

A Simulation-Based Evaluation of Setup and Tool Change Time Reduction in CNC Machining: A Case Study in the Metal-Mechanical Sector

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ABSTRACT: *This study aims to analyze the impact of setup times and tool changeovers on production efficiency in a metal-mechanical sector company through system modeling using FlexSim and Excel. A machining process on a CNC lathe, which presents significant programmed and unplanned downtimes, was modeled due to their influence on timely order fulfillment. Through the simulation of alternative scenarios, three improvement proposals were evaluated: (1) elimination of unplanned downtimes related to missing tools and materials, (2) simultaneous operation of two lathes by a single operator, and (3) addition of a second metrologist in the quality department. The results show that the planning improvement alternative—requiring no additional resources—enabled a reduction in total production time from 18 to 11.6 shifts, making it the most efficient cost-benefit option. This study highlights the value of simulation as a decision-support tool for operational and strategic planning in manufacturing environments.*

KEYWORDS -*manufacturing systems, setup time, simulation, tool changeover, unplanned downtime*

I. INTRODUCTION

Manufacturing systems in the era of Industry 4.0 are increasingly pressured to deliver high-quality products, in shorter lead times, and with greater customization. In this context, operational efficiency and flexibility are critical for maintaining competitiveness, especially in sectors such as metal-mechanics, where low tolerance for variability and strict delivery requirements prevail [1][2]. One of the most significant challenges in discrete manufacturing environments is the setup time, which includes all activities required to prepare machines and tools for a new production order. While necessary, setup time is considered a non-value-adding activity, contributing to downtime and inefficiencies [3][4]. High setup times often lead companies to increase batch sizes to offset costs, which in turn generates overproduction, longer lead times, and inventory accumulation [5][6]. To address this issue, various lean manufacturing techniques have been proposed, among which the SMED (Single-Minute Exchange of Die) methodology stands out. SMED aims to

convert internal setups (performed while the machine is stopped) into external ones (performed while the machine is running), thereby drastically reducing setup times and improving flow [5] [7].

However, reducing setup time alone is not sufficient. Many production systems are affected by unplanned downtimes, including equipment malfunctions, tool unavailability, material shortages, and programming errors [8][9]. These interruptions increase variability and compromise scheduling and resource utilization, especially in high-mix, low-volume environments [10][11]. Discrete-event simulation (DES) has proven to be a powerful tool for modeling and optimizing complex manufacturing processes without disrupting actual operations. Simulation software such as FlexSim enables the creation of digital twins that replicate real-world conditions, allowing the evaluation of different scenarios and strategies for improvement [12][13]. In combination with spreadsheet tools like Excel, DES facilitates the analysis of probabilistic events,

such as random failures and stochastic processing times [14]. Moreover, simulation-based decision-making aligns with the broader goals of digital manufacturing, enabling data-driven strategies for capacity planning, resource allocation, and performance evaluation [15][16]. Several studies have shown that the use of simulation leads to better identification of bottlenecks, more accurate forecasting of system behavior, and higher adaptability in production planning [17][18]. This study focuses on analyzing the impact of setup times and unplanned downtimes on the production process of a CNC lathe used in the aerospace component manufacturing industry. By modeling the process using FlexSim and Excel, a series of alternative scenarios are proposed and evaluated to determine the most effective strategies for reducing total production time. The results aim to support operational decision-making, improve system utilization, and contribute to leaner, more responsive manufacturing systems.

II. SIMULATION SETUP

2.1 Methodological Details of the Simulation

Modeling Environment. The simulation models were developed using two main tools: FlexSim 2024 and Microsoft Excel. FlexSim was used to model discrete event processes and to visualize the CNC machining operations. Excel was used to simulate probabilistic events such as the occurrence and duration of unplanned downtimes, using random number generation and average response times. **Input Parameters Key** were used in all simulation scenarios (Table 1).

Table 1. Input parameters key used in all simulation scenarios.

Parameter	Value / Description
Number of parts to produce	111 (to ensure 105 good parts with 5% scrap)
Setup time for Operation 1	120 minutes
Setup time for Operation 2	120 minutes
Processing time Operation 1	15 minutes per part
Processing time Operation 2	13 minutes per part
Quality inspection frequency	1 piece every 10 produced
Adjustment time	5 to 30 minutes

(tolerance issue)	
Shift length	480 minutes

Unplanned Downtime Modeling. Unplanned downtimes were introduced in the simulation as discrete events with assigned probabilities and ranges of response time. For each piece, a random number was generated to determine if a downtime event occurred, and if so, the associated delay was simulated. The types of events and their parameters are listed in Table 2.

Simulation Replications and Output. Each scenario was run as a single replication with deterministic setup and process times. For probabilistic downtimes, the average of multiple simulated runs in Excel was used to estimate total impact. The outputs measured included total production time, number of shifts, and utilization rates of resources (CNC lathe, operator, metrologist).

Table 2. Types of events and their parameters.

Event	Probability	Response Time (min)
Corrective maintenance	0.01	60–120
Program error on model change	0.01	60–120
Missing tool	0.30	60–90
Missing material	0.10	30–60
Power outage / machine reconfig	0.05	30–90
Unavailable tool	0.20	90–180

To evaluate potential improvements in the CNC machining process, three alternative scenarios were modeled and compared against the baseline simulation. The baseline model, created using FlexSim and Excel, considered programmed downtimes and the stochastic occurrence of unplanned events, such as tool or material shortages and machine errors. The objective was to analyze how specific changes in operational planning or resource allocation could reduce total production time and optimize resource utilization.

2.2 Creation of scenarios as alternatives

Scenario 1 – Improved Planning: Elimination of Selected Unplanned Downtimes. In the first alternative, the simulation model was adjusted to eliminate two of the most frequent unplanned downtimes: tool shortages and material unavailability. This scenario was simulated using

Excel by reducing the number of unplanned events from six to four, maintaining only maintenance, programming errors, power outages, and tool unavailability. The result was a total unplanned downtime of 240 minutes, compared to 3,300 minutes in the baseline case. The total time required to produce 111 parts decreased from 8,638 minutes (baseline) to 5,578 minutes, equivalent to 11.6 shifts, indicating a substantial reduction.

Scenario 2 – Two Lathes Operated by a Single Operator. In the second alternative, the company allocated two CNC lathes to be operated by a single operator per shift. The simulation, conducted in FlexSim, evaluated whether the operator's workload justified a second machine. The result showed lathe utilization rates of 93.53% and 98.72% respectively, while the operator had significant idle time, demonstrating feasibility. The machining time was reduced to 2,771 minutes (5.7 shifts), but adding the original 3,300 minutes of unplanned downtime brought the total to 12.6 shifts, still an improvement over the baseline.

Scenario 3 – Two Metrologists for Quality Inspection. In the third alternative, two metrologists were assigned to the quality control area to divide the inspection workload. FlexSim was used to simulate the inspection and part release process. While lathe utilization remained high (99.9%), metrologist utilization dropped significantly (5.61% and 5.32%), indicating underuse. The processing time decreased to 4,755 minutes (9.9 shifts), but with the same 3,300 minutes of unplanned downtime added, the total production time reached 16.8 shifts—a marginal improvement over the baseline.

III. RESULTS AND DISCUSSION

The evaluation of different scenarios reveals the impact of operational changes on total production time and resource utilization. The baseline scenario, which includes both planned and unplanned downtimes, resulted in a total of 18 shifts to complete the production of 111 parts. The analysis of each scenario is summarized below:
Scenario 1 (Improved Planning): By eliminating tool and material shortages, production was completed in 11.6 shifts, the most efficient scenario. This improvement required no additional resources and was achieved purely through better planning.

Scenario 2 (One Operator, Two Lathes): Although this scenario introduced an additional lathe, the operator's utilization remained acceptable, and production was completed in 12.6 shifts. This reflects a reasonable trade-off between time savings and resource investment.

Scenario 3 (Two Metrologists): While this scenario reduced inspection bottlenecks, it showed minimal improvement (16.8 shifts) and underutilized the added metrology resource, suggesting it may not be cost-effective. Figure 1 illustrates the total number of shifts required under each scenario. The graphical comparison highlights that Scenario 1 is the most efficient in terms of both time and resource utilization.

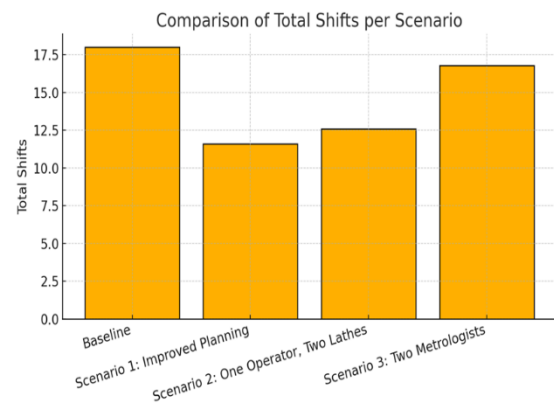


Figure 1. Comparison of total production time in shifts across scenarios.

Detailed Time Breakdown. The breakdown of production time into setup time, processing time, and unplanned downtime for each scenario is summarized in Table 3 and visualized in Figure 2.

Table 3. Breakdown of setup, processing, and downtime per scenario.

Scenario	Setup Time (min)	Processing Time (min)	Unplanned Downtime (min)	Total Time (min)
Baseline	1064	3108	3300	8638
Scenario 1	1064	3108	240	5578
Scenario 2	1064	2771	3300	6071
Scenario 3	1064	4755	3300	8055

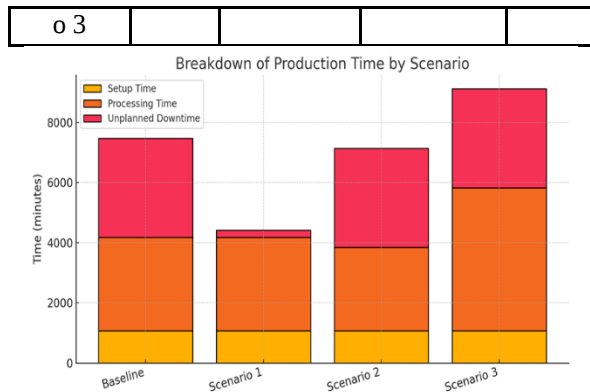


Figure 2. Stacked bar chart showing time components by scenario.

IV. CONCLUSIONS

The simulation-based study evaluated the impact of setup time and unplanned downtimes on the total production duration of a CNC machining process in the metal-mechanical sector. Three alternative scenarios were tested against a baseline model that included all known inefficiencies. The main conclusions drawn from the analysis are as follows:

1. The elimination of frequent unplanned downtimes (Scenario 1) led to the most significant improvement, reducing the number of shifts from 18 to 11.6 without adding resources.

2. Operating two CNC lathes with a single operator (Scenario 2) was feasible and moderately efficient, reducing production to 12.6 shifts.

3. Adding a second metrologist (Scenario 3) provided minimal gains (16.8 shifts) and resulted in underutilization of quality inspection personnel.

These results demonstrate that operational planning and the mitigation of recurring unplanned events can yield greater benefits than merely increasing staffing or equipment, provided the system is properly balanced. Simulation proved to be a valuable tool to anticipate outcomes and optimize manufacturing strategies.

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