

Line Balancing Study and Analysis at a Tractor Assembly Line

Shakilla Nur Asimah Mat Hussin¹, Salleh Ahmad Bareduan^{1*}

¹ Faculty of Mechanical and Manufacturing Engineering

Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, 86400, MALAYSIA

*Corresponding Author: saleh@uthm.edu.my

DOI: <https://doi.org/10.30880/rpmme.2024.05.01.022>

Article Info

Received: 15 May 2024

Accepted: 10 July 2024

Available online: 15 Sept 2024

Keywords

Line balancing, Tractor assembly line, Precedence diagram, Assembly process, Productivity, Manufacturing

Abstract

This study addresses the extended cycle time of 165 minutes in the tractor assembly process at a manufacturing plant, resulting in a low weekly output of 14.5 units. The objectives were to analyze the existing assembly line, implement line balancing techniques, and evaluate the impact on productivity and efficiency. Data collection included task durations, worker assignments, and resource utilization, followed by a precedence diagram construction. Line balancing techniques, particularly the Largest Candidate Rule (LCR), were applied. Results showed a significant reduction in cycle time from 165 minutes to 111 minutes, leading to a 49% increase in theoretical maximum weekly output and a decrease in balance delay from 19.1% to 9.52%.

1. Introduction

In the dynamic and competitive landscape of manufacturing, achieving an optimized balance between efficiency and precision in assembling complex machinery is crucial. Assembly lines play a vital role in the production process, where each workstation performs specific tasks in a synchronized manner to produce standardized items at high rates [1]. Effective line balancing ensures a harmonious workflow by evenly distributing tasks across workstations, which eliminates bottlenecks and enhances overall productivity. This study focuses on the final assembly line for tractors, aiming to address inefficiencies and propose solutions to improve productivity and efficiency through strategic task allocation.

1.1 Problem Statement

The existing tractor assembly line at the manufacturing plant is characterized by various significant problems, such as uneven distribution of tasks among workstations, potential bottlenecks, and inefficient use of manpower. The presence of these inefficiencies leads to a prolonged cycle time of 165 minutes per unit, which in turn leads to a low weekly production of only 14.5 units. It is crucial to address these problems to improve the efficiency of the assembly line and successfully achieve production goals. The objective of this study is to examine the current layout of the assembly line, identify areas that can be upgraded, and apply line balancing methods to maximize the efficiency of the whole production process.

1.2 Objectives of Study

This research is structured around three key objectives. First, to construct a detailed precedence diagram that maps out the assembly process and gathers essential line balancing parameters; second, to conduct a comprehensive performance analysis of the current assembly line to identify bottlenecks and inefficiencies; and third, to propose and evaluate alternative line balancing arrangements that can improve task distribution, reduce cycle time, and increase overall productivity [3]. By achieving these objectives, the study aims to provide actionable insights and recommendations for optimizing the tractor assembly process.

1.3 Scope

This study focuses only on the final assembly process for tractors at the manufacturing company. It does not include the processes of creating sub-assemblies or manufacturing individual components. The primary objective is to measure the duration of each task and station in the final assembly line, analyze the data to detect any inefficiencies, and evaluate the performance of the existing assembly line in comparison to potential enhancements. Important criteria for assessment include the quantity of workstations, the duration of each cycle, the amount of time that workstations are not in use, the delay in achieving balance, the overall efficiency of the production line, and the total output. This precise method guarantees a comprehensive and concentrated examination of the final assembly process [5].

1.4 Significance

The significance of this study is in the ability to improve productivity and operational effectiveness in tractor assembly. The study aims to propose efficient alternatives that may improve the assembly line layout by strategically addressing the current inefficiencies through line balancing. Increased productivity and efficiency not only help achieve production goals but also optimize resource allocation, reduce costs, and enhance the overall profitability. The insights gained from this study can serve as a valuable reference for other manufacturing processes facing similar challenges, thus extending its impact beyond the immediate context [2].

2. Literature Review

2.1 Assembly Line Systems

Assembly lines are a defining characteristic of modern manufacturing, including synchronized processes in which products at different stages of production are transported over conveyor belts. Skilled individuals or automated equipment carry out specialized tasks at each workstation, which help in the assembly of the final product. The purpose of this organized allocation of tasks is to optimize productivity, decrease manufacturing duration, and ensure consistent quality. Efficiently designing and optimizing assembly lines is crucial for reaching optimal productivity and meeting the requirements of mass production [1].

2.2 Line Balancing

Line balancing is a fundamental aspect of optimizing assembly line performance. It involves the strategic allocation of tasks to workstations in a way that minimizes idle time, reduces bottlenecks, and maintains a steady production pace. Various heuristic methods, such as the Largest Candidate Rule (LCR), Kilbridge and Wester's Method (KWM), and Ranked Positional Weight Method (RPW), have been developed to address the challenges of line balancing. These methods aim to improve the flow of work, enhance resource utilization, and achieve a balanced distribution of tasks across the assembly line [3].

3. Methodology

3.1 Data Collection

The data collection process involved gathering detailed information on task durations, worker assignments, and resource utilization along the final assembly line. This comprehensive data set provided a clear understanding of the current assembly process and highlighted areas where improvements could be made. The data was collected through direct observations, time studies, and consultations with line managers and operators. Finally, in-person observation served to validate the data gathered from time studies and interviews, ensuring a comprehensive and accurate assessment of the assembly line's performance [6]. This thorough approach ensured the accuracy and reliability of the data, forming a solid foundation for subsequent analysis and optimization efforts [5].

3.2 Precedence Diagram

A precedence diagram was constructed to visualize the assembly process and identify the relationships between different tasks. This visual representation depicts the sequential dependencies between jobs within the assembly line [7]. This diagram mapped out the sequence of tasks, highlighting dependencies and potential bottlenecks. By providing a clear and detailed representation of the assembly line, the precedence diagram facilitated the identification of critical tasks and areas where workflow improvements could be implemented. By illustrating the flow of relationships between jobs through directed arrows, the precedence diagram acts as a roadmap for the strategic implementation of line balancing techniques [8].

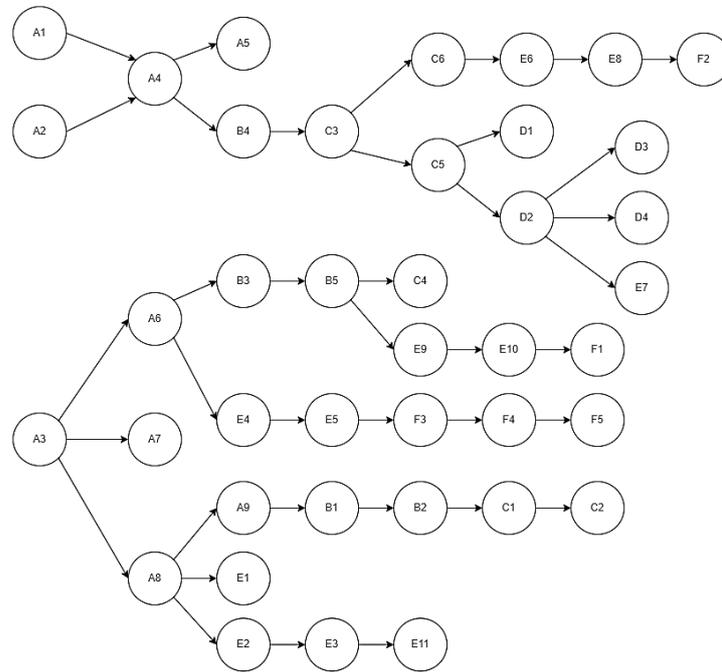


Fig. 1 Precedence Diagram for Line Balancing at XYZ Manufacturing

3.3 Line Balancing Techniques

The Largest Candidate Rule (LCR) was applied as the primary line balancing technique to reassign tasks across workstations strategically. LCR prioritizes tasks based on their duration, assigning the longest tasks first to ensure an even distribution of workload. This method aimed to minimize cycle time, reduce idle time, and achieve a more balanced and efficient workflow. The application of LCR involved a detailed analysis of the precedence diagram and task durations, followed by iterative adjustments to optimize task allocation and workstation performance [3].

4. Results and Discussion

The data collected encompassed workstation cycle times, task durations, and the sequential order of tasks within the tractor assembly process. Production line status was further visualized through detailed graphical formats. These graphical representations served to highlight inefficiencies and bottlenecks within the assembly line, fostering a deeper understanding of its operation [4]. While Table 1 might detail these processes for each station, a separate section dedicated to data analysis would be more appropriate for elaborating on this aspect. This study focuses on the main tractor assembly line at XYZ Manufacturing. The production target for this line is set at 20 fully assembled tractors per week. The assembly line operates for a total of 40 hours per week. Based on standard times, the expected production time for 20 units is 110 hours. However, this ideal scenario does not account for idle time, which is estimated to be around 20% of the standard time. Consequently, the actual production time is likely to be higher.

Table 1 Data for each process in tractor assembly in XYZ Manufacturing

Remark	Activity	Station	Time (m)	Manpower in job	Total time	Cycle time (hrs)	When one move 2 units
A1	install step bracket	52	24	1	121	2.016667	4.033333
A2	install air tank	52	27	1			
A3	install steering box	52	30	1			
A4	install diesel tank	52	20	1			
A5	bateri	52	15	1			
A6	cabin tilt cylinder+electrical switch	52	25	1			
A7	install exhaust	52	16	1			
A8	steering tank+hydraulic hose	52	30	1			
A9	cooler tube	52	20	1			
B1	water separator	56	10	1	130	2.166667	4.333333
B2	install front axle brake fittings	56	10	1			
B3	install fuel line + wiring main switch	56	30	1			
B4	routing air hose	56	80	2			
B5	routing wire harness	56	80	2			
C1	front axle	62	72	1	130	2.166667	4.333333
C2	coupling drag link to pitman arm	62	15	2			
C3	rear axle	62	59	1			
C4	rear lamp+reverse buzzer	62	15	2			
C5	install propeller shaft	62	13	2			
C6	install mudguard	62	15	2			
D1	engine installation	72	60	2	130	2.166667	4.333333
D2	radiator+transmission cooling system	72	40	2			
D3	engine cooling system	72	20	1			
D4	exhaust system	72	30	1			
E1	expansion tank with susie hose	74	40	1	125	2.083333	4.166667
E2	safety linkage	74	10	1			
E3	step+floor 72	74	15	1			
E4	propeller shaft	74	15	1			
E5	cabin suspension	74	20	1			
E6	install mudflap front+rear	74	15	2			
E7	install AC hose (compressor-condensor-dryer)	74	15	1			
E8	air filter/air intake	74	30	1			
E9	wire preparation for cabin	74	20	1			
E10	fifth wheel	74	20	2			
E11	step+floor 76	74	15	1			
F1	install tyre	76	30	2	165	2.75	5.5
F2	pump hydraulic+transmission oil+diesel+coolant	76	15	1			
F3	install cabin	76	30	2			
F4	install cabin wiring	76	90	2			
F5	install AC hose(blower to compressor)	76	15	2			

4.1 Data Calculation

Considering a 40-hour workweek and a cycle time of 2 hours per station, XYZ Manufacturing's target of producing 20 tractors per week appears achievable on a single assembly line, assuming minimal non-productive time. The formula used are as below:

Output Rate

$$\text{Output rate} = \frac{\text{Production time}}{\text{Cycle Time}} \quad (1)$$

Balance Delay

$$\text{Balance Delay} = \frac{(CT_{max} \times n) - T_p}{CT_{max} \times n} \quad (2)$$

Standard Deviation

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}} \quad (3)$$

4.2 Data Comparison

4.2.1 Cycle Time Reduction

The application of line balancing techniques resulted in a significant reduction in cycle time from 165 minutes to 111 minutes, representing a 33% improvement. This reduction was achieved by strategically reallocating tasks across workstations to eliminate bottlenecks and ensure a more efficient workflow. The decrease in cycle time not only enhanced the overall productivity of the assembly line but also increased the capacity to meet production targets [2].

Table 2 *Original Data*

W/S	Group 1				Group 2			
	Candidate	Choose	Time	Idle/Total	Candidate	Choose	Time	Idle/Total
1	A1,A2,A3	A1	24		A2,A3	A3	30	
	A2	A2	27		A6,A7,A8	A6	25	
	A4	A4	20		A7,A8,B3,E4	A7	16	
	A5,A8,B3,E4	A5	15		A8,B3,E4	A8	30	
					A9	A9	20	
			35/121				0/121	
2	B5	B5 (2)	80		B1,B3,B4,E4	B1	10	
					B2,B3,B4,E4	B2	10	
					B3,B4,E4	B3	30	
					B4,E4	B4(2)	80	
			50/130				0/130	
3	C1,C3,C4,E2,F3	C3	59		C1,C4,E2,F3	C1	72	
					C2,C4,C5,C6	C2(2)	15	
					C4,C5,C6	C4(2)	15	
					C5,C6	C5(2)	13	
					C6	C6(2)	15	
			71/130				0/130	
4	D3,D4,E3,E7,E10	D3	20		D1,D2,E6,E4	D1(2)	60	
					D2,E4,E6	D2(2)	40	
					D4	D4	30	
			110/130				0/125	
5	E1,E2,E4,E6,E7	E1	40		E2,E4,E7,E6	E2	10	
	E3,E4,E6,E7	E3	15		E4,E6,E7,E9	E4	15	
	E6,E7,E5,E9	E7	15		E5,E6,E9,E11	E5	20	
	E6,E9,E11,F3	E9	20		E6,E10,E11,F3	E6(2)	15	
					E8,E10,E11,F3	E8	30	
			0/125	E10,E11	E10(2)	20		
				E11	E11	15		
							0/125	
6	F2	F2	15		F1,F3	F1(2)	30	
					F3	F3(2)	30	
					F4	F4(2)	90	
					F5	F5(2)	15	
			150/165				0/165	

The theoretical current output of 14.5 tractors per week is 27.5% lower than the company's desired output of 20 tractors per week. This discrepancy highlights the need to re-balance the assembly line to improve output. Analysis of the balancing data in Table 4.3 reveals that Workstation 6 has the highest cycle time of 165 minutes, while the other workstations have cycle times ranging from 121 to 130 minutes. By redistributing some of the workload from Workstation 6 to other workstations, the overall line cycle time could be reduced from 165 minutes to a lower value, thereby improving the total output. Consequently, exploring a new balancing table with a cycle time of 131 minutes is recommended.

The initial evaluation of the assembly line with a cycle time of 165 minutes indicated significant inefficiencies and imbalances, serving as a critical reference point for subsequent improvements. This extended cycle length was associated with prolonged inactivity and uneven task distribution, resulting in a balance delay of 19.1%. Calculations show that a theoretical maximum output of 14.5 units per week can be achieved with a 165-minute cycle time, but real-world factors reduce production efficiency. The factory data indicated an average output of 14 tractors per week, close to the theoretical maximum, with only a 3.57% discrepancy. This suggests that the Precedence Diagram used by the company is accurate and can be applied to alternative line balancing approaches.

Table 3 *Second Data (Cycle Time Changed to 131 Minutes)*

W/S	Group 1				Group 2			
	Candidate	Choose	Time	Idle/Total	Candidate	Choose	Time	Idle/Total
1	A1,A2,A3	A1	24		A2,A3	A3	30	
	A2	A2	27		A6,A7,A8	A6	25	
	A4	A4	20		A7,A8,B3,E4	A7	16	
	A5,A8,B3,E4	A5	15		A8,B3,E4	A8	30	
	A9,E1,E4	E1	40		A9	A9	20	
			5/131	E2	E2	10	0/131	
2	B1,B2,B3,B4,E4	B1	10		B1,B3,B4,E4	B3	30	
	B1,B3,B4,E4	B2	10		B5,E2,E4	B5(2)	80	
	B4,E4	B4(2)	80					
				10/110				0/110
3	C1,C3,C4,F3	C3	59		C1,C4,F3	C1	72	
	C2,C4,C5,C6	C5(2)	13		C2,C4,C5,C6	C2(2)	15	
	C4,C5,C6	C6(2)	15		C4,C5,C6	C4(2)	15	
	E9	E9	20		E4	E4	15	
				10/117				0/117
4	D1,D2,E6,E4	D2(2)	40		D1,D2,E6,E4	D1(2)	60	
	D3,D4,E3,E7	D3	20		D4,E3,E7	D4	30	
	E3,E7	E7	15		E3	E3	15	
				30/105				0/105
5	E6,E10,E11,F3	E10(2)	20		E6,E11,F3	E6(2)	15	
	E5, E8,E11,F3	E11	15		E5,E8,F3	E5	20	
	E8, F1, F2	F2	15		E8, F1	E8	30	
	F1,F3	F1(2)	30		F3	F3(2)	30	
				15/95				0/95
6	F4	F4(2)	90					
	F5	F5(2)	15	0/105				

Following the first phase of optimization, the cycle time was reduced to 131 minutes. This intermediate step demonstrated a significant improvement, with a 20.6% reduction in cycle time from the original data. The implementation of initial line balancing techniques began to reduce some of the identified inefficiencies. However, despite this improvement, the cycle time and balance delay indicated that further optimization was necessary. The progress at this stage highlighted the effectiveness of the initial interventions while also identifying the need for more comprehensive solutions to achieve the desired performance levels.

Table 4 *Third Data (Cycle Time Changed to 111 Minutes)*

W/S	Group 1				Group 2			
	Candidate	Choose	Time	Idle/Total	Candidate	Choose	Time	Idle/Total
1	A1, A2, A3	A3	30		A1, A2	A1	24	
	A7, A8	A7	16		A2	A2	27	
	A8, B3, E4	A8	30		A4	A4	20	
	A9	A9	20		A5, A7, A8	A5	15	
				15/111	A6, A7, A8	A6	25	0/111
2	B1, B3, B4	B1	10		B3, B4, E4	B3	30	
	B2, B4, E4	B2	10		B4, B5	B5 (2)	80	
	B4, E4	B4(2)	80					
				10/110				0/110
3	C1, C3, E4	C3	59		C1, E4, E1, E2	C1	72	
	C5, C6, C4, E9	C5(2)	13		C2, C6, E4, E9	C2(2)	15	
	C6, D1, D2, E9	C6(2)	15		C4	C4(2)	15	
				15/102				0/102
4	D1, D2, E9, E1	D2(2)	40		D1, E9, E1, E2	D1(2)	60	
	D3, D4, E6, E7, E9	D3	20		D4, E4, E6, E7, E9	D4	30	
	E1	E1	40		E4, E6, E7, E9	E7	15	
				5/105				0/105
5	E2	E2	10		E4, E6, E9	E4	15	
	E3, E4, E6, E9	E3	15		E5, E6, E9, E11	E5	20	
	E5, E6, E9, E11	E9	20		E6, E9, E10, E11	E6(2)	15	
	E8, E9, E10, E11, F3	E10(2)	20		E8, E11, F1	E8	30	
	E11	E11	15		F1, F2, F3	F2	15	
				15/95				0/95
6	F1, F2, F3	F1(2)	30					
	F2, F3	F2	15					
	F3	F3(2)	30					
				0/75				
7	F4	F4(2)	90					
	F5	F5(2)	15					
				0/105				

In the final phase of the optimization process, the cycle time was further reduced to 111 minutes. This represents a significant 33% improvement from the original cycle time of 165 minutes. The third data set confirms the success of the implemented line balancing techniques, resulting in a highly efficient and well-balanced assembly line. The balance delay was also substantially reduced, demonstrating a more synchronized workflow and minimal idle time. The final cycle time of 111 minutes aligns with industry benchmarks and exemplifies the transformative impact of systematic line balancing on assembly line performance. This stage of the study provides compelling evidence of the value of continuous optimization in achieving operational excellence.

4.2.2 Assembly Line Cycle Time Statistics

The data from Table 5, "Assembly Line Cycle Time Statistics," presents the performance trends of a 6-workstation assembly line across three cycles. Initially, cycle times ranged from a maximum of 165 minutes to a minimum of 121 minutes, averaging 143 minutes with a standard deviation of 14.48 minutes, indicating variability. In the second cycle, cycle times improved with reductions in maximum (131 minutes) and minimum (95 minutes) times, averaging 113 minutes with a lower standard deviation of 11.28 minutes, showing increased consistency. The third cycle saw further improvements with 7 workstations, reducing maximum and minimum times to 111 minutes and 75 minutes, respectively, and averaging 93 minutes. Although the standard deviation increased slightly to 11.49 minutes compared to the second cycle, overall efficiency and consistency improved, reflecting the line's progression.

Table 5 *Assembly Line Cycle Time Statistics*

Metric	Original Data	2nd Cycle Time	3rd Cycle Time
No. W/S	6	6	7
Maximum Cycle Time (min)	165	131	111
Minimum Cycle Time (min)	121	95	75
Average Cycle Time (min)	143	113	93
Standard Deviation (min)	14.48	11.28	11.49

The observed decrease in both average cycle time and standard deviation suggests significant enhancements in assembly line efficiency. This translates to a reduction in the time allocated for each workstation, potentially leading to increased overall productivity and shorter delivery times.

4.2.3 Balance Delay Reduction

The balance delay, which measures the inefficiency in task allocation, decreased from 19.1% to 9.52%. This reduction indicated a more balanced and efficient workflow, with tasks evenly distributed across workstations. The decrease in balance delay reflected the success of the line balancing techniques in minimizing idle time and ensuring a steady production pace. The improved balance contributed to higher line efficiency and reduced the risk of bottlenecks and production delays [1]. Balance delay refers to the time wasted on an assembly line due to uneven workload distribution among workstations. It occurs when some stations complete their tasks faster than others, leading to inactivity as they wait for slower stations. Balance delay is expressed as a percentage of the total cycle time for one unit. Table 2 shows the balance day for each workstation.

Table 2 *Balance Delay for each workstation*

Metric	Original Data	2nd Cycle Time	3rd Cycle Time
No. of W/S	6	6	7
Cycle Time (min)	165	131	111
Balance Delay (%)	19.1	15.65	9.52

The analysis of Table 2 shows a significant decrease in balance delay percentages from 19.1% to 9.52% as workstations increased from 6 to 7 and cycle time reduced. The third data set, with 7 workstations and a 111-minute cycle time, demonstrated the lowest balance delay, indicating the highest efficiency. These findings suggest that optimizing the number of workstations and reducing cycle time significantly enhance productivity and minimize idle times, with the third data set representing an ideal system configuration.

5. Conclusion

The line balancing study at XYZ Manufacturing led to significant productivity and production improvements in the tractor assembly line. The study began with the development of a precedence diagram, which helped identify inefficiencies. Performance analysis, including time studies and data collection, resulted in a cycle time reduction from 165 to 111 minutes (33%), increasing weekly output from 14.5 to 21.62 units. Balance delay decreased from 19.1% to 9.52%, indicating better workload distribution and efficiency. Additionally, adding another workstation balanced the workload further and reduced cycle time variability. Overall, the study enhanced operational capabilities, meeting market demands with improved efficiency and quality.

Acknowledgement

The authors would like to thank the Ministry of Higher Education Malaysia for supporting this research under Fundamental Research Grant Scheme Vot No. FRGS/1/2018/TK03/UTHM/02/9 and partially sponsored by Universiti Tun Hussein Onn Malaysia.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Shakilla Nur Asimah Mat Hussin, Salleh Ahmad Bareduan; **data collection:** Shakilla Nur Asimah Mat Hussin; **analysis and interpretation of results:** Shakilla Nur Asimah Mat Hussin, Salleh Ahmad Bareduan; **draft manuscript preparation:** Shakilla Nur Asimah Mat Hussin, Salleh Ahmad Bareduan. All authors reviewed the results and approved the final version of the manuscript.*

References

- [1] Groover, M. P. (2016). *Automation, production systems, and computer-integrated manufacturing*. Pearson.
- [2] Heizer, J., & Render, B. (2014). *Operations management: Sustainability and supply chain management* (11th ed.). Pearson.
- [3] Salvendy, G. (2001). *Handbook of industrial engineering: Technology and operations management*. Wiley-Interscience.
- [4] Barnes, R. M. (1980). *Motion and time study: Design and measurement of work* (7th ed.). John Wiley & Sons.
- [5] Wild, R. (2002). *Essentials of production and operations management*. Routledge.
- [6] Yin, R. K. (2016). *Case study research: Design and methods* (5th ed.). Sage Publications.
- [7] Rekiek, B., Dolgui, A., & Ivanov, D. (2002). Assembly precedence diagram generation through assembly tiers determination. *International Journal of Production Research*, 40(18), 4323-4342.
- [8] Smunt, T. (2018). Assembly line balancing in the manufacturing industry: A review. *Journal of Manufacturing Systems*, 47(2), 101-122.