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Production Process Optimization and Improvement for Company A's S1 Product based on VSM

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Abstract

Addressing issues such as insufficient production capacity, low efficiency, and prolonged cycle times for Company A's S1 product, this study employs Value Stream Mapping (VSM) to conduct an in-depth analysis of its actual production status.to identify inefficiencies such as waste and waiting. Optimization was achieved through methods including ECRS (Engineering Change, Reengineering, Simplification, and Reduction) principles for quick die change and lean manufacturing practices. These measures eliminated or reduced non-value-added activities, improved line balancing rates, and refined process parameters via DOE (Design of Experiments) experiments. Consequently, S1 production efficiency and capacity increased, cycle times decreased, customer responsiveness accelerated, and overall company competitiveness enhanced.

Keywords

Value Stream Mapping (VSM); DOE; Process Optimization.

1. Introduction

Value Stream Mapping (VSM), a core visualization tool in lean production, employs standardized symbols to depict the entire product flow from raw materials to the customer. It integrates material flow with information transfer, annotates key data at each stage, and visually illustrates value creation and waste distribution [1].Its core methodology involves first creating a "current state map" to reconstruct the process and identify the seven types of waste, then designing a "future state map" based on customer needs to plan an ideal process, thereby facilitating lean transformation [2]. Automotive sealing strips, as critical body components affecting vehicle comfort, safety, and durability (used in doors, windows, etc., for sealing, sound insulation, and waterproofing), face opportunities for technological advancement and market expansion as the automotive industry shifts toward electrification and premiumization. Companies must seize market share by reducing non-value-added activities and enhancing efficiency and capacity. Based on this,This paper applies Value Stream Mapping (VSM) to analyze Company A's seal production process. By selecting representative product S1 to define the scope, collecting on-site data such as customer demand rates and production cadences, and tracing the current production flow from the customer end to map the process, it identifies waiting, inventory waste, and bottleneck operations. Combining methods from industrial engineering and lean production-such as quick die change and line balancing-the process is optimized to ultimately achieve goals of shortening production cycles, increasing capacity, and reducing costs [3].

2. Analysis of Current Production Status for Sealing Strips

2.1 Production Process Analysis

The S1 seal production process comprises 14 steps: extrusion, cutting, TPV jointing, spraying, TPV jointing, trimming, adhesive fastening, tape application, first inspection (deburring), second

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inspection (coating removal), and packaging. Each automotive door set includes four seals: front left, front right, rear left, and rear right.In Company A's actual production, the extrusion workshop performs the initial rubber extrusion separately, with all subsequent processing conducted in downstream workshops. During production, front and rear door cutting shares one machine, coating shares one machine, front and rear door splicing occurs in separate zones, while trimming and adhesive bonding are performed concurrently in the same area. Finally, products are transported to secondary inspection for separate checks, then moved to the packaging area for wrapping and shipment to customers.Monthly working days: 30 days Daily working hours: 11 hours (single shift) Customer orders: 5,000 units per month Customer required cycle time: 238 seconds per unit

2.2 Drawing the Current Value Stream Map

Through on-site research at Company A's production workshop, field data for the S1 seal strip production process was collected, including production cycle time (C/T), equipment utilization rate, overall yield rate, and first-pass yield (FPY) [4]. This data was used to create the current state value stream map for this product, as shown in Figure 1. Definitions: CT denotes single-station operation time;BT denotes bottleneck process time; PC indicates single-station manpower allocation; UPH represents hourly capacity; PY signifies product yield rate. Data analysis of the current value stream map yielded the following metrics for S1 production: Total Yield Rate (TGR), First Pass Yield (FPY), Information Flow Metric (IMF),Material Flow (MF), Process Time (PT), Lead Time (L/T), Value-Added Time (VAP), Non-Value-Added Time (NVAP), Line Balance (LB), and Utilization Index (UI) [5] as follows: TGR=96%, FPY=55%, L/T=290H, PT=36min, ST=74min, LB=49%, IMF=201H, MF=88.8H, VAP=36min, NVAP=27min, UI=0.21%.

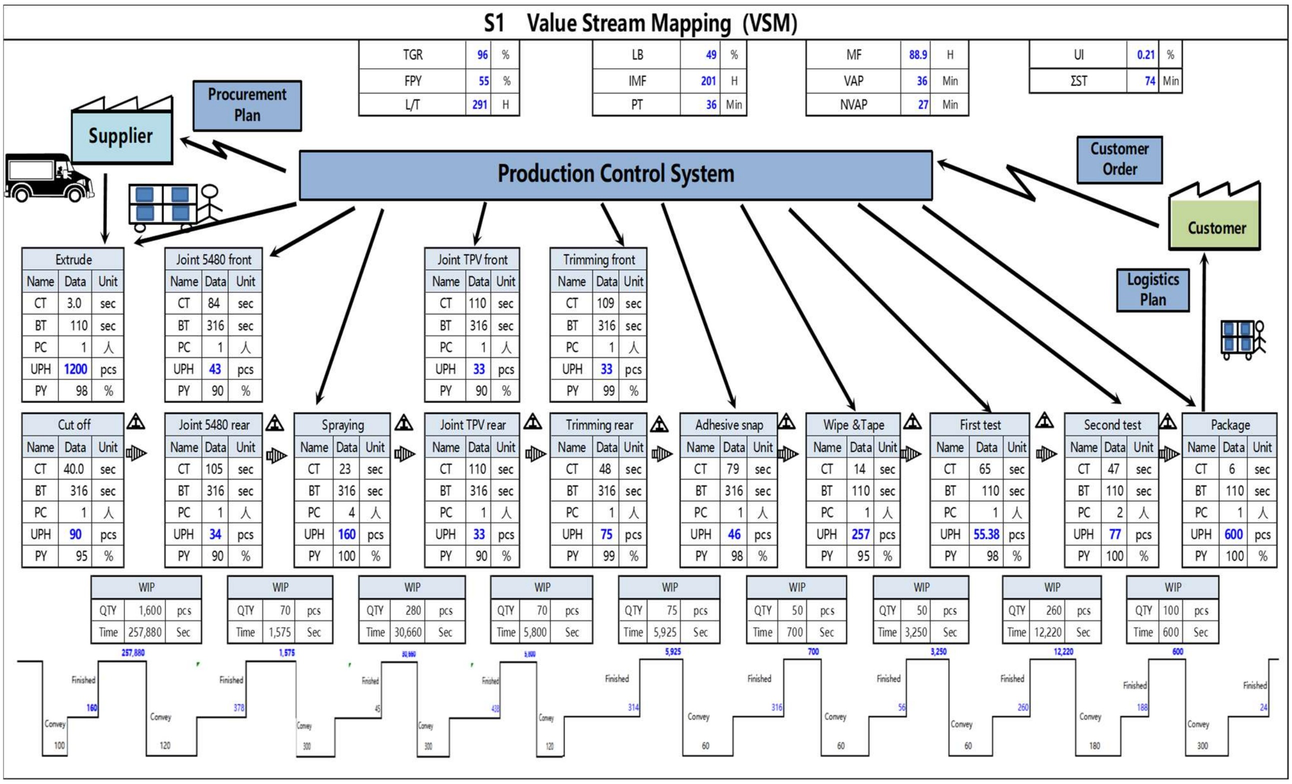

Fig. 1 S1 VSM

2.3 Current Value Stream Map Analysis

Analysis of the S1 seal strip production value stream map reveals a lengthy production cycle, low value-added time, and significant non-value-added time waste.When receiving customer orders, the company schedules production based on capacity. Production team leaders then assign daily output targets. However, employees possess limited skills, resulting in low efficiency. The jointing process, as a bottleneck operation, incurs significant time waste. When urgent orders are inserted, meeting customer demands becomes challenging. This necessitates rescheduling night shifts to compensate for capacity, significantly impacting the entire production line. The system exhibits low flexibility and high risk.

2.4 Core Issue Identification and Analysis

Based on the value stream map, combined with specific data collected during production, and through direct communication with team leaders and production personnel, an in-depth analysis using industrial engineering thinking and lean production principles revealed the following issues in the S1 product production process:

(1) Handling Waste: The main issues are: 1) The rear door linear joint equipment is positioned too far away; 2) Frequent logistics transfers between the joint TPV equipment and the trimming station require operators to constantly monitor inventory levels or handle excess production; 3) Workers must walk from the trimming station to the rear door linear joint, then return to the front door 5480 joint before proceeding to the spray area.

(2) Waiting waste: Low utilization with one operator managing two machines. Observed instances of personnel waiting for machines, resulting in approximately 6-10 seconds of waiting time per product.

(3) Mold Changeover Waste: During mold changes, issues observed include long-distance handling, prolonged changeover times, low efficiency, and disorganized tooling station layouts. Extended changeover periods cause machine downtime.

(4) Unbalanced cycle times: Trimming and adhesive application areas are concentrated, causing inconsistent production rhythms. Production is not balanced, with significant cycle time variations between processes, resulting in line imbalance;

(5) High defect rate: Multiple defect categories exist, including contact issues, damage, and shortfalls. Problems are complex, and solutions lack direction.

The aforementioned issues resulted in numerous problems for the S1 seal strip production process, including imbalance, extended production cycles, and low first-pass yield.

3. Production Line Improvement Plan

Analysis identified various types of waste and improvement directions within the production line. The improvement plan for the S1 product is as follows: Adjust jointing equipment and handling devices to address handling waste; conduct motion analysis to eliminate waiting waste in the jointing process; implement quick die change to reduce changeover waste [6]; Rearrange processes to address imbalances in adhesive application and trimming operations; for high defect rates, compile common defect issues and employ DOE experimental design for parameter setting.

3.1 Handling Waste Improvement

Due to the excessive distance of the rear door straight joint from the subsequent spraying process, relocate this equipment to the north side of the front door 5480 joint, which also requires spraying. After operations conclude, transport both joints together to the fixed spraying station. For the centralized trimming area, standardize shelving by model zone. Require trimming and adhesive application personnel to retrieve and place items only in their designated zones to prevent cross-handling and disorganized movement.

3.2 Waiting Waste Improvement

Conducted human-machine collaboration analysis. Standardized personnel actions during machine waiting periods: inspection tasks completed during the previous part's processing were shifted to the time when the next part was being machined. Standardized jointers' retrieval motions by pre-positioning semi-finished parts for easy access, enhancing jointing efficiency and significantly saving time.

3.3 Die Changeover Waste Improvement

Addressing issues like disorganized retrieval and inefficient movements during mold changes, improvements were implemented using the ECRS principles of motion economy. By distinguishing between internal and external operations, internal tasks were converted to external ones. Waste and redundant movements were eliminated through standardization and tooling. A quick mold change guidebook was established to standardize the process [8]. Mold change time was reduced from 1944 seconds to 1556 seconds, a 20% decrease, significantly boosting efficiency.

3.4 Balancing Rhythm Improvement

Analysis of the chaotic cycle times in centralized operation areas such as post-process trimming and adhesive bonding revealed the need for balancing based on customer demand cycle times. The customer's monthly order volume is 5,000 units. Company A plans 30 working days per month with an 11-hour daily shift. Thus, the customer demand cycle time is calculated as effective working time divided by customer demand volume, resulting in 238 seconds per unit.The pre-improvement process is shown in Table 1, totaling 2,191 seconds.

Table 1. Process Schedule Before Improvement

Workstation	Process	Standard Time/sec	Required Quantity	Total Single-Process Time/S
1	Extrusion	3	4	12
2	Cutting	40	4	160
3	Connector 5480 Front Door	84	2	168
4	Connector 5480 Rear Door Straight	105	2	210
5	Spray 5480	22.5	2	45
6	TPV Joint Front Door	109.5	2	219
7	TPV Rear Door Connector	109.5	2	219
8	Front Door Trim	109	2	218
9	Front Door Trim	48	2	96
10	Velcro fasteners	79	4	316
11	Wipe base coat and apply tape	14	4	56
12	1 Deburring	65	4	260
13	Second Inspection: Wipe Coating	47	4	188
14	Packaging	6	4	24

Analysis reveals that the core bottleneck, Velcro fastener assembly (316S), exceeds the customer's cycle time (328S/pcs). Secondary bottlenecks at stations 6, 7, 8, and 12 operate near cycle time but face tight capacity, with significant short-process waiting waste and substantial gaps from the bottleneck. Pre-adjustment line balance rate:

$$LB = \frac{PT}{BT \times N} \times 100\% = \frac{2191}{316 \times 14} \times 100\% = 49.5\% \tag{1}$$

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Therefore, the primary adjustment directions are as follows:

(1) Increase personnel at the core bottleneck snap fastener station for parallel processing and optimize operational procedures; post-improvement time reduced to 158S < 238S;

(2) Optimize secondary bottlenecks: - Workstation 12: Increase burr removal from one to two operators for single-product inspection, addressing low visual inspection efficiency; - Merge joint assembly at workstations 6/7: Improve machine efficiency by enhancing operator proficiency (one operator managing four machines); - Workstations 8/9: Replace trimming blades with sharper ones, mark critical trimming areas, and boost trimming efficiency;

(3) Consolidate short-cycle operations: Merge Stations 1 and 2 to streamline processes and reduce material waiting time; combine Stations 11 and 14 so post-process inspection leads directly to packaging, shortening turnaround time.

Adjusted process times are shown in Table 2.

Table 2. Process Schedule After Improvement

New Workstation	Process Content	Improved Work Time (s)	Number of Operators
1	Extrusion + Cutting	172	1
2	Joint 5480 Front Door	168	1
3	Connector 5480 Rear Door Straight	210	1
4	Spray 5480	45	4
5	Joint TPV Front Door	175	1
6	Connector TPV Rear Door	175	1
7	Front Door Trim	190	1
8	Rear Door Trim	96	1
9	Velcro fasteners (2 people working in parallel)	58	2
10	Deburring (2 people working in parallel)	130	2
11	Second Inspection: Wiping Coating	188	1
12	Wipe primer + packaging	80	1

After improvement, the total process time (PT) across all operations is 1887 seconds, reduced by 304 seconds, representing a 14% efficiency increase. Line balance rate:

$$LB = \frac{PT}{BT \times N} \times 100\% = \frac{1787}{210 \times 12} \times 100\% = 70.9\% \tag{2}$$

Line balance rate increased from 49.5% to 70.9%, reducing process waiting waste by 40%. Bottleneck process time was compressed from 316S to 210S, boosting production capacity by approximately 34%.

3.5 Analysis of Major Quality Defects and DOE Experimental Design

Statistical analysis of defect categories for the company's S1 product over the past two months identified primary issues including scratches, contact defects, underfilling, breakage, adhesive leakage, cross-section compression, uneven trimming, and injection defects. Through discussions with on-site management, common defect categories and their severity for S1 are summarized in Table 3.

Table 3. Table of Defect Categories and Their Criticality

Name	A	B	C	D	E	F	G	Total
Scratches	√			√			√	3
Contact	√	√	√	√	√	√	√	7
Brushed		√	√				√	3
Shortage		√	√	√		√		5
Damaged	√		√	√	√	√	√	5
Glue		√	√				√	3
Pollution	√			√	√			3
Trim						√	√	2
Pressure Section	√		√	√		√	√	5
Injection	√		√	√	√			4

Analysis identified poor contact as a key area for improvement. An investigation into the causes revealed that vulcanization temperature and time were not clearly defined, with operators arbitrarily adjusting parameters based on personal experience, lacking standardized procedures. A Design of Experiments (DOE) study was conducted to address the poor contact issues [8], controlling jointing time at 60-90-120 seconds and temperature at 220-230-240℃.A total of 9 numbered groups were established, with 4 samples produced per group. As shown in Table 4.

Table 4. Vulcanization Experiment Design

Combination No.	Temperature A/℃	Time B/s	Sample ID	Contact Failure Grade	Average Y
G1	220	60	G1-1, G1-2, G1-3, G1-4	3, 4, 3, 4	3.5
G2	220	90	G2-1, G2-2, G2-3, G2-4	2, 3, 2, 3	2.5
G3	220	120	G3-1, G3-2, G3-3, G3-4	2, 2, 3, 3	2.5
G4	230	60	G4-1, G4-2, G4-3, G4-4	2, 2, 1, 2	1.8
G5	230	90	G5-1, G5-2, G5-3, G5-4	1, 1, 2, 2	1.5
G6	230	120	G6-1, G6-2, G6-3, G6-4	2, 1, 2, 2	1.8
G7	240	60	G7-1, G7-2, G7-3, G7-4	3, 4, 3, 4	3.5
G8	240	90	G8-1, G8-2, G8-3, G8-4	2, 3, 2, 3	2.5
G9	240	120	G9-1, G9-2, G9-3, G9-4	4, 5, 4, 5	4.5

Univariate analysis of variance (ANOVA) was conducted for vulcanization temperature and vulcanization time separately, as shown in Tables 5 and 6.

Table 5. Analysis Table of Average Vulcanization Temperature

Vulcanization Temperature	Including Group Number	Average Grade per Group	Overall Average Temperature Rating	Degree of Contact Failure
220	G1, G2, G3	3.5, 2.5, 2.5	2.8	Moderate
230	G4, G5, G6	1.8, 1.5, 1.8	1.7	Lightest
240	G7, G8, G9	3.5, 2.5, 4.5	3.5	Heavier

Table 6. Analysis Table of Mean Vulcanization Times

Vulcanization Time	Group Number Included	Average Grade per Group	Overall Average Temperature Rating	Degree of Contact Failure
60	G1, G4, G7	3.5, 1.8, 3.5	2.9	Moderate
90	G2, G5, G8	2.5, 1.5, 2.5	2.2	Lightest
120	G3, G6, G9	2.5, 1.8, 4.5	2.9	Medium

Based on the above mean analysis and in accordance with the evaluation criterion that "lower grades indicate better performance" for poor contact levels [9], the following conclusions are drawn:

The experimental results indicate that both vulcanization temperature and time influence the rubber contact defect grade, with temperature having a more significant effect. The defect grade follows a decreasing-then-increasing trend with temperature: 220℃→230℃→240℃, with 230℃ being the optimal temperature. Similarly, the defect grade shows a decreasing-then-increasing trend with time: 60S→90S→120S,with 90s being the optimal duration. Overall, 230℃+90s represents the optimal process combination, corresponding to the lowest average contact failure grade (Grade 1.5) and the mildest contact failure severity.

4. Implementation Results

Table 7. Comparison of Value Stream Maps Before and After Improvement

Comparison Item	**Name**	**Pre-Improvement Value Stream Map**	**Post-Improvement Value Stream Map**	**Unit**
TGR	Overall Yield Rate	96	97	%
FPY	First-pass yield	55	67	%
Lead Time	Order Cycle Time	290	223	H
PT:	Total time for all processes	36	30	Min
∑ST	Total working time	74	42	Min
LB	Balance Rate	49	71	%
IMF	Information Flow	201	201	H
MF	Material Flow	88.9	52.1	H
VAP	Value-added processing	36	30	Min
NVAP	Non-Value-Added Processing	27	16	Min
UI	Value Stream Utilization Rate	0.21	0.22	%

The value stream maps before and after the improvement are compared in Table 7. The comparison reveals significant enhancements across all aspects following the improvements.

5. Conclusion

This paper takes Company A's S1 product production line as the research subject. By applying value stream mapping techniques to conduct an in-depth analysis of its actual production status, various issues were identified, including waste from handling, waiting, and changeovers, as well as cycle time imbalance.Optimization methods including quick die change, ECRS economic principles, DOE, and lean production were applied to eliminate or reduce waste and non-value-added activities in the production process. This enhanced the production efficiency and capacity of the S1 product, shortened the production cycle, enabled rapid customer response, and ultimately improved the company's competitiveness.

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