess the impact of the intervention. This included time studies to measure the new die changeover times and comparison analysis to quantify the reduction in setup time. A cost-benefit analysis was performed, applying numerical methods to calculate the percentage reduction in setup time, the productivity gain achieved, and the labor cost savings resulting from the reduced setup times. The formulas below are used in numerical analysis:

1. **Formula for calculating percentage reduction in setup time** = $(Original\ setup\ time\ - New\ setup\ time)\ /\ (Original\ setup\ time * 100)$
2. **Formula for calculating productivity gain=** $(Previous\ downtime/\ Reduced\ downtime) * 100$

This comprehensive methodology allowed for a rigorous investigation of the problem and the effective implementation of SMED, leading to significant improvements in the die changeover process at the pipe extrusion facility.

4.2 Reliability and Validity:

To ensure the reliability and validity of the time study data, multiple sets of study observations were conducted. This allowed for the triangulation of findings and minimized the impact of any potential outliers or inconsistencies in the data. For consistency, the average result of the multiple time study sets was used in the analysis. After implementing SMED, this study conducted a learning curve analysis to verify that the **desired** setup time was achieved.

4.3 SMED Techniques:

The core of the methodology involved the implementation of the SMED technique. This systematic approach focused on separating internal and external setup activities, converting internal setup to external setup wherever possible, and simplifying and standardizing the remaining steps in the die changeover process. This study embeds the conventional SMED stages by following the SMED framework proposed by Ebrahimi et al. (2023). The major steps of SMED include:

Step 1: Analyze the current process and identify all steps.

Step 2: Separate internal and external setup activities.

Step 3: Streamline external setup activities.

Step 4: Simplify and standardize remaining activities.

5.0 Application of Industry 4.0-Enabled SMED- A Case study

5.1 Brief description of the company case:

Our pipe extrusion facility houses 10 machines and produces approximately 250 different pipe items, resulting in a complex production environment. To meet the diverse demands of the market, efficient production planning and scheduling are crucial, yet challenging due to the extensive product range. A major obstacle to efficient production is the frequent die changes required to accommodate the variety of pipe products. Each die-change necessitates a significant amount of downtime, hindering overall productivity and potentially causing delays in fulfilling customer orders. **Recognizing the need** to optimize this process, we initiated the implementation of the SMED methodology. SMED, a core principle in lean manufacturing, focuses on minimizing setup times, thus maximizing productive time and enhancing the overall efficiency of the facility.

Our SMED implementation focused on optimizing the die changeover process by targeting three key areas. **Firstly**, the die-punch, initially a single unit requiring full disassembly for die changes, was redesigned into a two-part separable configuration, simplifying die replacement and reducing the time and effort involved. **Secondly,** standardized toolboxes were introduced to ensure that all necessary tools and equipment were readily available and organized, eliminating wasted time searching for tools and promoting a more efficient and consistent process. **Lastly,** the die changeover process was analyzed to identify opportunities for performing tasks concurrently. Cleaning and lubrication activities, previously performed sequentially, were reorganized to be carried out simultaneously with other external setup activities, further optimizing the process flow.

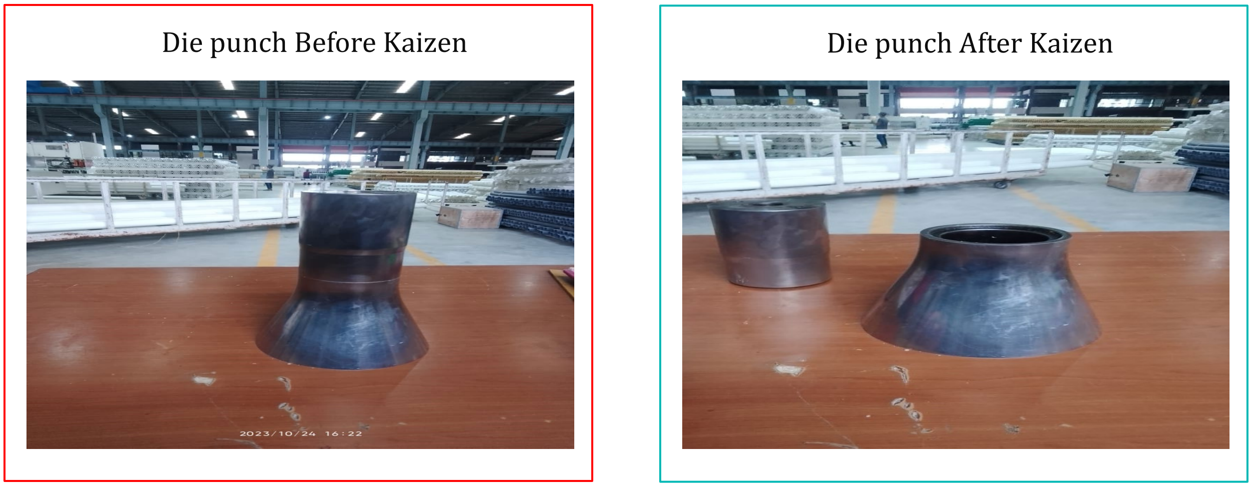

Figure 2. Inseparable to separable Die Punch

These targeted improvements, achieved through the application of SMED principles, resulted in substantial time and cost savings for the facility, ultimately enhancing its overall efficiency and competitiveness. The specific outcomes and numerical analysis of these improvements are detailed in the following sections.

6.0 Numerical Illustrations

To provide a clear and detailed understanding of the SMED implementation and its impact, this section outlined the numerical illustrations related to time saved, cost saved, and productivity gain.

6.1 Setup Time Reduction

SMED is particularly beneficial for pipe manufacturing machines, which often require frequent die changes. By reducing setup time, SMED can help to increase production efficiency. To find out total setup time reduction, all die changing activities were divided into external and internal activities by analyzing the current process.

Table 1. Internal & External activities of Die changing

External Activities	Internal Activities
✓ Prepare the new die and place it in position	✓ Remove the old die.
✓ Gather all the necessary tools and equipment.	✓ Install the new die.
✓ Clean and lubricate the machine	✓ Adjust the machine settings

Before SMED implementation, the total time required for external setup activities was 50 minutes. This included:

Table 2. Time required to perform External activities before SMED

External Activities	**Average Time Required (Minutes)**
Preparing the new die and placing it in position	25 minutes
Gathering all the necessary tools and equipment	14 minutes
Cleaning and lubricating the machine	11 minutes
Total	**50 minutes**

After implementing SMED, the total time for external setup activities was reduced to 20 minutes by streamlining external setup activities. This reduction was achieved through the following improvements:

Die Modification: The die punch was redesigned into two separable parts, simplifying the removal and replacement process.

- **Standardized Toolbox:** A standardized tool arrangement box ensured all necessary tools were readily available, minimizing search time.
- **Concurrent Activities:** Cleaning and lubrication tasks were performed concurrently with other external activities, optimizing time utilization.

Table 3. Time required to perform External activities after SMED

External Activities	Average Time Required (Minutes)
Preparing the new die and placing it in position	11 minutes
Gathering all the necessary tools and equipment	05 minutes
Cleaning and lubricating the machine	04 minutes
Total	**20 minutes**

Therefore, the total time saved per die change is:

50 minutes (before SMED) - 20 minutes (after SMED) = 30 minutes

This represents a **60% reduction** in setup time. (50 minutes - 20 minutes) / 50 minutes * 100 = 60%

6.2 Learning Curve

The learning curve, also referred to as the experience curve or the efficiency curve, captures the idea that any employee, regardless of position, takes time to learn how to carry out a specific task or duty. The amount of time needed to produce the associated output is high in the initial phase. Then, as the task is repeated, the employee learns how to complete it more quickly, reducing the time needed for a unit of output (Anzanello & Fogliatto, 2011). After implementing SMED and achieving a reduced setup time, we conducted four-time studies per day and calculated the average setup time for each day. We continued this process until the target setup time of 20 minutes was consistently achieved to observe the learning curve of implementing SMED. This target was met on the 9th and 10th days. The table below shows the average setup time per day.

Table 4. Average Time Study Result for 10 days after SMED implementation

Day	Day 1	Day 2	Day 2	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Time (Min)	28	27	25	23	22	22	21	21	20	20

Based on the gathered data, we plotted it into a chart to visualize how the die-changing time improved over time, and the process became more efficient. The graph's downward slowing curve visually demonstrates the learning curve effect. Initially, the setup time decreases rapidly, indicating quick learning. As the team gains experience, the curve becomes less steep, suggesting a gradual reduction in setup time. This aligns with the learning curve theory, where initial gains are substantial, followed by diminishing returns. The graph shows that it required less time as days passed, and by the 10th day, the desired setup time of 20 minutes was achieved. This observation underscores the effectiveness of SMED implementation in facilitating process standardization and promoting efficient learning.

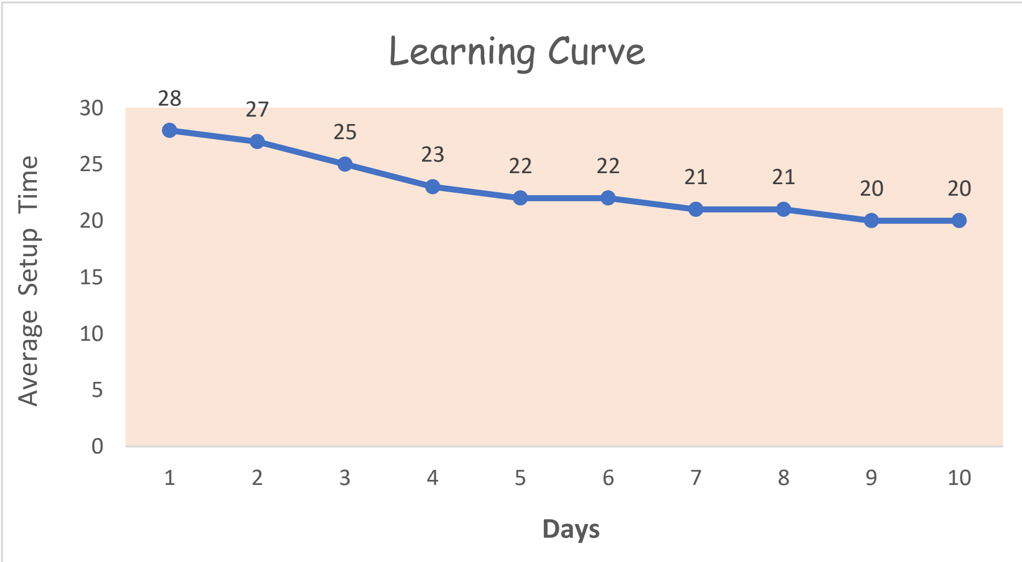

Figure 3. Learning Curve of Setup Time

6.3 Cost Saved

The cost savings were calculated based on the time saved per die change, the number of die changes per day, and the labor cost per hour**. It's important** to highlight that the investment cost for implementing SMED was not significant, as we primarily utilized our in-house tools and focused on process and die modifications. Additionally, the manpower cost for implementing SMED is negligible, as it was integrated into our regular Kaizen work. We used the following data to conduct cost saving analysis:

Table 5. Data used for cost saving analysis

Metric	Value	Source
Manpower Required (persons) per Die Change	6	Production Process Analysis
Labor Cost per Hour (taka)	120	Based on Minimum Hourly Wages (from HR)
Average Die Changes per Day	4	Production Process Analysis

Calculations:
Total time saved per day: 30 minutes/die change * 4 die changes/day = 120 minutes/day
Total time saved per day in hours: 120 minutes/day / 60 minutes/hour = 2 hours/day
Total labor cost saved per day: 2 hours/day * 120 taka/hour * 6 laborers = 1440 taka/day
Total labor cost saved per year: 1440 taka/day * 30 days/month * 12 months/year = 518,400 taka/year
Total labor cost saved per year in US dollars: 518,400 taka/year / 120 taka/USD = 4320 USD/year

6.4 Productivity Gain

The reduction in setup time through SMED implementation directly translates to a productivity gain. This is because less time spent on setup means more time available for production. The productivity gain was calculated by comparing the downtime before and after SMED implementation.

Calculations:
Total downtime before SMED: 50 minutes/die change * 4 die changes/day = 200 minutes/day
Total downtime after SMED: 20 minutes/die change * 4 die changes/day = 80 minutes/day
Productivity gain: (80 minutes/day / 200 minutes/day) * 100 = 40%

This indicates a 40% increase in productive time available for pipe extrusion, leading to higher output and improved efficiency.

7.0. Results and Discussion

This study investigated the implementation of Single-Minute Exchange of Dies (SMED) in a pipe extrusion facility to optimize setup processes. The results demonstrate SMED's effectiveness in reducing setup time, leading to significant cost savings and productivity gains. Analysis revealed a **60%** reduction in setup time, **reducing it from 50 minutes to 20 minutes,** achieved through targeted improvements. These included modifying the die punch for easier replacement, introducing a standardized tool arrangement box to streamline tool retrieval, and performing cleaning and lubrication concurrently with other external activities.

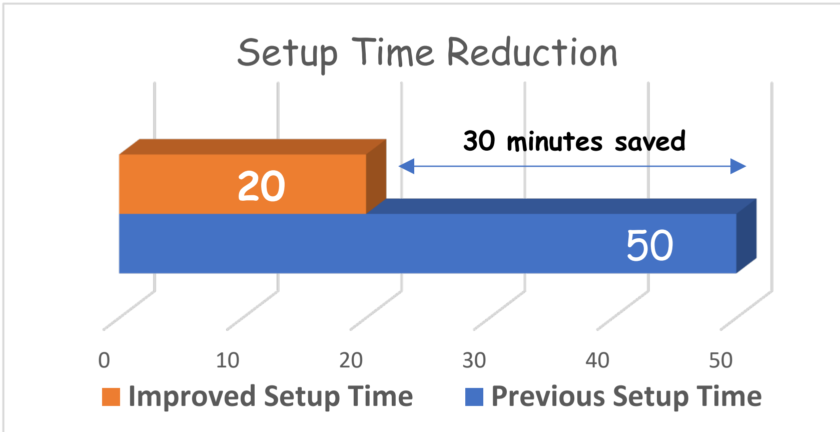

Figure 4. Time Saved

These changes resulted in a more efficient setup process, allowing for increased production. The overall cost savings from this productivity gain are estimated to be **518,400 taka/year or 4320 USD/year**, based on calculated labor cost savings. Furthermore, the reduction in setup time translated to a **40% productivity gain**, with total downtime decreasing from 200 minutes/day to 80 minutes/day. This increase in productive time signifies higher output and improved efficiency.

This study overcame resistance to change and initial production disruptions through active employee involvement, training, and clear communication of SMED's benefits. The learning curve analysis showed rapid adaptation, with setup times improving daily and stabilizing at the target of 20 minutes by day nine. This highlights the role of structured implementation and workforce engagement in achieving sustainable process improvements.

Beyond quantitative benefits, SMED implementation also yielded qualitative improvements. Employees reported increased engagement and motivation due to their involvement in the process. Standardized procedures reduced stress associated with die changes, contributing to a more positive work environment. Additionally, the streamlined setup process minimized errors and enhanced consistency in pipe quality. The successful SMED implementation in this pipe extrusion facility aligns with previous research highlighting its effectiveness in optimizing setup times and enhancing productivity across various manufacturing sectors. The findings demonstrate SMED's potential to significantly improve operational efficiency and competitiveness in the pipe extrusion industry.

8.0 Conclusion

This study successfully implemented SMED in a pipe extrusion facility, demonstrating its effectiveness in reducing setup time and increasing productivity while fostering a more engaged and empowered workforce. These findings have substantial **implications** for pipe manufacturers, offering a clear pathway towards optimizing production processes, reducing costs, and enhancing competitiveness in a dynamic industry. From a **managerial perspective**, the study highlights the importance of employee involvement and structured change management to overcome resistance and ensure smooth implementation. Additionally, the improved setup efficiency contributes to **environmental** sustainability by minimizing downtime and resource waste.

However, the study's **limitations** must be acknowledged. Conducted in a specific facility with existing automation systems, the findings may have limited applicability to industries reliant on manual processes. Furthermore, the research primarily focused on the quantitative benefits of SMED. **Future studies** could explore its impact on employee morale, teamwork, and the potential for reducing pipe scrap and material waste during changeovers. To achieve further optimization, subsequent research should investigate integrating SMED with Industry 4.0 technologies and lean tools such as TPM and VSM. Such integrations could enable online setup adjustments, enhance delivery times, improve product quality, and support long-term sustainability within organizations.

9.0. References

Arroyo-Huayta, C., Cruces-Raimudis, S., Viacava-Campos, G., Leon-Chávarri, C., & Aderhold, D. , Model to improve efficiency in the extrusion area in a manufacturing sme of the industrial plastic sector based on SMED, autonomous maintenance and 5s. In Human Interaction, Emerging Technologies and Future Applications *III: Proceedings of the 3rd International Conference on Human Interaction and Emerging Technologies: Future Applications (IHIET 2020), August 27-29, 2020, Paris, France (pp. 545-551). Springer International Publishing,2021.*

Anzanello, M. J., & Fogliatto, F. S. , Learning curve models and applications: Literature review and research directions. *International Journal of Industrial Ergonomics*, *41*(5), 573-583,2011.

Bhuiyan, N., & Baghel, A. (2005). An overview of the applications of SMED in manufacturing industries. *International Journal of Advanced Manufacturing Technology, 25(9-10), 944-952,2005.*

CAMARA, E. M., NAJERA, J. L., DIEZ, J. C. S., MACIAS, E. J., BRUZZONE, A., & FERNANDEZ, J. **B. (2024).** METHODOLOGY TO MAXIMIZE ZERO LOSSES THROUGH SMED IN FOOD INDUSTRY. *DYNA, 99(3), 240-244,2024.*

Cakmakci, M., & Demirel-Ortabas, N. , Performance measurement of SMED improved plastic injection molding production by using process capability analysis for attribute data. In *Advances in Manufacturing II: Volume 2-Production Engineering and Management* (pp. 188-205),2019. Springer International Publishing.

Ebrahimi, A., Khakpour, R., & Saghiri, S. , Sustainable setup stream mapping (3SM): a systematic approach to lean sustainable manufacturing. *Production Planning & Control*, *34*(4), 311-329,2023.

Godina, R., Štemberger, M. I., & Kokol, P. (2018). Systematic literature review of SMED implementation. *Strojniški vestnik - Journal of Mechanical Engineering, 64(12), 739-751.*

Haddad, T., Shaheen, B. W., & Németh, I. , Improving overall equipment effectiveness (OEE) of extrusion machine using lean manufacturing approach. *Manufacturing technology, 21(1), 56-64,2021.*

Liker, J. K. (2004). The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. McGraw-Hill.

McCarthy, D., & Rich, N. (2004). Lean TPM: A Plantwide Strategy for Equipment Effectiveness. *Productivity Press.*

Mendhe, S., & Rathi, M. G. , Implementation of SMED Technique to Reduce Setup Time of Bandsaw Cutting Machine. *International Journal of Engineering Research & Technology, 6(01), 2278-0181,2017.*

Mulla, M. L., Bhatwadekar, S. G., & Pandit, S. V. , Implementation of lean manufacturing through the technique of Single Minute Exchange or Die (SMED) to reduce change over time. *International Journal of Innovative Research in Science, Engineering and Technology, 3(6), 13069-76,2024.*

Malindzakova, M., Malindzak, D., & Garaj, P. , Implementation of the Single Minute Exchange of Dies method for reducing changeover time in a hygiene production company. *International Journal of Industrial Engineering and Management*, *12*(4), 243-252,2021.

Nablus, P. ,) Performance Improvement Using the Single Minute Exchange of Die (SMED) Methodology in an Aluminum Profiles Extrusion Production System.,2014

Ohno, T. (1988). Toyota Production System: Beyond Large-Scale Production. *Productivity Press.*

Pellegrini, S., Shetty, D., & Manzione, L. (2012). *Study and implementation of single minute exchange of die (SMED) methodology in a setup reduction kaizen* (Doctoral dissertation, Unioversity of Hartford).

Rother, M., & Shook, J. , Learning to See: Value Stream Mapping to Add Value and Eliminate Muda. *Lean Enterprise Institute, 2003.*

Shigeo Shingo (1985). A Revolution in Manufacturing: The SMED System. *Productivity Press*.

Singh, J., Singh, H., & Singh, I. , SMED for quick changeover in manufacturing industry–a case study. *Benchmarking: An International Journal*, *25*(7), 2065-2088,2018.

Trovinger, S. C., & Bohn, R. E. , Setup time reduction for electronics assembly: Combining simple (SMED) and IT-based methods. *Production and operations management*, *14*(2), 205-217,2005.
Womack, J. P., & Jones, D. T. (, The machine that changed the world. *Rawson Associates,1990*

Biographies

Dewan Hafiz Nabil is a Supply Chain Production Planner at Akij Pipes and Fittings and Co-Founder of Gadget MaMu. He holds a BSc in Industrial and Production Engineering from KUET. His research focuses on systems engineering, optimization, Supply chain, particularly Industry 4.0, Blockchain, AI, and Data Analytics for sustainable solutions. He has published three research articles in international journals, accumulating 22 citations till now.

Shamsunnahar Khanam holds a BSc in Industrial and Production Engineering from KUET, specializing in supply chain management. Her current research focuses on supplier selection based on multi-criteria for multi-products. She is proficient in Python, C, Matlab, MS Office, and Power BI.

Sifat Ajmeer Haque is an Industrial and Production Engineering professional with experience at Square Apparels and Akij Plastics. He currently oversees Solvent Cement Production, and manages Filter Pipes, Fabricated Fittings, and corporate sales at Akij Plastics. He is passionate about leadership, research, and innovation in his field.