ISSN: 2614-6754 (print)
ISSN: 2614-3097(online)

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Volume 8 Nomor 1 Tahun 2024

Application of Discrete-Event Simulation to Increase Machine Availability – A Case Study in Cigarette Filter Manufacturing

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Abstrak

Penelitian ini menjawab tantangan yang dihadapi industri filter rokok dalam mengelola perubahan produksi yang sering terjadi, sehingga mempengaruhi produktivitas di tengah meningkatnya permintaan akan beragam produk. Perusahaan ini menggunakan Simulasi Peristiwa Diskrit (DES) untuk mengoptimalkan pemanfaatan mesin, khususnya menargetkan periode pergantian yang berkepanjangan untuk meningkatkan daya saing. Studi ini meninjau kontribusi terkini dalam penerapan DES pada proses manufaktur, dengan menekankan kemanjurannya dalam meningkatkan efisiensi. Metode penelitian melibatkan tiga fase utama: studi proses yang komprehensif, simulasi proses manufaktur, dan peningkatan skenario sistematis. Melalui studi kasus terperinci mengenai pembuatan filter rokok, makalah ini menunjukkan penerapan praktis DES untuk meningkatkan proses pergantian. Dengan membandingkan berbagai skenario, studi ini mengidentifikasi solusi paling efektif, yang menghasilkan peningkatan signifikan sebesar 35,8% dalam operasi penggantian bagian selama konstruksi mekanis. Peningkatan ini setara dengan pengurangan waktu pergantian sebesar 2,2 jam. Penerapan skenario yang dioptimalkan terbukti berperan penting dalam meningkatkan ketersediaan alat berat secara keseluruhan, sehingga memberikan kontribusi positif terhadap efisiensi operasional industri.

Kata kunci: Arena, Waktu Henti Pergantian, Simulasi Peristiwa Diskrit, Lean Manufacturing, Pemodelan Sistem

Abstract

This research addresses challenges faced by the cigarette filter industry in managing frequent production changes, affecting productivity amid growing demand for diverse products. It employs Discrete-Event Simulation (DES) to optimize machine utilization, specifically targeting prolonged changeover periods to enhance competitiveness. The study reviews recent contributions in applying DES to manufacturing processes, emphasizing its efficacy in improving efficiency. The research method involves three key phases: a comprehensive process study, simulation of the manufacturing process, and systematic scenario enhancements. Through a detailed case study on cigarette filter manufacturing, the

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paper demonstrates the practical application of DES for improving changeover processes. By comparing various scenarios, the study identifies the most effective solution, resulting in a significant 35.8% improvement in the change part operation during mechanical construction. This improvement equates to a 2.2-hour reduction in changeover times. Implementing the optimized scenario proves instrumental in boosting overall machine availability, contributing positively to the industry's operational efficiency.

Keywords: Arena, Changeover Downtime, Discrete-Event Simulation, Lean Manufacturing, System Modelling

INTRODUCTION

High downtime in textile industries, averaging 800 hours annually, causes a 5% production loss. The downtime's cost, estimated at $30,000 to $50,000 per hour, leads to an annual budget impact ranging from 10 to 25 million dollars (Patale et al., 2021). Other study encompassing 101 automotive industry leaders, reveals significant manufacturing challenges, with a notable 30% downtime during scheduled production. This signals a prevalent concern, as nearly every factory experience at least a 5% reduction in production capacity, translating to an astounding average cost of $1.3 million per hour of downtime (Emaint, 2013). To enhance production efficiency, Discrete-Event Simulation (DES) is employed for real-time modelling of production floor systems. Utilizing computer software enables simulation and analysis, evaluating alternative scenarios for the optimal improvement. Model validation involves replicating each scenario 10 times for robust assessment (Riskadayanti & Hisjam, 2019). Arena is simulation software developed by Rockwell Automation. It is a leading simulation software widely used in manufacturing including analysing system behaviour through Discrete-Event, Flow, and Agent-Based modelling methods (Rockwell Automation, 2023). This aids in visualizing both the current and redesigned processes under different scenarios, benefiting tactical and strategic person in a company. Arena offering solutions without disrupting the systems and people involved to enhance the existing process (S. Kumar & Phrommathed, 2006). Leveraging DES in lean manufacturing pinpoint key production line issues, reduce both setup time and non-value-added process. It eliminates bottlenecks that reduce the buffer by around 20%. Throughput analysis reveals an 10.67% improvement actual value addition in the production line. Storage and transportation utilize 43.32% and 40.86%, respectively, while production utilization lags at 15.81%. The cycle time throughput stands at 11.63 per hour (Sachin et al., 2018).

The changeover time refers to the duration between the final quality piece of one product and the initial quality piece of the subsequent product. This time is utilized for cleaning, altering machine parts, and configuring the setup for the upcoming product (Karam et al., 2018). The downtime arises due to factors such modifying or changing spare parts and adjusting equipment settings. Downtime duration influenced by part complexity and automated tool usage, leads to productivity losses and decreased machine performance (Sayem et al., 2014). During a changeover operation, there are two key activities: internal and external. Internal activities involve tasks performed when the machine is not running, while external activities occur when the machine is operationally active as shown in Figure 1.

ISSN: 2614-6754 (print)
ISSN: 2614-3097(online)
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The operation worksheet provides a detailed overview, distinguishing between internal and external activities for a comprehensive understanding of the changeover process (R. Kumar et al., 2022).

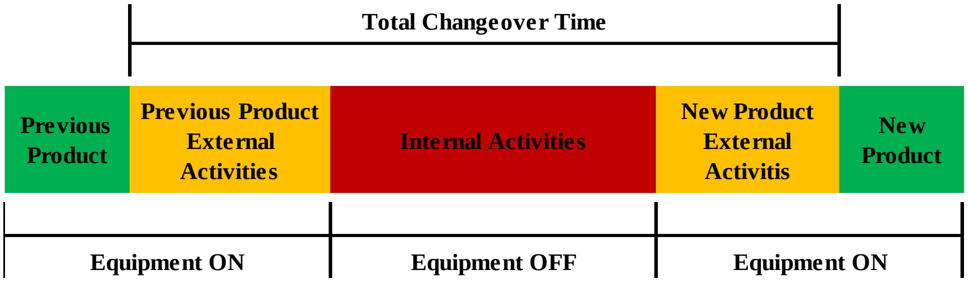

Figure 1. Changeover process category based on internal and external activities.

In lean manufacturing, the focus is on shifting internal setup tasks to external activities. This involves streamlining processes through eliminate, combine, rearrange, simplify (ECRS) and implementing parallel operations to enhance efficiency (Sayem et al., 2014).

A Discrete-Event Simulation model, built on observed data, integrates lean methodologies. It's refined to visually depict proposed improvements, leading to a 7.14% surge in throughput. This combined approach effectively reduces work-in-progress and cycle time, significantly elevating daily component production from 14,030 to 15,032. The simulation provides a practical framework for implementing lean principles and demonstrates tangible improvements in operational efficiency (Harish et al., 2023). DES enhance delivery performance within the pharmaceutical sector. The implementation of the optimal scenario could result in a remarkable 44.83% increase in productivity, and complete elimination of delayed jobs becomes feasible under the best-case scenario proposal (Troncoso-Palacio et al., 2018). DES method validated current state Value Stream Mapping (VSM) data for plastic pipe production. Key metrics include 9.7 minutes for value-added (VA) processing, 93 minutes for non-value-added (NVA) time, and a 14-minute wait time. Improvement areas highlight in minimizing order lead time, reducing changeover (CO) time, and enhancing product quality (Aomar et al., 2020). The integration of VSM and Discrete-Event Simulation using Arena support problem identification led to a result of a 23.6% lead time reduction, 9% value-added time reduction, and a 4.2% boost in productivity, contributing significantly to the overall 22.5% improvement (Singh et al., 2022).

This research was conducted in Company A which operate in a dynamic environment with diverse products and unpredictable demand. It focuses on optimizing operational efficiency, specifically reducing the time consumed by frequent changeovers in producing various cigarette filter products. The primary goal is process improvement, emphasizing the need to minimize machine downtime. This research investigates how implementing Discrete-Event Simulation at Company A contributes to reducing machine downtime in changing parts during the changeover process. The paper covers theoretical foundations, literature review, research methodology, data analysis, and conclusions.

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METHOD

The study follows a structured approach encompassing three key phases: process study, simulating process, and improvement scenarios, aligning with lean manufacturing principles and simulation study. Beginning with a defined problem statement related to changeover processes, the study outlines its objectives, scope, and process category, focusing on change part operation. Through actual data collection on resources availability, process times study, and work sequence, an Arena model is constructed. Rigorous validation testing performed to ensures model accuracy where successful validation allows progression. In cases of the validation process failed, data collection is reiterated until validation is achieved. Validated models enable exploration of alternative scenarios, facilitating iterative adjustments for optimal change part operations. Results obtained guide proposed process improvements derived from scenario development. The overall flow of the study is shown in Figure 2 below.

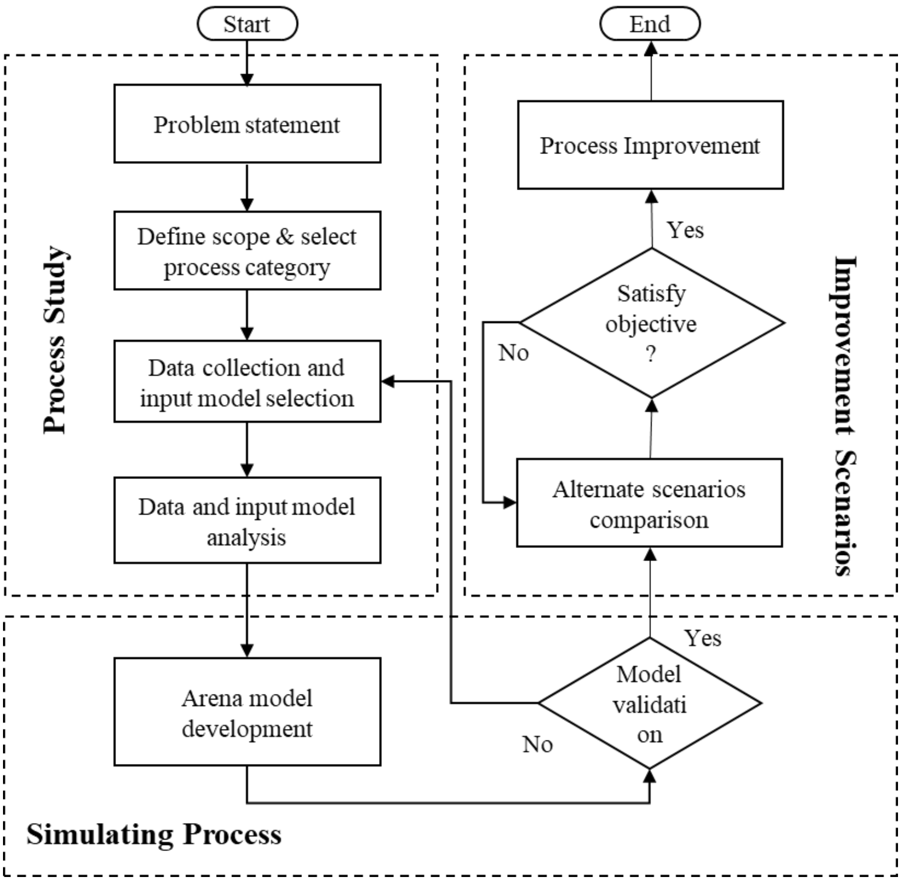

Figure 2. Flowchart of the study

ISSN: 2614-6754 (print)
ISSN: 2614-3097(online)

RESULT AND DISCUSSION

Problem Definition

In 2022, Company A's machine experienced a production time of 4685 hours, constituting 68% of the total available 6912 hours for the year. The changeovers accounted for 1147 hours (17%), equivalent to 4 days of downtime per month. This translates to 24 hours of downtime for each changeover process. Within the current process, parameter setting (set-up time) and mechanical construction contribute significant portion which consumed 50% and 33% of the overall changeover time. This accumulated to annual downtime at 579 hours and 382 hours, respectively. A substantial portion of non-value-added time, amounting to 106 hours (9%) from shift break was used because of these two operations. While the rest of 80 hours (7%) was used for the quality verification process as shown in Figure 3.

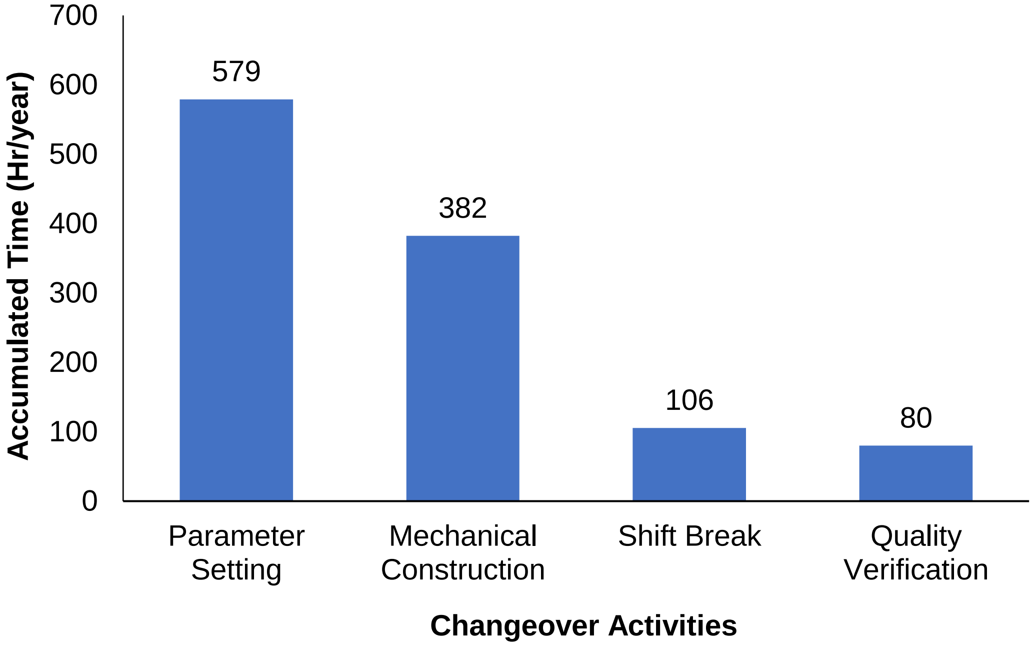

Figure 3. Annual changeover time distribution in Company A.

During the observation, improper change part operation resulted in repetitive set-up processes, creating a domino effect that impacted subsequent stages. Addressing the inefficiencies in change part operation during mechanical construction emerges as a vital strategy to reduce the overall duration of changeovers. This focus can streamline the production process, reduce downtime, and enhance operational efficiency.

Scope determination and process category selection

As outlined in section 4.1, the study emphasizes to concentrate on the change part operation in mechanical construction. This strategic choice is sounded in the understanding that getting it right during the initial phase substantially influences subsequent processes. The primary aim is to optimize the change part operation time by 20%. To achieve this objective, following assumption were made during the study:

1. The simulation mimics a 24-hour, three-shift workday.
2. During shift changes, if two operators are present, only one handles changeovers.
3. Raw materials and parts are pre-loaded into machines, eliminating wait times.
4. Measurement instruments have infinite capacity, avoiding queues.
5. Reworked entities consistently exhibit improved quality.
6. There are no machine breakdowns throughout the process, ensuring uninterrupted operations.

Data collection and input model selection

After the study scope, objective, and process category selection were established, data collection ensues for constructing a comprehensive model. Initial focus lies on resource allocation, process time, and work sequence. During the observation, the process time assumed to follow a triangular distribution. Table 1 show the observation data, presenting process time (in minutes) for each work process, along with their min, max, and most likely time duration.

Table 1. Change part operation time study observation.

Changeover Activities	Average Time (min)	Min	Most Likely	Max
Cooler Bar Set Change	66	62	66	69
Drum set change	35	31	35	37
Garniture set change	19	15	19	21
Length set change	191	176	191	203
Length set-up adjustment	12	10	12	15
Surface flatness alignment	23	21	23	24
Tray content setup	18	15	18	20

Thus, data in Table 1 is essential to create a model of the current operation in Arena. After validating the model, we explore alternative strategies using the same simulation model, enabling a comprehensive study for informed decision-making in lean manufacturing.

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ISSN: 2614-3097(online)

Arena Model Development

The simulation model initiates a changeover order every 24 hours, followed by mechanical construction work. This stage includes two key activities: modifying machine parts for changes in length and diameter configurations. Construction Work 1 involves Length Set Change, Length Setup Adjustment, Adjustment Rework, and Length Adjustment Rework Checking, all related to filter length configuration, as depicted in Figure 4. Alignment processes ensure correct part installation, with Alignment Rework undertaken if misalignment is detected. Additional checks during rework assess length alignment, and the count of rework operations is tracked. Upon successful alignment inspection, the duration of the length change is recorded, ensuring adherence to required standards.

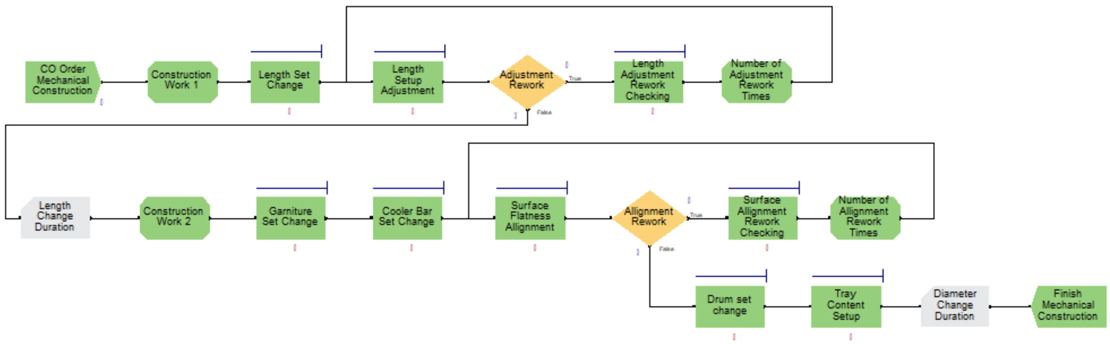

Figure 4. Arena model of change part operation during mechanical construction.

Model Verification and Validation

After creating and running simulation models, it was vital to confirm their accuracy by validating adherence to input parameters. This step ensures the reliability of the input function for the simulation's execution. The verification stage encompasses various sub-processes, detailed in Table 2 during the changeover.

Table 2 Model verification for input function compared to actual time.

Sub-process Activities	Actual Observation (Min)	Arena Model Output (Min)	Half Width
Cooler Bar Set Change	66	67.2	6.29
Garniture set change	19	18.8	1.77
Surface flatness alignment	23	24.7	2.74

The verification process ensures the model aligns with real-world processes. After successful verification, the complete model undergoes execution. A crucial step involves comparing simulation results with observed data to ensure operational validity, assessing the model's ability to replicate actual operations accurately. Table 3 shows simulation results closely aligning with observed data, falling within the confidence interval and percentage

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error limit. Following Sargent validation method, the simulation model is validated, with all observation data within the confidence interval and acceptable error percentage (Sargent, 2010). The length set change with the highest half width (17.71) corresponds to validation, while the lowest half width (1.39) for length setup adjustment reinforces model accuracy.

Table 3. Model validation using confidence interval and percentage error method.

Changeover Activities	Actual Observation (Min)	Arena Model Output (Min)	Half Width (CI)	%Error (PE)
Cooler Bar Set Change	66	67.2	6.29	1.8%
Drum set change	35	34.3	3.15	-2.0%
Garniture set change	19	18.8	1.77	-1.1%
Length set change	191	194.1	17.71	1.6%
Length set-up adjustment	12	12.8	1.39	6.7%
Surface flatness alignment	23	24.7	2.74	7.4%
Tray content setup	18	17.8	2.90	-1.1%
Total	**364.0**	**369.7**	**-**	**1.6%**

Proposed Model Scenarios

In this research, we observed into three scenarios involving workflow changes and additional resources as shown in Table 4. In the first scenario, doubling resources for a changeover operator reduces setting rework chance by 15% while maintaining the same process (Shahpanah et al., 2014). The second scenario explores changing the mechanical construction sequence with the same resources. The third scenario combines changing the construction sequence and doubling resources for the changeover operator to alleviate strain on critical process points (Mishra et al., 2020).

Table 4 Scenarios model with modification in workflow and resources.

Parameters Name	Initial Model	Scenarios 1	Scenarios 2	Scenarios 3
Machine	1	1	1	1
CO Operator	1	2	1	2
Work Sequence	Same	Same	Change	Change

The study assessed enhancements to a model through three scenarios, comparing them to the original. The simulation indicated that changing the workflow and doubling changeover operators decreased the chance of rework by 15% and notably improved the changeover process from 369.7 minutes to 237.4 minutes. The comprehensive results are presented in Table 5 for reference.

Table 5. Model scenarios result comparison for process improvement.

Changeover Activities	Initial Model (Min)	Scenarios 1 Model (Min)	Scenarios 2 Model (Min)	Scenarios 3 Model (Min)
Cooler Bar Set Change	67.2	66.0	29.8	29.5
Drum set change	34.3	33.7	36.8	36.1
Garniture set change	18.8	18.4	11.4	11.3
Length set change	194.1	192.3	107.8	107.0
Length set-up adjustment	12.8	10.6	13.3	11.3
Surface flatness alignment	24.7	21.4	27.0	23.6
Tray content setup	17.8	17.3	18.4	18.6
Total Time	**369.7**	**359.7**	**244.5**	**237.4**

In scenarios 2 and 3, changing the construction sequence significantly reduce mechanical construction time by 33.9% and 35.8%. Scenario 3 emerged as the optimal model, yielding an 35.8% reduction, equivalent to a 132-minute reduction in overall change part operation during mechanical construction. Both Cooler Bar and Length set change experienced substantial minute-based reductions with 56% and 45% respectively. The Length set change exhibited the most time improvement, showing an 87-minute time reduction, as detailed in Table 6.

Table 6. Best scenarios result comparison for process improvement.

Changeover Activities	Initial Model (Min)	Best Scenarios (Min)	Half Width	Time Change	% Change
Cooler Bar Set Change	67.2	29.5	2.85	-37.7	-56.1%
Drum set change	34.3	36.1	3.47	1.8	5.2%
Garniture set change	18.8	11.3	1.12	-7.5	-39.9%
Length set change	194.1	107.0	10.27	-87.1	-44.9%
Length set-up adjustment	12.8	11.3	1.23	-1.5	-11.7%
Surface flatness alignment	24.7	23.6	2.34	-1.1	-4.5%
Tray content setup	17.8	18.6	3.20	0.8	4.5%
Total	**369.7**	**237.4**	**-**	**-132.3**	**-35.8%**

CONCLUSION

In this study, we effectively applied discrete event simulation to enhance the efficiency of cigarette filter manufacturing, which was struggle with frequent changeovers and prolonged changeover cycle times. We created an Arena simulation model of the change part operation during mechanical construction, utilizing time study data. This model underwent thorough validation against real-world observation data, demonstrating less than an 8% difference for sub-process and only 1.6% error for overall model. The simulation pinpointed bottlenecks in the mechanical construction, specifically in cooler bar set and length set change activities.

Our proposed scenario introduced an additional changeover operator and change in operational sequence to curtail rework chances by 15%. The simulation results show 35.8% improvement, with a 132-minute reduction in changeover time compared to the original model. This outcome contrasts favourably with a prior study in the production of wooden furniture, combining VSM and Arena simulation, which reported a 6% efficiency improvement (Alzubi et al., 2019). By minimizing total changeover time, the company prevented unplanned breakdowns and potential productivity losses associated with extended machine downtime. This strategic reduction in changeover time underscores the significance of avoiding unnecessary delays, enhancing overall operational efficiency in lean manufacturing.

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