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Lean on the Shop Floor: Setup Time Reduction with Soft Systems Methodology

Robert S Keyser[1,*], **Parisa Pooyan**[1]

[1] Kennesaw State University, Marietta, Georgia, USA; rkeyser@kennesaw.edu; ppooyan@kennesaw.edu.

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Abstract

In a lean production environment, reduced setup times can lead to many benefits, including reduced lead times. Previous research has primarily relied on the SMED methodology and mathematical modeling to reduce setup times at machine centers – and both are very useful techniques. We use the Soft Systems Methodology, combined with the Seven Tools of Quality, to provide a structured, illustrative means for diagnosing production and quality issues. A baseline average setup time was established by which future setup times would be compared. The intervention included brainstorming sessions between management and the converting center work crew that disclosed many reasons for increased setup times, some of which were under management's control. Our findings resulted in a 24% reduction in average setup times and a 62% reduction in the moving range at a bottleneck machine center in the corrugated box industry.

Keywords: Soft systems methodology, Setup time reduction, Corrugated boxes, Cause-and-effect, Control charts.

1 | Introduction

The lean philosophy has had a significant impact in manufacturing, supply chains, healthcare applications, and many other economic sectors. Setup time reduction offers a plethora of benefits to an organization, such as bottleneck relief, increased production capacity, and faster order turnaroundswithout incurring the financial burden of investing in additional machinery or people [1].

This research illustrates a setup time reduction effort employing the Soft Systems Methodology and the Seven Tools of Quality on a bottleneck machine center in a corrugated box plant. The machine center, known as the Saturn II, converts raw sheet stock on the input side through the printing, slotting, scoring, gluing, and folding sections into finished boxes in the stacker section on the output side. The Saturn II can run small- to medium-sized boxes and is often the bottleneck machine center due to its large proportion of product mix that runs through this plant. Reducing setup times would have an enormous impact towards increasing production capacity without incurring additional resources or expense. The Soft System Methodology fosters an appreciation of a problem situation between a group of stakeholders and provides an organized way of thinking leading to actionable solutions [2].

Corresponding Author: rkeyser@kennesaw.edu

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2 | Literature Review

The literature reveals setup time reduction successes utilizing a variety of techniques including lean concepts, SMED, work measurement, mathematical modeling, and statistical and reliability techniques, however, there is scant research regarding the application of the seven tools of quality to specifically aid in the reduction of setup times.

2.1 | Lean Manufacturing

Lean and SMED methodologies have been coupled with other continuous improvement and root cause analysis techniques to successfully reduce setup times [1]. Modified applications of SMED include combining the Five Whys technique to identify all possible root causes and their possible interactions of setup losses to reduce setup times on a screen-printing machine [3] and a 5-axis CNC machine [4]. Rosa et al. [5] used Value Stream Mapping to identify areas of waste and simulation software to calculate simulated completion times and lead times in a steel-wire-rope manufacturing process resulting in 58.3% reduction in weekly setup times.

Filho and Uzsoy [6] constructed a systems dynamic model combined with the Factory Physics perspective on a single-stage system producing a single product to demonstrate cumulative improvement gains in both machine setup time and repair time. King [7] suggests that dramatic breakthroughs can be gained by involving knowledgeable people in brainstorming sessions during the SMED process.

SMED can be used to reduce the time per setup and to decrease the number of setups Orta-Lozano and Villarreal [8]; Amrina et al. [9] and to reduce other time-wasted activities in a metal stamping plant [10]. SMED was applied at two bottleneck operations to study the cost savings effect after reducing the setup times on an automotive battery assembly line [11]. Setup time reduction techniques have also been used to reduce inventory [12], inventory holding costs [13], total costs [14], and lead time in the supply chain [15].

2.2 | Work Measurement

Cakmakci and Karasu [16] integrated MTM with SMED, whereby MTM analysis was used to standardize internal setup activities and SMED was used to standardize and document logical setup procedures.

2.3 | Information Technology

Modern information technology can be used with SMED in complex situations such as printed circuit oard assembly processes to reduce setup times by 85% with savings of $1.7 million per year [17] and in flat glass processing with savings up to 30% annually of the time spent on setups [18]. Lozano et al. [19] suggest using mean time between failure and mean time to repair for a more in-depth analysis of internal setup steps once internal and external steps have been identified.

2.4 | Mathematical Modeling

Mathematical modeling has been used to determine optimal setup cost reduction through economic lot sizes [20]-[23] and various cost considerations, such as inventory carrying cost, setup cost, storage cost, setup time reduction cost, and the cost of quality [24].

2.5 | Total Quality Management

The seven tools of quality have been used extensively in Total Quality Management (TQM) [25], [26]. Cakmakci [27] applied a Cpk index to actual data from dies of an air hole boring machine as a measure

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of equipment efficiency in conjunction with SMED to reduce setup times in an automotive rim manufacturing process.

3 | Methods

The objective of this study was to reduce average setup times on the Saturn II, an automated packaging center using the Soft Systems Methodology, as shown in *Fig. 1*.

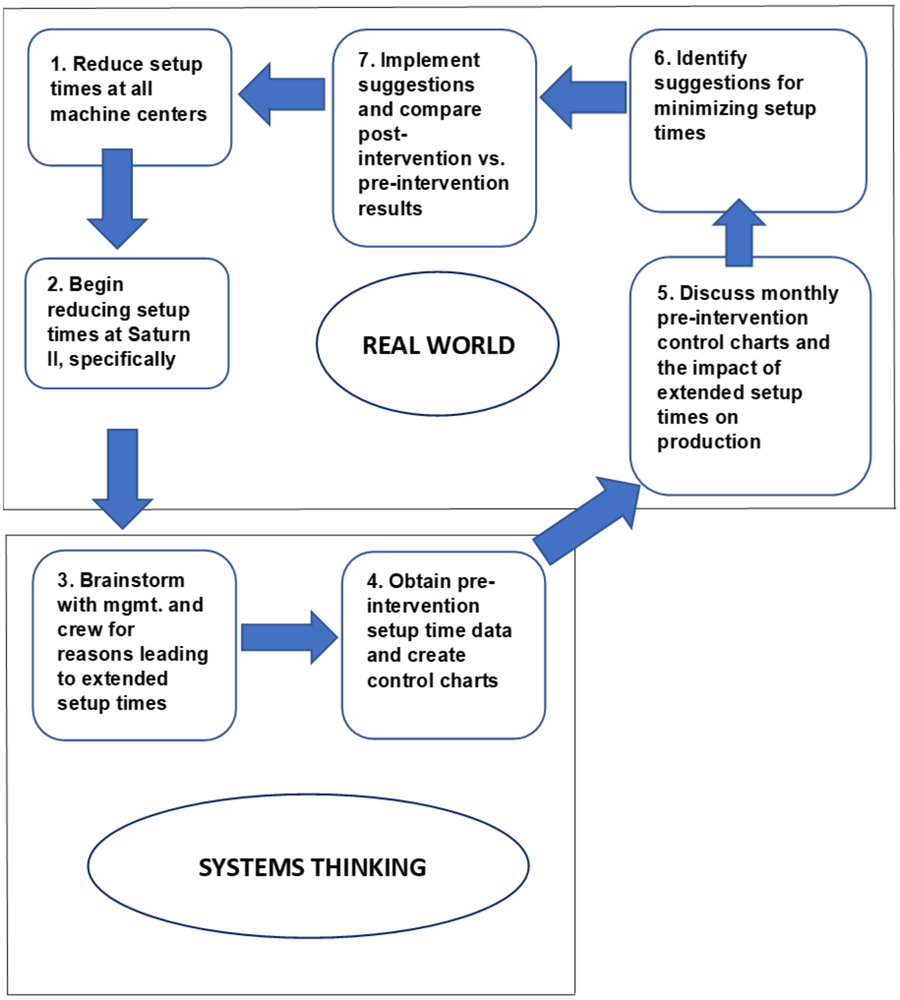

Fig. 1. Soft systems methodology for reducing.

The study began during a pre-intervention phase by capturing actual setup times on this machine center based on data on the machine operator's daily production time sheets during the first three months, October – December 2021. The raw data was stored in MS Excel files during data collection. This data was imported into Minitab v16 to generate the control charts and graphs. MS Word was used to create the summary table.

The intervention began with the Plant Manager meeting with the machine crew, which consisted of the operator, setup person, and stacker, and the Maintenance Manager in a non-threatening manner to discuss the study objective and to obtain their "buy-in". To establish a baseline average setup time, setup times for orders were documented on production time sheets during the last three months of 2021. Average setup times were computed for each month using X-Individuals and Moving Range control charts as well as for the cumulative three-month period. Reasons for delays during setups were also recorded on the daily production time sheets by the operator so that common types of delay reasons and their respective frequencies could be evaluated using a Pareto chart. Once a baseline average setup time and average moving range was established, the Plant Manager held a brainstorming session with the machine crew and the Maintenance Manager in late December 2021 to explain setup time metrics during the past three months. A discussion followed with ideas exchanged for ways to reduce setup times using a Cause-and-Effect diagram.

In the post-intervention phase, the suggestions resulting from the December 2021 brainstorming session were implemented at the beginning of January 2022 and setup times were tracked for two months using X-Individuals and Moving Range charts. Reasons for delays on setups were also recorded on the daily production time sheets by the operator. These reasons are shown using a Pareto chart. In early March 2022, the Plant Manager reviewed the improvement results and met with the Saturn II crew and Maintenance Manager to discuss the improvement results.

4 | Results

X-Individuals and Moving Range charts are displayed for October 2021 (*Fig. 2*), November 2021 (*Fig. 3*), and December 2021 (*Fig. 4*) to track setup times for order on the Saturn II.

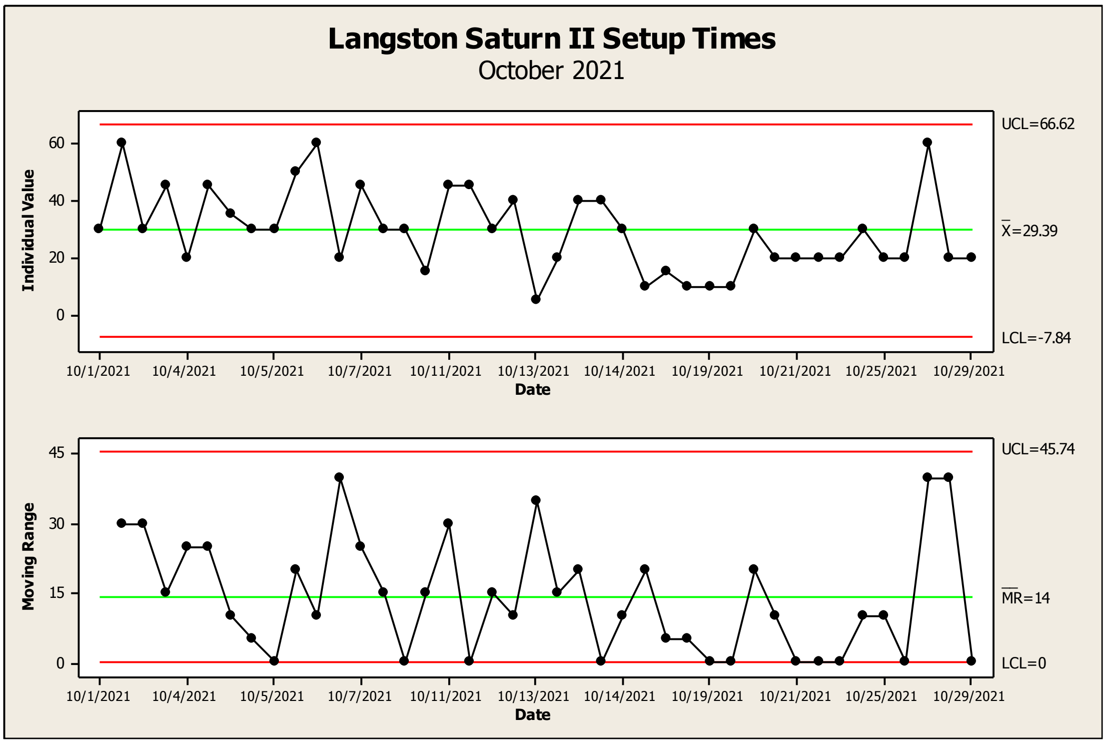

Fig. 2. Setup times during October 2021.

During each of the months of October through December 2021, the average setup time was consistent between 29.39 minutes and 32.40 minutes. Each data point on the control charts represents the actual setup time for one order. Although all data points appear within the control limits for each month, a lot of variation is observed, ranging from a LCL =0 minutes (effectively) to an UCL of 66.62 minutes for October, 84.1 minutes for November, and 78.6 minutes for December.

During the same three-month period, the average moving range was reasonably consistent between 14 minutes and 19.43 minutes. Each data point on the Moving Range chart represents the difference in setup times between consecutive setups. Again, although all data points are within the moving range control limits, we observe a lot of variability from one setup to the next, ranging from a LCL = 0 minutes to an UCL = 45.74 minutes for October, 63.49 minutes for November, and 57.02 minutes for December.

Aggregating monthly data into one three-month X-Individuals and Moving Range chart provides additional insight into average setup times as shown in *Fig. 5*.

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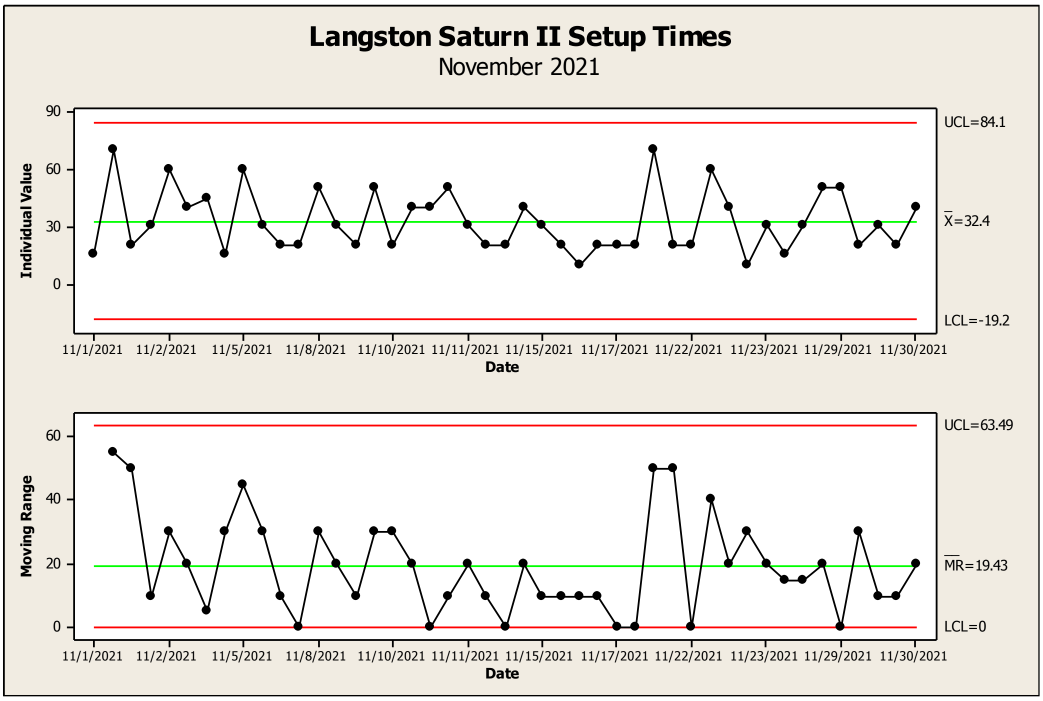

Fig. 3. Setup times during November 2021.

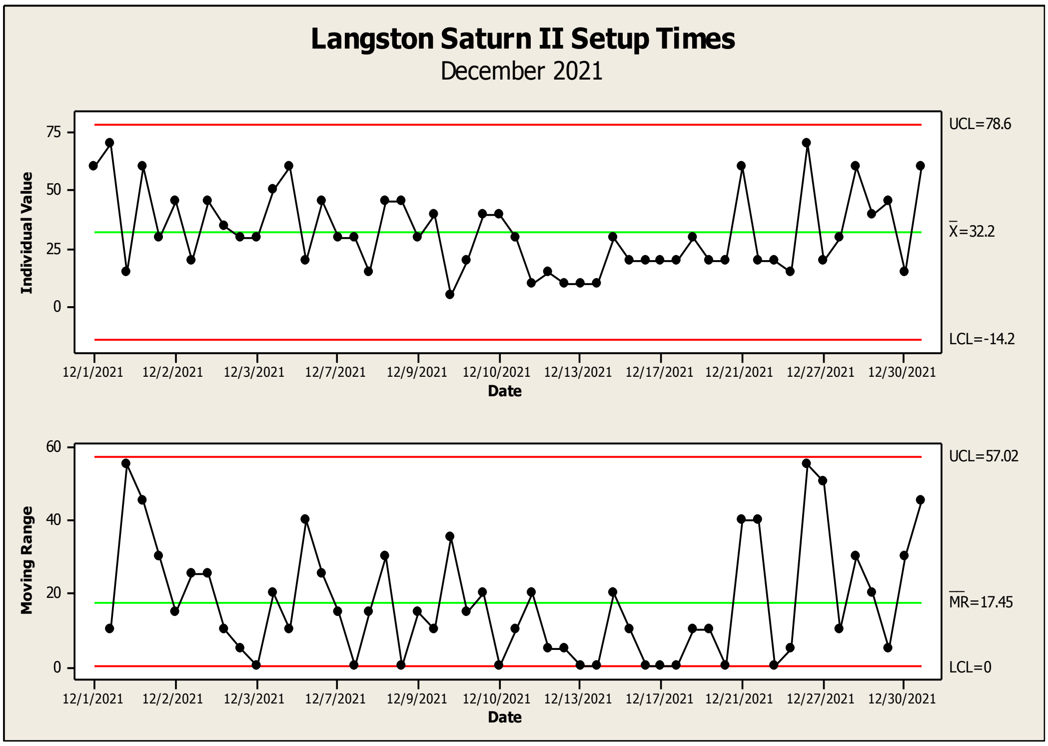

Fig. 4. Setup times during December 2021.

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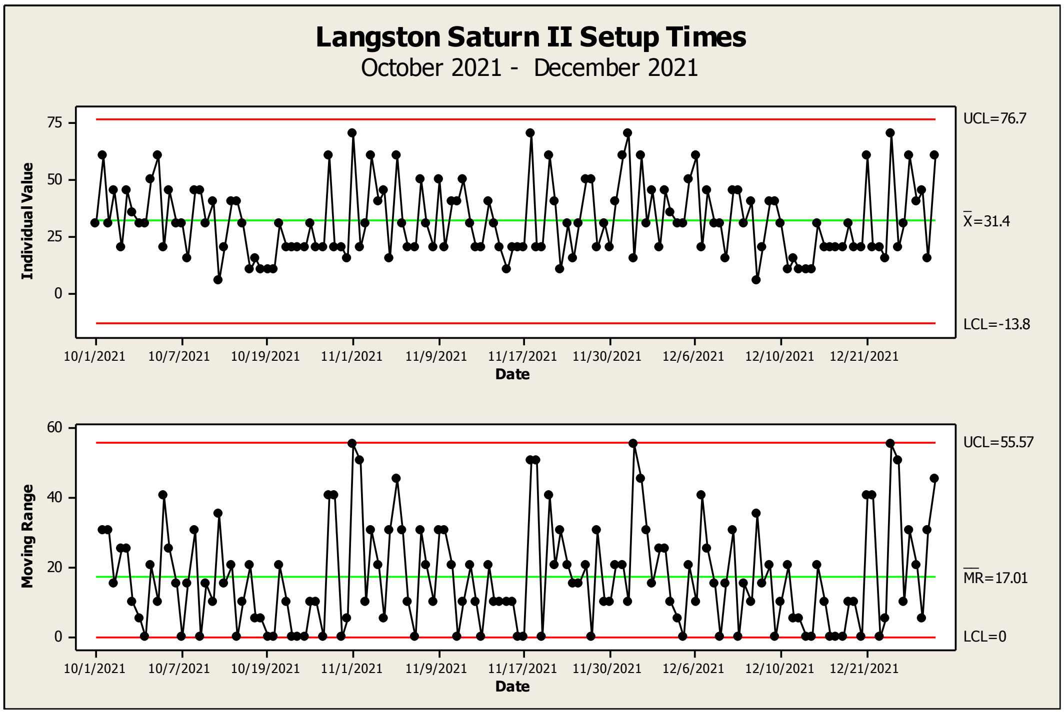

Fig. 5. Setup times between October 2021 and December 2021.

Here, we observe that the average setup time from October through December is 31.4 minutes and the average moving range is 17.01 minutes. All data points for both charts are within their respective control limits; however, we also note the wide variability in setup times. In particular, the UCL = 55.57 minutes on the moving range chart. This indicated that the difference in consecutive setup times could be as much as 55 minutes and still be within a state of statistical control. By following suggested improvements provided in the December 2021 brainstorming session, reducing the average moving range would have a significant impact on reducing the average setup time in addition to shrinking the control limits.

Reasons for delayed (or extended) setup times between October and December 2021 were obtained from the operator's daily production time sheets and are displayed in *Fig. 6*.

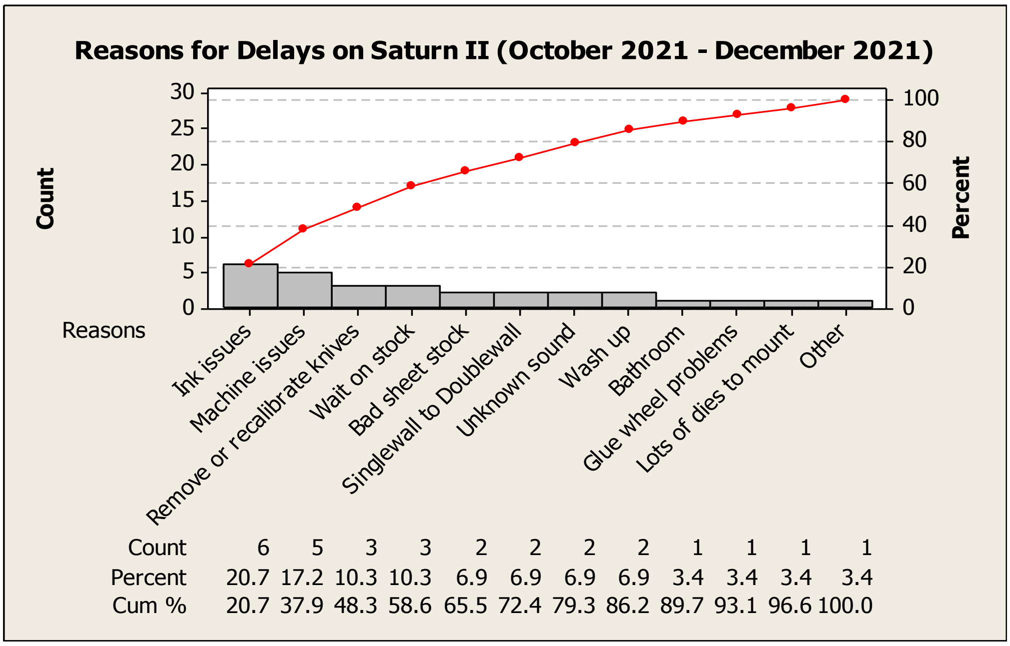

Fig. 6. Reasons for delays between October 2021 and December 2021.

Of the 29 delay reasons cited, approximately 1/3 were attributed to ink and machine issues. Ink issues (6) were comprised of ink viscosity issues, ink spills that required cleanup, starting the inking process, putting incorrect ink color on the machine, and the ink system making a strange noise that required investigation. Machine issues (5) were comprised of adjusting the folding rails, anilox roll problems (i.e., the roller that transfers ink to the printing dies), repairing worn scrap belt fasteners, and feed problems in the hopper section). Close behind were issues involving the removal or recalibration of knives (4) and waiting on stock (3).

During the December 2021 brainstorming session, the Saturn II crew suggested key factors that they believed would aid in reducing setup times as shown in *Fig. 7*.

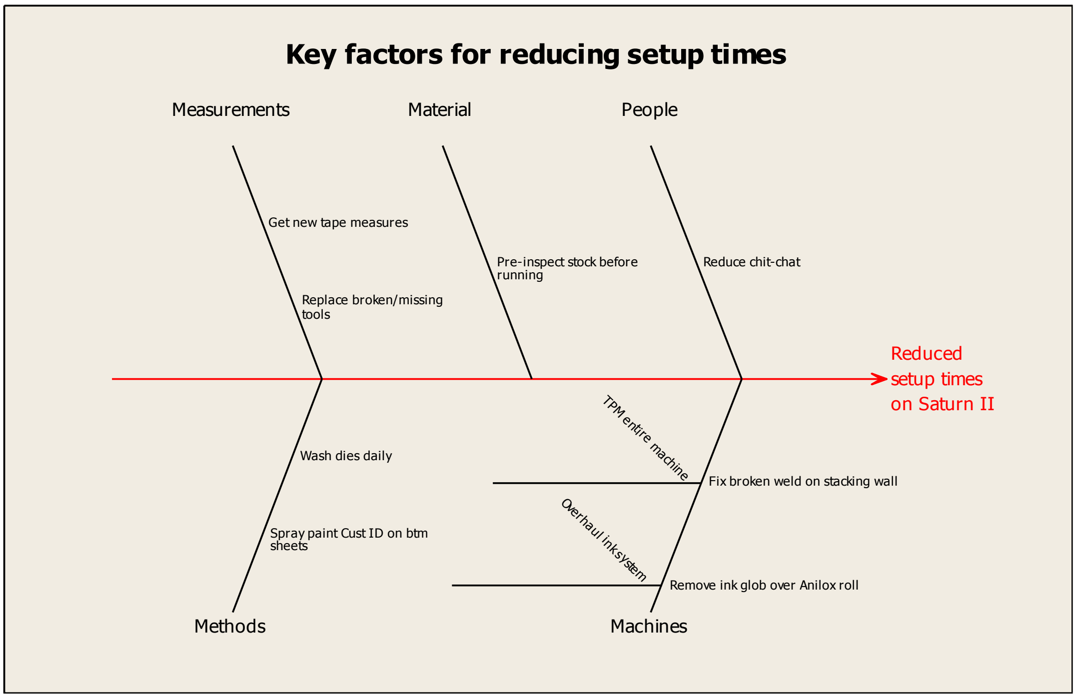

Fig. 7. Key factors for reducing setup times.

Much was learned from this brainstorming session. The production crew suggested the purchase of new tape measures and replacement of broken or missing tools, citing readability issues with old, worn-out tick marks on tape measures and the fact that they often worked with broken wrenches or missing tools that required borrowing tools from a neighboring machine center. They also suggested have someone (i.e., a floater, forklift operator, supervisor) pre-inspect raw material sheet stock before setting it on the floor conveyor line leading to the machine. This would prevent lost time sorting through off-spec sheet stock prior to running an order. The production crew also suggested spray painting the customer ID on the protective corrugated bottom sheets (i.e., dunnage) and keeping a ready supply in stock for repeat orders to reduce time spent searching for dunnage on each order. The stacking wall had a broken weld for months that needed repair. Sufficient time should be allowed to remove an ink glob over the Anilox roll instead of feeling rushed through each setup. This led to the suggestion that both the ink system and the entire machine needed to be overhauled by maintenance to find and fix ink and machine issues. When asked why these issues had not been mentioned before, the production crew responded that all the above issues had been brought to various supervisors' attention in the past, yet nothing had been done to remedy these issues. Hence, they had been fighting these issues daily when performing setups for the past several months. This prompted the Plant Manager and Maintenance Manager to schedule the two-week holiday shutdown in late December 2021 to address these issues and suggestions with the maintenance team.

Following the late-December brainstorming session and consequent maintenance intervention, setup times continued to be recorded on the operator's daily production time sheets during January and February 2022. The X-Individuals and Moving Range control chart results for January 2022 are shown in *Fig. 8*.

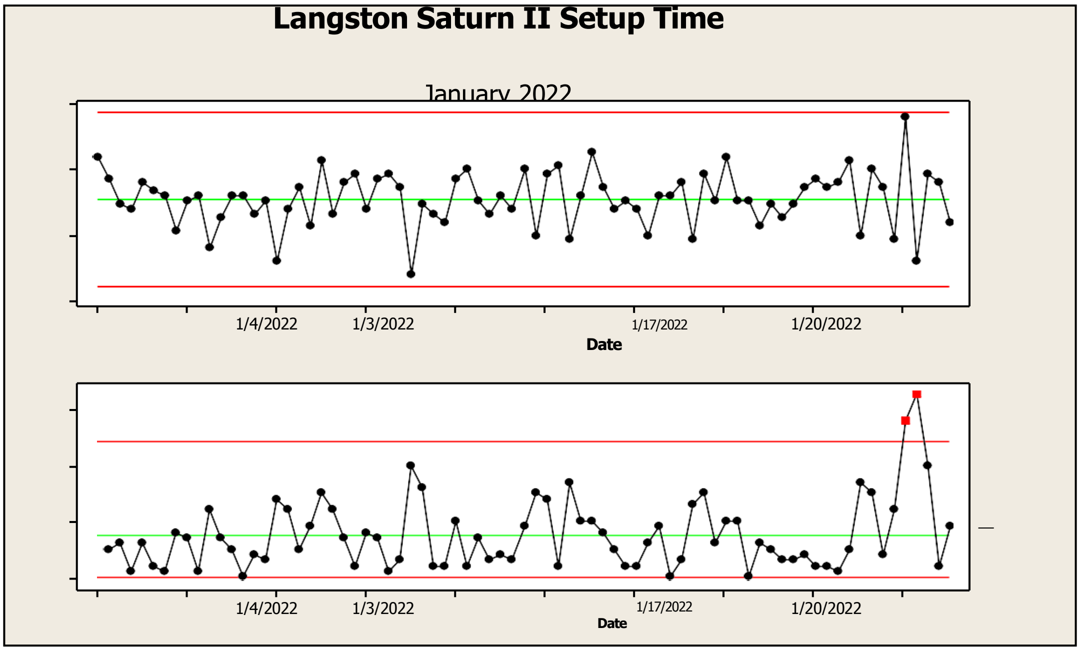

Fig. 8. Post-intervention setup times during January 2022.

We observe that the two out-of-control points for January 30, 2022 on the moving range chart are attributed to difficulty in changing the gap width on the machine on successive orders to accommodate going from thin sheet stock (i.e., singlewall with 3/16" caliper) to thick sheet stock (i.e., doublewall with 5/16" caliper), resulting in extended setup times of 14, 42, and 9 minutes, respectively. It was discovered that a rag that rested on top of the machine had been drawn into the machine and was stuck under a pull roll, creating the difficulty in machine adjustments. The rag was subsequently removed, and the issue was resolved. X-Individuals and Moving Range control charts for February 2022 are displayed in *Fig. 9*.

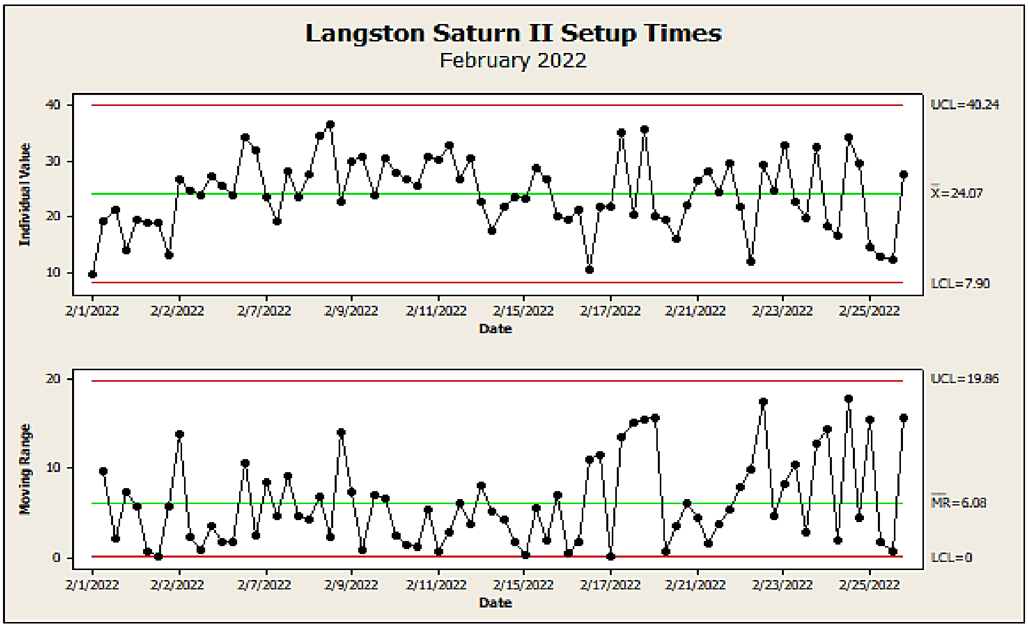

Fig. 9. Post-intervention setup times during February 2022.

Post-intervention, the months of January and February 2022 revealed consistent average setup times between 23.30 minutes in January and 24.07 minutes in February. We also observed a significant reduction in variability between the UCL and LCL during the two months when compared to the three-month pre-intervention period.

During the same two months, we notice a considerable reduction in the average moving range, with 7.49 minutes in January and 6.08 minutes in February. We also observe a significant reduction in the spread between the UCL and LCL, although two outliers appear in late January. The individual setup time for the order with the gap width issue was 42 minutes and had the effect of driving up the averages for individual setups and moving range, resulting in the two outliers in the January moving range chart.

When observing the post-intervention setup time results in a cumulative sense, as shown in *Fig. 10*, we observe that the average setup time during the two-month period was 23.73 minutes, compared to the three-month pre-intervention average setup time of 31.4 minutes, a 24.4% reduction in average setup times. We also note that the range between the UCL and LCL was significantly reduced on the X-Individuals chart from a pre-intervention range of 76.7 minutes (effectively) to a post-intervention range of 40.87 minutes.

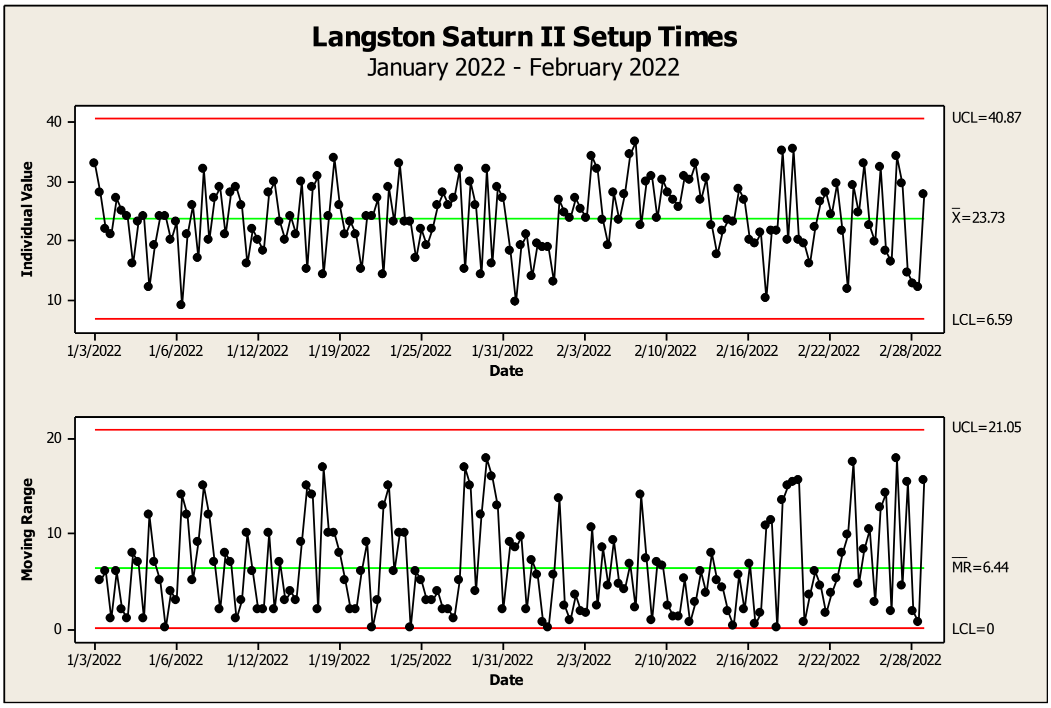

Fig. 10. Post-intervention setup times for January and February 2022.

Further, the post-intervention average moving range is 6.44 minutes for January through February 2022, compared to the pre-intervention average moving range of 17.01 minutes for October through December 2021, a 62.1% improvement. The variability in control limits on the moving range chart was substantially reduced, from an UCL = 55.57 minutes from October through December 2021 to an UCL of 21.05 minutes for January through February 2022.

Reasons for delays were retrieved from the operator's daily production time sheets during January and February 2022 and are displayed in Fig. 11. Of note, there were only 4 instances documented, each occurring one time, during the two months. This represents a considerable difference vs. the 29 reasons for delays between October through December 2021.

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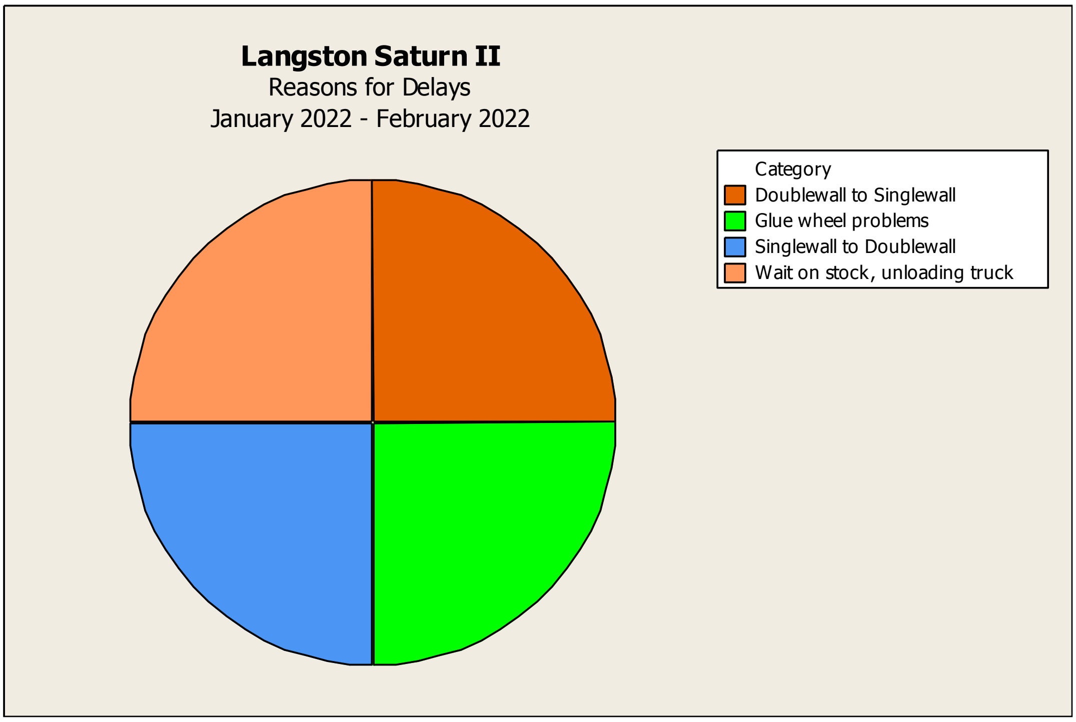

Fig. 11. Reasons for delay during January and February 2022.

5 | Discussion

The objective of this study was to reduce average setup times on the Saturn II machine center. This initiative involved the production crew, consisting of the operator, the setup person, and the stacker, along with the Plant Manager and Maintenance Manager. Communication of the objective, in a non-threatening environment, was crucial towards obtaining "buy-in" by the production crew. During brainstorming sessions, quality tools were employed to illustrate the results for discussion. In particular, the tools used were X-Individuals and Moving Range charts, Cause-and-Effect diagram, Pareto chart, and a pie chart.

Setup time results, both pre-and post-intervention, for both X-Individuals and Moving Range charts are displayed in *Table 1*.

Table 1. Setup time results pre- and post-intervention.

	X-bar	MR
October-December 2021 (pre-intervention)	31.4 min	17.01 min
January-February 2022 (post-intervention)	23.73 min	6.44 min
Net change	↓ 7.67 min	↓ 10.57 min
% Improvement	↑ 24.4%	↑ 62.1%

6 | Final Considerations

Contributing factors to the success of this study include the tremendous effort by all involved and was enhanced by open communication between the management and the production crew in a non-threatening environment. This feeling of mutual trust led to open discussions and suggestions by the production crew, who had long recognized issues that needed to be addressed, and even conveyed these issues to management on previous occasions, only to be ignored. These issues came to light during the December 2021 brainstorming session, resulting in a dedicated effort by the Plant Manager, Maintenance Manager, and maintenance crew to address these issues and follow many of the production crew's improvement suggestions – most notably, to provide proper tools and to overhaul the entire machine so that it is in proper working condition. Rather than continuing to endure frustration with setups and operation of the Saturn II, the implementation of these improvement suggestions enhanced the ease of setups post-intervention.

Upon reflection, management realized that they need valuable problem-solving tools in their "toolbox" much like production workers. The various quality tools employed by the Plant Manager to convey information aided in everyone's understanding of the setup time results via the control charts. Other meaningful ways to illustrate results included a Cause-and-Effect diagram, Pareto chart, and a pie chart.

In summary, the success of this study is attributed to the employment of a soft systems methodology whereby active involvement in improvement efforts, honest reciprocal communication in a non-threatening work environment, mutual trust between management and production workers, listening skills, and utilization of proper tools.

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No funding was received for this study.

Conflicts of Interest

All authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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