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Improvement in Construction Equipment Assembly Line Using Industrial Engineering Techniques

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Abstract - *The integration of new product lines into existing manufacturing systems presents complex operational challenges, particularly in mixed-model assembly line environments. This study explores a comprehensive improvement initiative undertaken at a construction equipment manufacturing company, a leading Indian manufacturer of construction equipment, aimed at integrating a new model—SKT—into its existing assembly line. Initial assessments revealed a high Defects Per Machine (DPM) rate of 424, along with systemic inefficiencies in documentation, facilities and quality control. The project employed a suite of industrial engineering methodologies and FlexSim-based simulation modeling. Data were collected across multiple stages of assembly, and the process flow was analyzed to identify bottlenecks and Non-Value-Added (NVA) activities. Corrective and Preventive Action (CAPA) measures were implemented to address key defect areas. Projectile study was performed to calculate the average NVA percentage of the assembly line. Simulation results post-intervention demonstrated a nullification in DPM, takt time alignment, and current process throughput. The study concludes by providing facilities and Standard Operating Procedure (SOP), leads to cycle time reduction by 14.2%, states that engineering tools can significantly enhance efficiency, product quality, and readiness for new product integration in complex manufacturing settings.*

Key Words: Mixed-model assembly line, Lean, Simulation, Non-Value-Added (NVA) activities, Corrective and Preventive Action, New product integration

1.INTRODUCTION

Indian manufacturing sector, particularly the construction equipment segment, has been evolving rapidly to meet domestic and international market demands. As part of a strategic initiative to expand its product portfolio, the company introduced a new model called SKT. Unlike legacy models, SKT required customized assembly processes due to its unique configuration and design considerations.

In high-mix, low-volume production settings such as construction equipment manufacturing, the integration of new products into existing lines without disrupting ongoing operations is a critical challenge. This calls for sophisticated planning and robust process control mechanisms. Industrial engineering provides a proven framework for achieving these objectives through data-driven analysis, workflow optimization, and implementation of lean principles.

Despite company's advanced manufacturing capabilities, the pilot run of SKT resulted in a DPM count of 424—significantly higher than industry-acceptable benchmarks. This high defect rate not only threatened product quality but also indicated systemic issues such as lack of standardized work procedures, insufficient operator training, and inadequate layout planning. Given these conditions, a comprehensive improvement project was initiated with the following goals:

- Nullifying the DPM count from the current level
- Ensure defect-free integration of SKT into the existing line,
- Optimize workflow and cycle time without additional capital expenditure.
- Provide facilities and the proper documentation for the integration.

This paper details the structured methodology, analysis, implementation, and outcomes of the project, demonstrating how the application of industrial engineering principles can revitalize assembly operations and enable seamless product innovation.

2.LITERATURE REVIEW

The reviewed literature collectively emphasizes the importance of productivity enhancement, defect reduction, and assembly line optimization within manufacturing environments.

Several studies have explored lean manufacturing principles. The summary of the previous research papers with their objectives, Approach and outcomes are summarized as shown in Table 1.

Table-1: Summary of Former Research(s)

S.No	Objectives	Approach	Outcome
[1]	To minimize product defects and prove the hypothesis regarding the impact of labor performance on product quality	Used Overall Labor Effectiveness (OLE), Linear Regression, and Six Sigma (DMAIC)	Significant correlation between labor performance and product quality; FMEA showed labor was a key defect source
[2]	To synthesize methodologies to minimize defects and identify challenges and directions in defect reduction	Literature review using defined inclusion/exclusion criteria	Identified defect reduction methods; emphasized employee engagement and need for integrated frameworks
[3]	Investigate how organizational interfaces mobilize resources in product development	Case study of industrial tool manufacturer (IndTool)	Highlighted importance of collaboration across organizational boundaries for innovation
[4]	Improve quality control for assembled products using predictive modeling	Developed DPU-chart based on defect prediction models considering product complexity	Effective real-world application in defect monitoring and control
[5]	Adapt assembly line balancing and scheduling for flexible manufacturing and market demands	Used neural networks and knowledge base for scheduling rule selection	Simulations validated improved scheduling and line balancing performance
[6]	Define and promote Zero-Defect Manufacturing (ZDM) for sustainable production	Literature and industry analysis to counter ZDM skepticism and illustrate benefits	Clarified ZDM and emphasized standardization for adoption in Industry 4.0
[7]	Improve productivity in sheet metal stamping subassembly area	Used Lean tools (VSM, Kaizen, 5S); focused on deburring and polishing	Processing time reduced by 62.5%; motion waste dropped from 1086 to 261 activities
[8]	Reduce cycle time in automotive assembly line to meet production targets	Mapped operations, used method study to remove NVAs and identify bottlenecks	Cycle time reduced from 17.37 to 15.02 mins; improved production and resource utilization
[9]	Enhance productivity using MOST for standard time measurement	Video study + MOST analysis; layout and storage redesigned to cut movement	Cycle time reduced by 2 mins; production rate increased by 29.63%
[10]	Optimize human-robot task allocation using complexity-based analysis	Assessed task characteristics; developed a task assignment methodology	Over 70% tasks automated; workload balanced; structured evaluation tool developed
[11]	Improve operations through Lean Six Sigma and VSM	Applied DMAIC with Six Sigma and Lean (VSM); root cause analysis	Time to manufacture rod reduced by 14.71%; WIP reduced by 17.76%; lead time down by 14.88%
[12]	Reduce lead time in spool casing assembly	Simulated current and future VSM in Flexsim; applied 5S and Kaizen	Lead time reduced by 5.7% (P3) and 6.3% (P5); improved storage, less movement
[13]	Automate time tracking in manual assembly using IoT and RFID	Developed a real-time method-time-measurement system with RFID-tagged tools	Enabled accurate time tracking and better manual process optimization
[14]	Balance fan assembly line and reduce delay using RPW method	Applied SALB and GALB; 9 workstations, 42 tasks analyzed via RPW	Delay reduced from 31% to 5%; efficiency up from 69% to 95%; output increased to 823 units
[15]	Solve bottleneck issues in single-model line balancing	Proposed a method to reduce standard time of non-critical tasks using slack time	Efficiency improved from 77% to 88%; balanced delay reduced from 23% to 12%
[16]	Address task and worker assignment based on skill and physical effort in ALB	Proposed ALWARBP in two phases: long-term balancing and short-term rebalancing	Improved task assignment; better handling of unskilled workers; performance enhanced

3. RESEARCH CHALLENGE

3.1 Introduction to The Problem

Despite company's excellency, it faced a critical challenge during the introduction of its new SKT product into the existing mixed-model assembly line. The SKT product, despite being a strategic addition to the portfolio, exposed numerous operational inefficiencies and inadequacies within the established assembly infrastructure.

3.2 High Defect Incidence

The foremost issue was a significantly high Defects Per Machine (DPM) count recorded during the initial production runs. A DPM level of 424 highlighted the system's inability to absorb a new product variant without quality deterioration. These defects were not isolated but spanned across multiple subsystems including electrical wiring, hydraulic integration, and chassis mounting—indicating a breakdown in process coherence and standardization.

3.3 Lack of Standard Documentation and Training

Another key issue was the lack of well-documented procedures and graphics to support in operator training. Without well-established standard work practices, operators based on their actions extensively on verbal feedback, leading to inconsistent task completion. The lack of a single, centralized system for tracking defects only added to the problem, as it's been a challenging one to study trends or enforce preventive actions.

3.4 Facility and Tooling Constraints

In the current assembly line, the products are lacked with the facilities such as the operating desks (or) table for some of the operations and requires the specialized tools and fixtures for SKT integration. For this purpose, the overall assembly line was analyzed with the tools, fixtures, tables, trolleys, special tools, torque wrenches, etc., for all workstations.

3.5 Systemic Process Limitations

The overall process of assembly doesn't have a standardized method for the changeover process, also there is a lack of documentation such as Standard Operating Procedures (SOP). The lack of these fundamental process controls defines that the launch of any new model was bound to bring difficulties instead of being smoothly integrated into the production process.

As a summary, the current configuration was not well-suited to handle the complexity and accuracy needed to integrate SKT, resulting in performance deficits that required rapid corrective action.

4. OBJECTIVES

4.1 Strategic Improvement Goals

The overall objective of this research was to facilitate the smooth incorporation of the SKT model into the current assembly line without compromising on quality or efficiency. This objective was formulated into clear, measurable goals to direct the intervention process.

The most important and initial goal was to nullify the count of DPM from 424 to zero an improvement of 100%. To accomplish this goal, systemic process improvements, the implementation of quality control checkpoints, and root cause elimination were needed.

4.2 Process Stability and Documentation

In order to make improvements maintainable, a standard work documentation is provided to all impacted stations. This involved the development of SOPs, visual work aids, checklists, and operator training modules. These were intended to impose consistency and minimize reliance on individual knowledge.

Another one is to streamline the layout and movement of the assembly line. By eliminating non-value-added activities and redistributing work, the goal was to reduce cycle time by at least 10% and thus enhance throughput without capital investment.

4.3 Simulation and Validation

Finally, it was necessary to confirm all suggested improvements with simulation modeling. Utilizing FlexSim, a virtual twin of the current and proposed assembly lines was developed. This enabled the research team to simulate multiple configurations, forecast outputs, and choose the most effective process flow prior to actual implementation.

Together, these goals shaped the study's design and determined its success metrics. The following project work explains how the integration of SKT was performed to the assembly line, to final volume ramp up based on the demand from the customers.

5. METHODOLOGY

The approach taken for this project incorporates both conventional industrial engineering methods and contemporary computer simulation software. A thorough analysis of the existing assembly process was undertaken with emphasis on determining process inefficiencies, risky operations, and non-value-added processes. The research commenced by gathering live data at four key assembly stages: chassis, tank, engine, and radiator. Time and motion studies were carried out at all the stages to standardize operations and identify deviations.

Root Cause Analysis (RCA) was utilized to track the source of significant defects documented during the Pilot phase process. Supporting this was the use of Failure Mode and Effects Analysis (FMEA), which prioritized the possible risks related to every process activity according to severity, occurrence, and detection ratings. This allowed remedial measures to be prioritized and engineering resources allocated accordingly.

To minimize manual errors, Poka-Yoke (or) error-proofing mechanisms were implemented at certain checkpoints. These measures were intended to prevent improper component assembly and sequence mistakes, especially in hydraulic connectors and wiring. Standard work processes were created and implemented at every workstation, with the result that operators consistently applied similar and tested procedures. All of these instruments employed are in the industry-specialized Corrective and Preventive Action (CAPA) form so that it may be seen through digital factory.

An important component of the methodology as shown in Fig-1 was the simulation of the assembly line using FlexSim software. The simulation model represented the existing workflow and layout, capturing cycle time variations, bottlenecks, utilization rates, work-in-progress levels, and throughput metrics. After validating the model after simulating for a defined time frame, proposed improvements were incorporated and tested under simulated conditions. This dual-track methodology as an empirical and virtual to ensure a comprehensive diagnosis and intervention process.

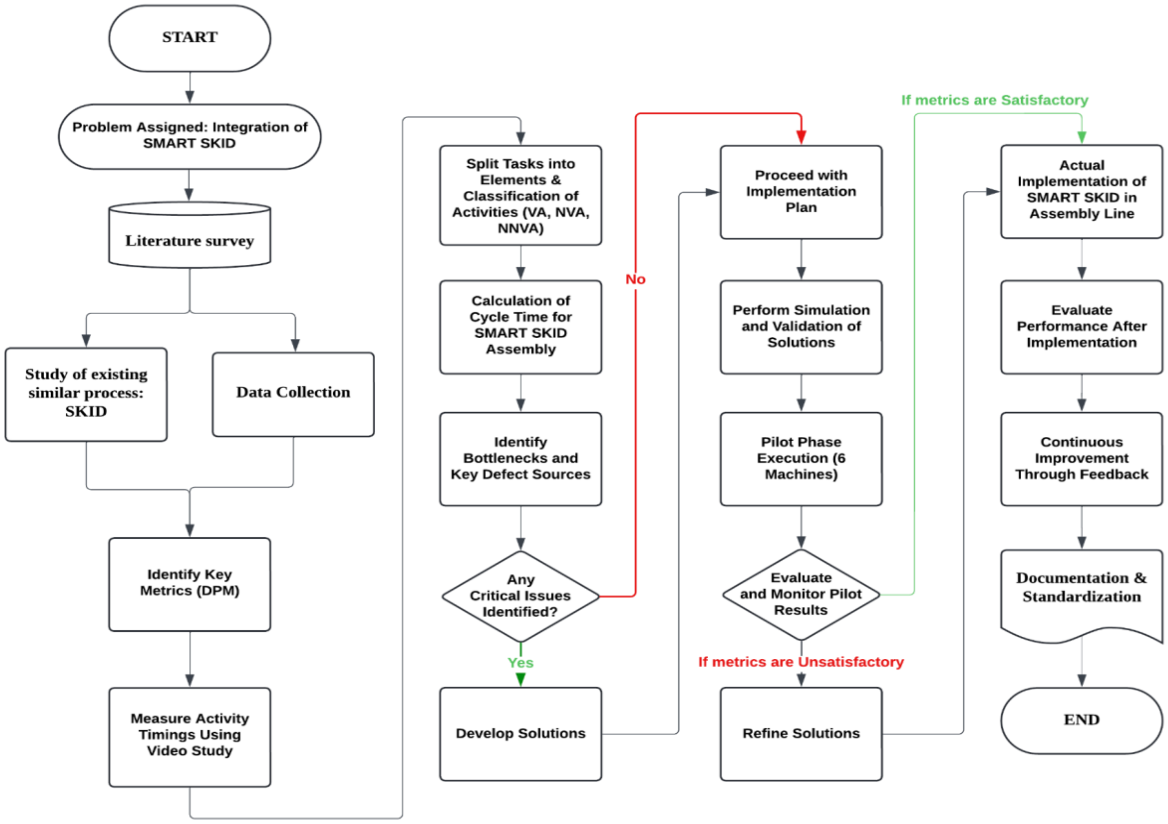

Fig – 1: Project Methodology

6. PILOT STUDY & ASSEMBLY LINE ANALYSIS

The existing assembly line at the industry follows a mixed-model configuration, allowing multiple product variants to be produced in tandem. While this provides production flexibility, it also increases the complexity of operations, particularly during new product integration. The analysis began with a detailed breakdown of defects recorded across departments, highlighting a DPM count of 424 during the SKT pilot phase.

The total defects are classified based on the assembly and are established in the Table-02. This represented not only a deviation from acceptable standards but also pointed to systemic shortcomings in the assembly environment.

Table-2: Defect counts based on assembly

Assembly Name	No of issues
BHO	36
Bonnet	18
Bucket	9
Cabin	90
Chassis	180
Engine	33
Fuel tank	5
Harness	1
Hydraulic tank	6
Hydraulics	27
Joystick	10
Loader Arm	9
Grand Total	**424**

The defects that are counted based on the assembly are incurred to the Pareto chart as in Fig-2 to prioritize the areas of most defects followed by the successive ones based on that 80% of results are derived from 20% of the causes (or) reasons (or) roots.

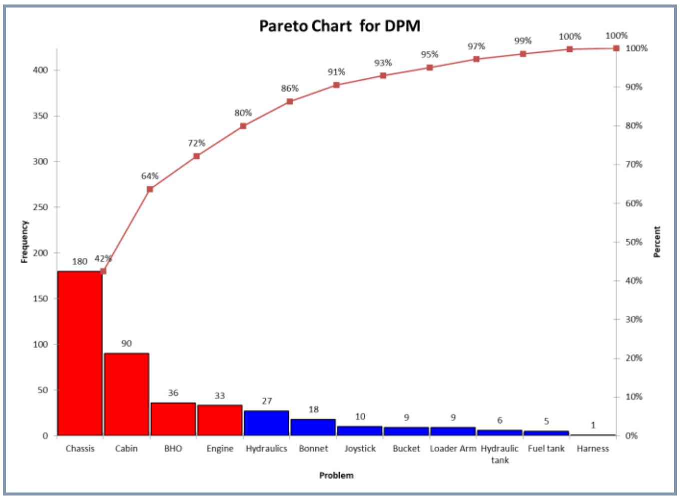

Fig – 2: Pareto chart for the DPM count

The total defects are assigned to the departments based on their cause. The defects in each department are shown using the pivot table as in Table-03.

Table-3: Defect counts based on departments

Row Labels	Count of Department
IED	74
MED	19
R&D	256
R&D-HYD	25
SOURCING	10
SQA	40
Grand Total	424

A cause-and-effect analysis was carried out to assign the defects to the respective ones across five departments: Research and Development (R&D), Sourcing, Industrial Engineering and Design (IED), Manufacturing Engineering Department (MED), and Hydraulics. The diagrams revealed recurring issues such as improper component specifications, unclear instructions, sourcing delays, and unstandardized workstation setups. For example, the R&D department showed significant lapses in version control of engineering drawings as in Fig-3.

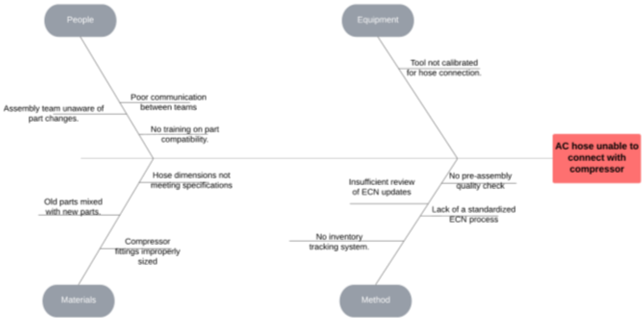

Fig – 3: Cause and Effect Diagram (Dept. R&D)

While IED lacked standardized methods for tool calibration as in Fig-4, so that the defect is assigned to the IED.

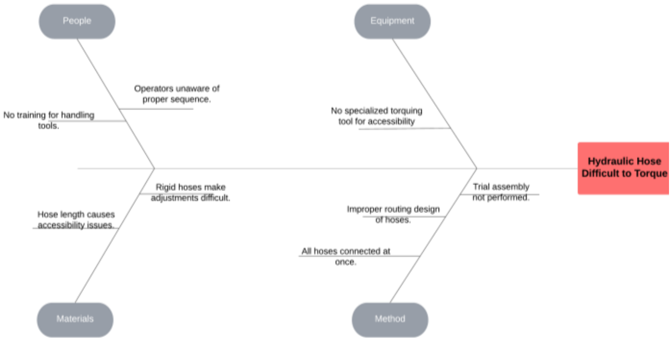

Fig –4: Cause and Effect Diagram (Dept. IED)

Hydraulics, a department critical to SKT functionality, reported frequent leakages due to inconsistent torque application and seal alignment errors as in Fig-5.

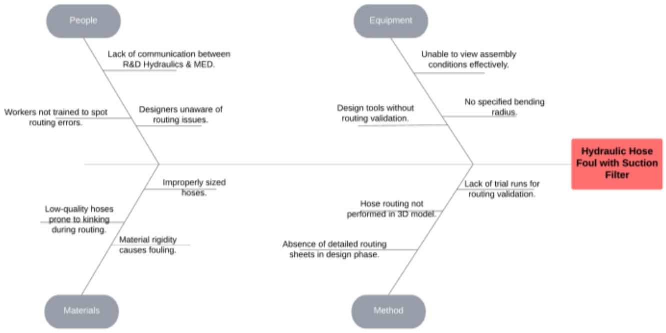

Fig – 5: Cause and Effect Diagram (Dept. R&D Hydraulics)

For the Sourcing department, the the effect of part not checked during the purchase leads to the foul of Back Bonnet with the Bonnet. The cause-and-effect diagram for this is shown in Fig-6.

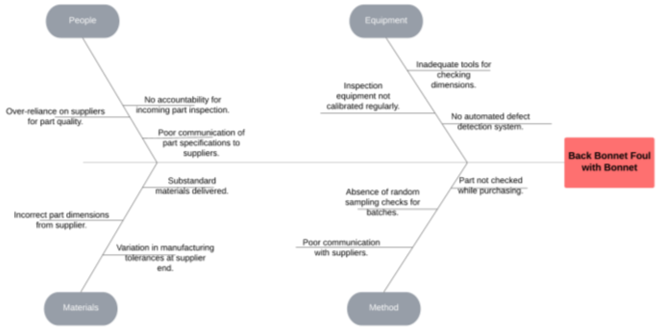

Fig – 6: Cause and Effect Diagram (Dept. Sourcing)

For the defect of Cabin HEX M8 bolt unable to assemble, the cause is due to the difference tolerances from the different laser machines used for cutting the plates. The cause-and-effect diagram for this is shown in Fig-7.

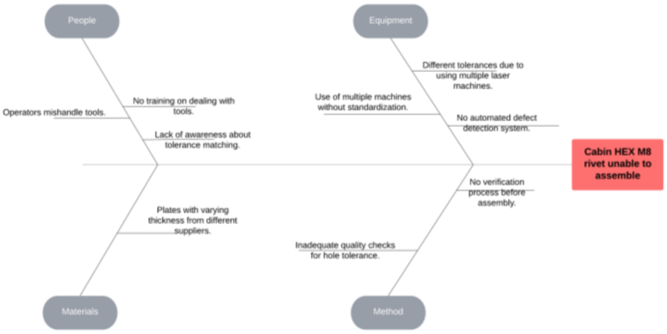

Fig –7: Cause and Effect Diagram (Dept. MED)

Further, data from time and motion studies revealed substantial non-value-added time, particularly in stages involving material handling and tool fetching. Operators spent considerable time walking between stations due to suboptimal layout design. These inefficiencies were mapped and consolidated into a table identifying non-value-added activities for each assembly stage, from chassis through radiator installation.

6. TIME STUDY & PROJECTILE STUDY

For the purpose of simulation of the mixed model assembly line in FlexSim software, the time study was performed and their standard times was calculated for the predominant 4 models, 01 to 04.

6.1 Projectile study

The projectile study plays a crucial role in estimating the overall cycle time for the complete assembly process. Since the current study has progressed up to Stage 04, the data collected from these stages was used to predict the non-value-added (NVA) activities for the remaining stages (Stage 05 to Stage 11). The video study was conducted, using that, the activities are classified into the elemental level and they are listed as Value-Added (VA), Non-Value-Added (NVA) and the Necessary-Non-Value-Added (NNVA), based on lean wastes. The NVA data with an average NVA percentage of 24% and this value was then applied to estimate the NVA for Stages 05 to 11, as summarized in Table-4.

Table-4: Consolidated NVA data for Stages 01 to 11

STAGES	TOTAL TIME TAKEN (Sec)	NVA TIME TAKEN (Sec)	CYCLE TIME WITHOUT NVA (Sec)
Stage 1	2395	575	1820
Stage 2	3008	722	2286
Stage 3	3658	878	2780
Stage 4	4455	1069	3386
Stage 5	2250	540	1710
Stage 6	2741	658	2083
Stage 8	2712	651	2061
Stage 9	1689	405	1284
Stage 10	4359	1046	3313
Stage 11	1780	427	1353
Total time	29047	6971	22076
Average	4455	1069	3386
Cycle time with NVA	4455	74.25	Cycle time reduced is *1046 seconds* or *17.4 minutes*
Cycle time without NVA	3386	56.43	

The NVA percentage identified in the stage-1 is about 16.82% among the 2395 seconds, in stage-2 is 26.29% from the 3008 seconds, in stage 03 is 30.42% from 3658 seconds comparing of 1113 seconds indicating the most among the other 4 stages, and in stage-04 is 22.85% from 4455 seconds. The table also shows the motion included in them as required by the industry to primary focus on the motion waste and to eliminate them.

The time analysis for these tasks from the stages 01 to 04 and their respective NVA percentage calculated is shown in Table-5.

Table-5: Consolidated NVA data for Stages 01 to 11

Stages	Assembly Split-up	VALUE ADDED (Sec)	NON-VALUE ADDED (Sec)	NECESSARY NON-VALUE ADDED (Sec)	MOTION (Sec)	TOTAL (Sec)	NVA %
Stage 1	Rear axle assembly	317	124	72	217	513	16.82%
	Front axle assembly	539	12	0	12	551	
	Hose guard assembly	230	27	0	27	257	
	Oil filling	0	0	270	0	270	
	Auto grease & power steering nipple assembly	56	0	0	0	56	
	Documentation & QA	0	240	119	299	359	
	TOTAL (Secs)	1459	403	533	772	2395	
Stage 2	Front bumper and weight assembly	502	632	0	632	1134	26.29%
	Engine mount (bed) assembly	247	24	0	24	271	
	Hydraulic oil tank and diesel tank assembly	447	10	0	10	457	
	Loader valve assembly	327	52	0	52	379	
	Backhoe valve assembly	417	73	0	56	490	
	Documentation & QA	60	0	217	0	277	
	TOTAL (Secs)	2000	791	217	774	3008	
Stage 3	Loader valve hose assembly	228	353	240	240	747	30.42%
	Backhoe valve hose assembly	465	230	309	343	1004	
	Cooler metal pipe assembly	234	64	79	140	377	
	Radiator mount assembly	120	113	113	141	346	
	Engine Assembly	530	353	301	398	1184	
	TOTAL (Secs)	1577	1113	968	1262	3658	
Stage 4	Radiator assembly	578	279	216	447	1073	22.85%
	Propeller shaft assembly	224	30	141	259	395	
	Sliding & Swivel base assembly	1258	666	215	736	2139	
	Rock breaker assembly	289	35	76	79	400	
	Rock breaker hose assembly	223	5	145	81	373	
	Horn assembly	59	3	13	13	75	
	TOTAL (Secs)	2631	1018	806	1615	4455	

6.2 Analysis of NVA Time Across Process Stages

The table-6 presents an analysis of Non-Value-Added (NVA) time across four different stages of a process. Each stage lists the total time taken in seconds, along with the corresponding NVA time in seconds and its percentage of the total. In Stage 1, the total time is 2519 seconds, with 403 seconds identified as non-value-added, resulting in 16.82% NVA. Stage 2 has a total time of 3008 seconds, of which 791 seconds are non-value-added, contributing to 26.29%. Stage 3 records the highest NVA percentage at 30.42%, with 1113 seconds out of 3658 being non-value-added. In Stage 4, 1018 seconds out of 4455 are categorized as non-value-added, resulting in 22.85%. Overall, the average NVA percentage across all four stages is calculated to be 24.095%, which is highlighted in red to emphasize its significance.

Table-6: NVA Time by Stage

STAGES	Total (Sec)	NVA (Sec)	NVA (%)	Average NVA
STAGE 1	2519	403	16.82	**24.10%**
STAGE 2	3008	791	26.29	
STAGE 3	3658	1113	30.42	
STAGE 4	4455	1018	22.85	

6.3 Standard time calculation after elimination of NVA for MODEL-1

The standard time for the Model-01, 02, 03, 04 was calculated after eliminating the NVA with provided the total allowance of 14%, was shown in Table-7.

Table-7: Standard time calculation

	Standard Time (seconds)			
Assembly Stage	**MODEL-01**	**MODEL-02**	**MODEL-03**	**MODEL-04**
1	2217	2168	2009	2105
2	1914	1541	1513	1659
3	4617	3748	4308	4199
4	2942	1810	2200	3038
5	2380	2550	2487	2615
6	2603	3115	1961	3463
8	2710	2885	2739	2926
9	1637	2080	1612	1739
10	3304	3436	3433	4895
11	1998	1962	2028	1899
Bottleneck stage (seconds)	**4617**	**3748**	**4308**	**4895**

7. SIMULATION AND OPTIMIZATION

After the root causes and inefficiencies were identified, the proposed changes were modeled using FlexSim to test their impact before physical implementation. The simulation included a representation of the entire line over a 20-day operational window, equivalent to 28,080 minutes. The model established in FlexSim was shown in Fig-8.

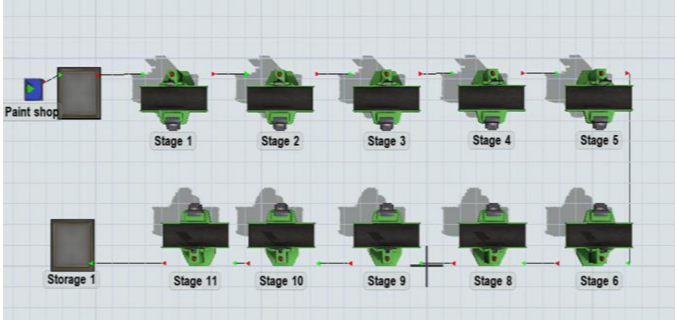

Fig –8: System Simulation using FlexSim

Input data included takt time per stage, operator availability, and workstation configuration, all validated through primary data collection.

The Gantt chart obtained from the simulation representing the processing, idleness, blockage and the setup periods are shown in the Fig-9.

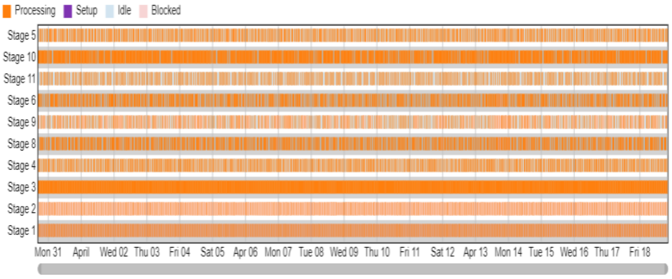

Fig –9: State Gantt

The software simulation exposed critical bottlenecks at the engine drop and radiator assembly stages, with utilization rates exceeding 95% indicating bottleneck points in the system.

Also, throughput was inconsistent, the throughput amount acquired from the simulation for the assembly stages was shown in the Fig-10, which is way less than the current demand.

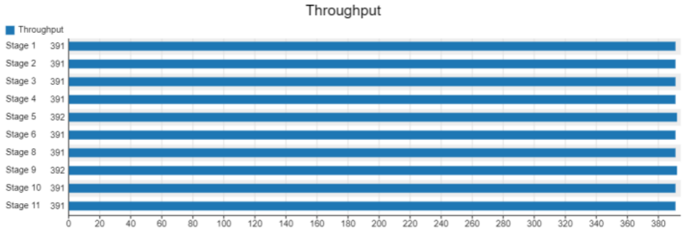

Fig –10: Assembly stages-throughput chart

The utilization of each stage with the idleness, blockage and processing periods are shown in Fig-11, shows the 100% utilization in Stgae-03 leading to the blockages in stages 01 and 02 also with the effect of idleness from the stages 05 to 11. This indicates the effect of the bottleneck stage (03) among the other stages, indicating the clear assessment of requirement of balancing the assembly line.

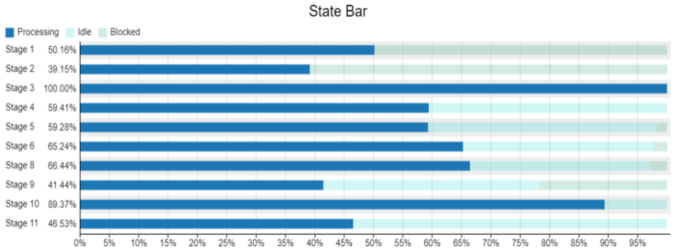

Fig –11: Assembly Stages-Utilization chart

The overall utilization of the assembly line from the simulation was established as shown in the Fig-12, shows the line utilization is 61.70% with the 24.3% of idleness along with 14% of blockage stage.

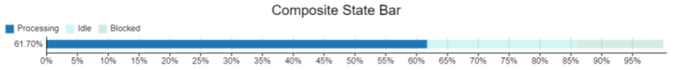

Fig –12: Overall line Utilization chart

The WIP levels fluctuated due to uneven process balancing. The Fig-13, shows the average content of work (product) accumulated in each stage of the assembly line.

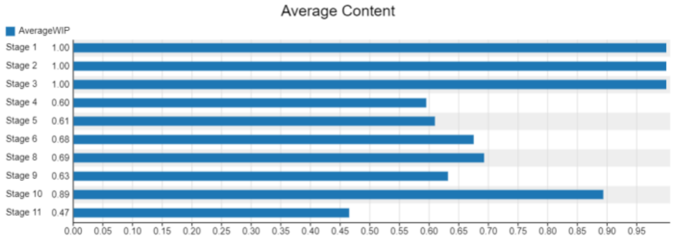

Fig –13: Average WIP content of each stage

The above charts describe the state of the mixed model assembly line for the calculated standard time for the 4 predominate models that are manufactured in larger quantity based on the customer demand.

The time taken for each of the stages and their state are visually seen in the charts, below in the Table-8, the time taken for each state in their respective stages are described for the 10 stages, from the stage 01-11. This table also indicates that there is no blockage and idleness in stge-03, leading to the identification of the bottleneck stage. The stages 01 and 02 has zero idleness and leads to blockage and processing state. Following the stage 03, from the stages 04 to 11, the idleness state is increased and decreased blockage compared to those of stages 01 & 02.

Table-8: Simulation summary of the stages

State	Sum of Minutes
Stage 1	
Blocked	13758
Idle	0
Processing	13812
Stage 2	
Blocked	16791
Idle	0
Processing	10779
Stage 3	
Blocked	0
Idle	0
Processing	27570
Stage 4	
Blocked	33
Idle	11172
Processing	16365
Stage 5	
Blocked	469
Idle	10754
Processing	16391
Stage 6	
Blocked	629
Idle	8972
Processing	17992
Stage 8	
Blocked	785
Idle	8481
Processing	18328
Stage 9	
Blocked	6003
Idle	10150
Processing	11458
Stage 10	
Blocked	0
Idle	2957
Processing	24659
Stage 11	
Blocked	0
Idle	14761
Processing	12856
Grand Total	275923

Simulation results corroborated real-world observations. The FlexSim model predicted the reduction in work-in-progress (WIP) inventory, primarily due to improved task balancing and elimination of bottlenecks. Utilization charts illustrated more equitable distribution of labor, avoiding overburden at specific stations, and ensuring optimal deployment of human resources.

Furthermore, the Gantt chart from the simulation illustrated improved sequencing across all workstations. Operators no longer experienced delays due to tool unavailability or unclear instructions. Overall system throughput increased, aligning with the plant's production capacity targets for the new SKT line.

8. RESULTS AND DISCUSSION

The implementation of industrial engineering interventions and simulation-based validation yielded quantifiable improvements across multiple performance indicators. One of the most notable achievements was the reduction of the Defects Per Machine (DPM) count from an initial 424 to zero, translating to a 100% improvement. This shows the targeted reduction threshold and brought the defect count within industry-acceptable limits.

The reduction in DPM was attributed to several factors. Firstly, the introduction of standard operating procedures (SOPs) provided clear, step-by-step guidance to operators, thereby minimizing ambiguity and process deviations. Secondly, error-proofing systems (Poka-Yoke) prevented the recurrence of frequent mistakes, especially in areas such as torque application, hydraulic fittings, and component sequencing. Additionally, daily defect checklists and feedback loops enabled continuous monitoring, allowing supervisors to take immediate corrective actions. The percentage reduction is shown in Table-9.

The analysis of cycle time using simulation also showed a positive outcome. Prior to intervention, the average cycle time for SKT assembly was 92 minutes. Following the layout and workflow optimization, this was reduced to 79 minutes—a 14.2% reduction as accumulated in form of NVA. This improvement shows the underscoring power of process re-engineering and time-motion analysis in achieving lean outcomes by means of proper training and awareness to the workers and sequencing in the assembly line.

Table-9: Percentage reduction stage wise

Stage	Model-01			Model-02			Model-02			Model-04		
	Before (sec)	After (sec)	% Reduction	Before (sec)	After (sec)	% Reduction	Before (sec)	After (sec)	% Reduction	Before (sec)	After (sec)	% Reduction
1	2567	2217	13.64	2492	2168	13.01	2593	2009	22.51	2732	2105	22.96
2	2101	1914	8.89	1718	1541	10.31	1803	1513	16.09	1919	1659	13.56
3	5241	4617	11.9	4902	3748	23.53	4632	4308	6.98	5110	4199	17.82
4	3397	2942	13.38	2289	1810	20.94	2546	2200	13.58	3407	3038	10.85
5	2857	2380	16.68	2839	2550	10.17	2906	2487	14.41	2960	2613	11.65
6	3146	2603	17.25	3217	3115	3.16	2526	1961	22.36	3606	3463	3.97
8	3460	2710	21.67	3199	2885	7.21	3578	2739	7.97	3568	2926	18.01
9	2192	1637	25.34	2212	2080	5.95	1851	1612	12.92	2222	1739	21.74
10	3823	3304	13.59	4053	3436	15.21	4090	3433	16.06	5735	4895	14.64
11	2332	1998	14.34	2065	1962	5	2246	2028	9.72	2342	1899	18.9

These results shows that the application of lean tools, combined with data collection and simulation, can significantly enhance assembly line performance—both qualitatively and quantitatively.

From the analysis, it was observed that the time taken before the elimination of Non-Value-Added (NVA) activities was 56 minutes per station. After eliminating these non-value-added activities, the time reduced to 48 minutes per station. This results in a reduction of 8 minutes per station. In terms of percentage, this corresponds to about 14.2% reduction in time per station, indicating a notable improvement in operational efficiency.

9. RECOMMENDATIONS

Based on the findings of this project, several recommendations are planned to ensure the long-term sustainability of improvements and to adopt continuous improvement (Kaizen) of the assembly line:

*Step 1: I*t is recommended that all product variants: current and future can be accompanied by documentation including process flowcharts, SOPs, defect checklists, and FMEA tables. This will create a standardized knowledge base for the organization and reduce the learning curve during product transitions.

Step 2: The plant should adopt a culture of continuous improvement (Kaizen) through regular audits and feedback loops internally. Even after initial success, processes should be periodically reviewed to identify new bottlenecks, inefficiencies, or defect patterns that may arise as production ramp up.

Step 3: There is a strong case for digital integration of quality control systems. The implementation of barcode scanning, digital defect logging, and operator dashboards could further reduce manual errors and improve traceability across the production line as a improvement in digital factory.

Step 4: Another recommendation pertains to workforce training. While SOPs can standardize operations, cross-training and upskilling will ensure operators remain agile in adapting to design changes, layout modifications, and tool enhancements.

Step 5: The FlexSim simulation model developed during this project should be maintained and updated with real-time data. This digital twin can be used to simulate future product introductions, production ramp-ups, or layout changes, thus serving as a strategic decision-support tool.

10. Conclusion

The present study successfully demonstrates the applicability and impact of industrial engineering techniques in improving a live construction equipment assembly line. Through a comprehensive combination of RCA, FMEA, Poka-Yoke, time and motion study, and FlexSim simulation, the integration of the new SKT product into the assembly line was accomplished for further volume ramp-up.

The DPM count was nullified, average cycle time was shortened by 14.2%, and WIP levels were effectively stabilized. Prominently, the interventions were implemented, highlighting the strength of analytical problem-solving and lean methodologies in manufacturing systems.

This project not only resolved immediate challenges related to product integration but also established a scalable framework for future improvements. The success of the initiative confirms the critical role of organized manufacturing methods in increasing productivity, quality, and operational excellence for the manufacturing firm.

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