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Research article

Application of lean Six Sigma methodology using DMAIC approach for the improvement of bogie assembly process in the railcar industry

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ABSTRACT

The quest for waste reduction, quality improvement and operational efficiency during the assembly process of the railcar bogie necessitates this study. Using a case study approach, this study employs the Lean Six Sigma (LSS) approach for process improvement of the railcar bogie assembly process. Primary data relating to the assembly process such as the labour and material flow, up and down times were collected at every stage of the assembly operation. The improvement process of the assembly process featured the use of some Lean tools such as the Kaizen, Value Stream Mapping, Pareto chart, Single-Minute Exchange of Die (SMED) and 5S. The investigation of the current assembly process with the use of the LSS technique indicates that the process efficiency is low due to waste generation. The results obtained showed significant improvement in the process cycle efficiency (PCE) by 46.8%, via the implementation of the Kaizen continuous process improvement approach, 27.9% reduction in the lead-time, 59.3% increase in the value added time and 71.9% reduction in the non-value added time after the implementation of the LSS approach. The findings of this work demonstrated the feasibility of the LSS approach for waste minimisation and process performance improvement in a bid to achieve operational excellence in a manufacturing organisation.

1. Introduction

There is increasing quest for improved process performance and product quality in many organisations today, in a bid to accomplish organisation's bottom-line goals of profitability, sustainability, market share and competitiveness. The duo of high productivity and good quality are imperative to the survival of any organization in this era of globalization and increasing market competitiveness (Costa et al., 2017a, b). Experts have proposed different definitions for quality. For instance quality has been defined as the suitability of the product for its intended use (Juran and Godfrey, 1999; Suárez 1992), product uniformity at an optimum cost and applicable to the market (Suárez, 1992), product compliance with the standards (Suárez 1992), capacity to meet the customers' requirements (Ishikawa, 1976) etc. The development of products with poor quality can be attributed to manufacturing errors. These manufacturing errors if not corrected are capable of generating additional costs without adding any value to the manufacturing process or product and as such can typically can cause delay in the manufacturing lead time (Rosa et al., 2017). For organisations to remain economically viable and competitive while meeting the regulatory compliance, quality requirements, and delivery schedules, there is a need to eliminate the failures and wastes identified during the manufacturing process (Costa et al., 2017a,b). Furthermore, the quest for improved productivity without sacrificing quality has continued to be the prime target of many manufacturing industries. This can only be possible with the development of a manufacturing system which offers a positive response to the changes in the market, customers' and product requirements. Hence, manufacturing industries are increasing seeking for suitable approaches to achieve performance improvement to gain a competitive edge. The Lean approach is a philosophy employed as a management system for continuous improvement and waste reduction during manufacturing (Antoniolli et al., 2017). The reduction of waste during the manufacturing processes can support the principles of circular economy which emphasises zero tolerance for waste generation. The Lean approach focuses on waste reduction via minimization of assembly error, component part variations to promote the quality of the assembled rail

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car parts while the Six Sigma approach focuses on process optimization for process efficiency improvement. The integration of Six Sigma and Lean tool (LSS) is to achieve zero defects, optimum production performance, improved product's quality and fast delivery at optimum cost. The approach seek to identify the activities that are capable of adding values and the ones that are not adding values to the railcar bogie assembly operations in the quest to enhance the overall productivity. Hence, the integration of the two approaches (Lean approach and Six Sigma) will promote zero tolerance for waste and component defects during the assembly process of the railcar and process improvement. The choice of the LSS will permit the identification of the challenges mitigating effective operation during railcar bogie assembly as well as area of potential improvement. It will also permit the comparative analysis of the process efficiencies of the different phases of the assembly process to streamline them. The LSS can also enhance the implementation of automation strategies for process improvement and effective delivery (Ahmed et al., 2018; Sunder and Mahalingam, 2018; Gijo et al. 2018).

2. Literature review

Lean approach is based on Toyota Production System (TPS) whose philosophy can be employed to industry. It focuses on waste elimination, inventory reduction, as well as improvement in throughput. This will foster the identification of problems and propose possible ways to address the identified problems (Womack et al., 1991). The Lean manufacturing can be defined as a prescribed manufacturing method to reduce waste and process cycle time, with improvement in proces flexibility and product quality (Suárez, 1992; Ishikawa, 1976). The Lean manufacturing principle emphasises customers' value maximisation and waste minimisation to achieve operational excellence via the creation of more values with limited resources. Hence, the main principle of Lean is to eliminate waste and improve the production processes. The implementation of the Lean principles for waste elimination and for improving the operational efficiency in the industries is increasing gaining awareness. The underpinning framework for the successful implementation of Lean principle in any organization is directed by five continuous cycle improvement phases (Womack and Jones, 2013). These are:

1. The first is the specification of value – This involves the identification of the product's value from the market or customer's perspective. Values can be specified for the producer by the market.
2. Identification of the value stream – The identification of value stream for the product will indicate the types of actions needed to be taken alongside the value stream. This comprises of the value adding and non-value adding steps that are unavoidable and the ones that can be eliminated. Hence, at this stage, the wasteful steps will be removed from the process.
3. Creation of flow – The identification, specification and mapping of the value stream for a particular product is followed by the creation of flow. This step ensures the continuous flow of work elements flow with nominal queues, rework or stoppages. This will promote the cycle time for the completion of the product manufacturing and the overall manufacturing lead time.
4. Establishment of pull – This is the fourth principle of the Lean approach after the removal of wasteful steps and the creation of flow. At this step, the customers are allowed to pull a product through the process. This is indicative of the organisation's responsive capacity to the needs of the customers.
5. Seeking for perfection – This is the fifth principle of Lean manufacturing which involves the analysis of each process to increase the value, and further eliminate the waste. At this step, the flow is tightened and value are delivered based on the need of the customers.

For small, medium or large scale organisations, the recent manufacturing trends has made it easy to form an assembly line. The challenge of locating machines on the shop floor can be resolved by ensuring a rhythm in the manufacturing Lean assembly line. This can be achieved through process mpping which identifies value adding and non-value adding activities. Presently, the formation of assembly lines is still essential in attaining flexibility and smooth operation of the production system (Miltenburg 2001; El-Maraghy, 2005; Calvo et al., 2007). The TPS founder Ohno (1988) and Shingo (1989) focused on the production engineering perspective and both analysed in details the required tools and techniques required for each process.

The Lean manufacturing approach is a method employed organizations to eliminate waste while the Six Sigma tools are embraced to improve production performance, and product's quality (Mwacharo, 2013; Madsen et al., 2017).

To eliminate waste and some other manufacturing challenges, the Lean manufacturing technique is needed to accomplish these objectives in the industry. The Lean manufacturing approach is feasible for effective process mapping and the identification of value adding and non-value adding activities. On the other hand, the Six Sigma tool is a scientific, systematic, statistical, and smart method that is suitable for the enhancing product's quality, innovation and improving customers' satisfaction (Krueger et al., 2014; Hekmatpanah et al., 2015; Gupta et al., 2018) The models of the Six Sigma are the DMAIC (Define, Measure, Analyze, Improve, Control) (Cronemyr, 2007; Improta et al., 2017 Ricciardi et al., 2020) which is usually deployed for the improvement of an existing process, and the DMADV (Define, Measure, Analyze, Design, Verify) (Uluskan and Oda, 2019; Jones et al., 2014). which is employed for the development of new products. The integration of the Lean and Six Sigma approaches is referred to as the Lean Six Sigma (LSS). LSS can assist the manufacturing industries to achieve zero defects, optimum production performance, improved product's quality and fast delivery at optimum cost thereby assisting organizations to succeed in exceeding future customers' demands. The Lean approach focuses on waste reduction via minimization of assembly error, component part variations to promote quality of the assembled railcar parts while the Six Sigma approach focuses on process optimization to improve the process efficiency. Hence, the combination of the two methodologies will promote zero tolerance for waste and component defects during the assembly process of the railcar. Existing studies have been reported on the use of LSS approach for organisation's strategy alignment, waste reduction, production performance improvement, and customer's satisfaction enhancement in various sectors such as health, manufacturing, education, banking sectors etc (Furterer and Elshennawy, 2005; Laureani and Antony, 2010; Edgeman 2010; Shahada and Alsyouf; 2012; Meza and Jeong, 2013; Ben Ruben et al. 2017; Bazrkar et al. 2017; Ahmed et al., 2018; Sunder and Mahalingam, 2018; Gijo et al. 2018). The outcome of these works establish the appropriateness of the LSS approach in achieving waste reduction and operational excellence in an organisation. Particularly, the application of Six Sigma DMAIC approach to accomplish process improvement in the railway operation and manufacturing sectors have been highlighted (Maleka et al., 2014; Nedeliaková et al., 2019). The LSS is a strategy to promote quality improvement, hence, it can assist organisations to achieve operational excellence, waste reduction and process improvements. According to Womack and Jones (1996), the Value Stream Map (VSM) which is referred to as the second principle of Lean important tool for process improvement. It is appropriate for the analysis of value and non-adding activities, material and information flow design etc. This is necessary in achieving high quality products with significant waste reduction during production (Belokar et al., 2012). A VSM diagram shows the details of each step involved in the production loop that are necessary for the completion of the product development phases. It is a vital technique for the visualisation and management of process improvements. The process of mapping out a process presents a better picture of the nature of wastes which characterise the production process. This will facilitate easy identification of the bottlenecks and inventory as well as other troubled spots for the necessary corrective actions.

Hill et al. (2018) developed a framework for LSS implementation In order to enhance optimum performance during the Maintenance Repair and Overhaul (MRO) of the aerospace facility. Ben Ruben et al. (2017) employed the DMAIC methodology which was validated using a case study of automotive component manufacturing industry in India. The findings of the work demonstrated significant operational improvement as well as environmental benefits. Furthermore, Gijo et al. (2018) implemented the LSS approach in an Indian automotive industry while Shahada and Alsyouf (2012) designed and implemented the LSS approach for process performance enhancement in a manufacturing organisation. The approach employed integrated the Lean and Six Sigma techniques into one framework which enables users to measure, the organisation's performance with respect to the customer requirements. The findings of this work demonstrated the feasibility of the LSS approach for waste minimisation and process performance improvement in a bid to achieve operational excellence in a manufacturing organisation.

This study is a case study of railcar bogie manufacturing unit (bogie assembly unit) in a railcar industry with the focus of improving the assembly operation process. It also addresses the implementation of LSS, with highlights on the activities of the bogie assembly to minimize wastes like waiting time, material handling time, etc. This work aims to reduce waste, improve the assembly and process efficiency operations of railcar bogie in a railcar industry using the models of the Six Sigma namely the DMAIC approach (Define, Measure, Analyze, Improve, Control).

The VSM was applied as a Lean tool to increase on the process cycle efficiency and minimise the manufacturing lead time. There is dearth of implementation framework of LSS in the railcar manufacturing industry, hence, this study will add to the understanding of the continuous process improvement implementation to optimize the manufacturing processes in the railcar industry. Hence, the study contributes to knowledge in the practical field of LSS. It showcases the application of the LSS principle to the railcar bogie assembly process, unlike some existing studies which focused more on discrete based manufacturing. The succeeding section presents the continuous improvement methodology employed (the DMAIC approach) and the case study while the next section highlights the results and discussion obtained following the application of the continuous improvement tool. Finally, the last section presents the conclusion and recommendations.

3. Methodology

The methodology employed in the study is a case study approach investigated using the integration of the Lean tools and Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) approach. The case study method was preferred because it is flexible both in design and practical thus permitting both quantitative and qualitative analysis of certain phenomena in an organisation (Krueger et al., 2014; Sunder and Mahalingam, 2018; Merriam and Grenier, 2019; Sanchez-Marquez et al., 2020). A case study method offers a means of investigating multifaceted issues with an organisation's value chain (Vinodh et al., 2011). Another merit of case study approach is that it is helpful for making direct observations and data collection in any organisation's setting for comparison analysis (Ingason and Jonsdóttir, 2017; Sunder et al., 2019). Yin (2009) explains that the case study approach can be employed to properly comprehend an organisation's challenge and obtain a basis for the deployment of feasible solution to such challenges.

According to Ghauri and Gronhaug (2005), the case study method can sufficiently provide answers to questions relating to why and how questions. In addition, the case study methodology is feasible for investigating complex phenomena in an organisation.

John and Kadadevaramath (2020) highlight some of the fundamental steps in the case study methodology as follow: problem definition and quantification, decision on the most suitable approach for resolving the identified problem, data collection and analysis, execution of the developed solution, as well as the reporting of the findings and implications to the concerned stakeholders.

In this study, a real-time problem of waste generation during the assembly operations of railcar bogie was considered. Primary data relating to the assembly process such as the labour and material flow, up and down times were collected at every stage of the assembly operation.

The Lean and Six Sigma DMAIC approach employed in this study illustrate how LSS can be used to assess the assembly process in a railcar manufacturing industry based on the manufacturing waste generated, and productivity performance. The study also presents lessons learned as well as practical implications of LSS implementation. The integration of the Lean and the Six Sigma approach eliminate the limitations of each of the tool in order to ensure waste reduction, reduction in process variability and improved process efficiency (Singh and Rathi, 2019; Thomas et al., 2016). The improvement process of the assembly process featured the use of some Lean tools such as the Kaizen, Value Stream Mapping, Pareto chart, Single-Minute Exchange of Die (SMED) and 5S. The choice of these tools stems from the fact that they are useful for troubleshooting and resolving some organisational challenges elating to waste generation, quality and process improvement (Bazrkar et al., 2017; Sunder et al., 2019). The DMAIC model of the Six Sigma was deployed to improve the existing assembly process of the railcar bogie. The Pareto chart was used to compare the PCE for the various assembly operations with the benchmark set a maximum value of 85% and minimum value of 25%. The subsequent subchapters presents an overview of the Lean tools employed. The statistical analysis of the data collected precisely for the lead times was performed using the Statistical Package for Social Science (SPSS) version 2019.

3.1. Value Stream Mapping (VSM)

This Lean manufacturing tool is appropriate for the analysis of value and non-adding activities, material and information flow design etc (Merriam and Grenier, 2019). It is suitable for troubleshooting and resolving some set of organisation's challenges relating to waste generation (Sunder et al., 2019; Edgeman, 2010). The tool was chosen because it can assist organisations in achieving significant waste reduction during the assembly process. It can enable the visualisation of the cycle time, human resources, inventory, and information flow at each stage across the whole assembly process. Thus, the future state can be projected from the current state (Belokar et al., 2012). These tools are valuable for diagnosing and resolving set of organizational problem (Sunder et al., 2019; Edgeman, 2010). The Qi Macros software embedded in the Microsoft Excel was employed for the mapping of the value stream for the whole process value chain. The Qi Macros software embedded in the Microsoft Excel was employed for the mapping of the value stream for the whole process value chain. The software can be integrated directly into the excel interface and it is suitable for statistical analysis, data transformation, chart generation or improvement (QiMacros User guide, nd).

3.2. Process cycle efficiency (PCE)

It is defined as the ratio of the value added time to the total time of the manufacturing process (Ying, 2011). The value added time is the productive time invested into the assembly operation while the total time is a function of the total time it takes the assembly operation to be completed. In other words, the between the start time and the finish time. The information about the value added time and the total time of the assembly operation of a bogie were obtained after a brainstorming session with the production manager and concerned personnel in addition to the information documented during previous bogie assembly operations. The PCE selected because it helps to prioritized improvement in the assembly operation. The PCE is expressed as Eq. (1).

$$PCE = \frac{VDT}{TT} \times 100\% \tag{1}$$

Where:

PCE is the Process Cycle Time (sec), VDT is the Value-Added Time (sec) and TT is the Total Lead Time expressed as the sum of the value added and non-value added time (Equation 2).

$$TT = VDT + NVDT \tag{2}$$

3.3. The case study

This case study was undertaken in a railcar manufacturing industry based in South Africa. The industry comprises of five major departments namely: production, logistics, procurement, central account and marketing. The production department accounts for about half of the entire workforce of the organisation. The company employs indigenous technology for the manufacturing and assembly of railcar components.

The process of bogie development usually consists of a series of phases. Some of these phases are: signing of contract, computer aided design of the component parts, sub assembly and the overall assembly, procurement of parts, materials and sub-assemblies, manufacturing and assembly, testing and delivery (The Railway Technical Website, 2019). The focus of this work is limited the assembly operation of the railcar bogie and the framework for the assembly operations is presented in Figure 1.

1. The determination of the body structure and assembly methods usually precede the design of the jigs so that the components parts can be held and positioned with accuracy.
2. Computer aided design of the component parts, sub assembly and the overall assembly.
3. Configuration control in order to ensure that all the designs, drawings, calculations and documents connected with the contract are properly registered, submitted to the customer for approval, and reviewed in line with the design and customer requirements. This will ensure proper monitoring to ensure that the parts fitted are at the correct modification state, both hardware and software. The configuration control process also ensures component parts control to ensure that no part is missing.
4. Production control. This is to ensure that all the various procurement and manufacturing areas are brought together so as to have a completed railcar bogie. To achieve this, the Bill of Engineering Measurement is usually employed to develop a schedule to show the tasks to be completed, the machines and tools to be used, the personnel involved as well as the various work stations, and the tasks that will be performed at each station. At this stage the resources time, human, materials are allocated for each of the processes leading to the development of production orders which are subsequently passed to the manufacturing shops together with the detailed designs.
5. Next is the procurement stage. This deals with the purchasing of the materials for components development as well as the procurement of component parts, and sub assembly according to design and specifications once an order is received from the manufacturing department.

This is to ensure a balanced stock of materials needed during the manufacturing so that the assembly operation can be carried out as scheduled.

6. Development of jigs for holding and positioning parts during the assembly operation. Some of the railcar bogie parts will be first assembled in the jigs to ensure the parts are held rigidly and in the correct position during the certain assembly operations.
7. Next is the manufacturing of the various parts that make up the railcar bogie in the machine shop. These parts are usually the structural members such as underframe, ribs, bolsters or panels etc.
8. The stages of the manufacturing include the assembly of the underframe and its principal parts which include: the sole bars, runners, bolsters, and transoms. The underframe is normally assembled in an

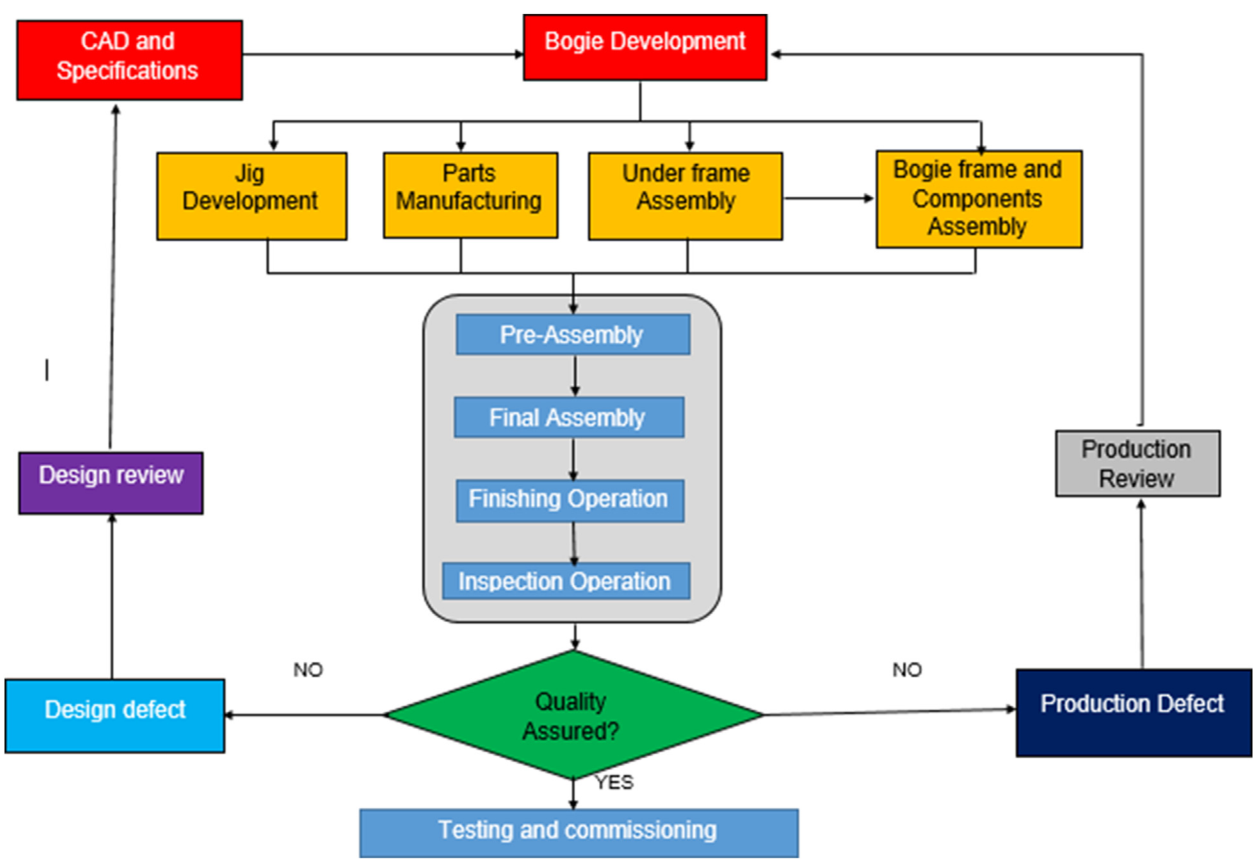

Figure 1. Flow diagram of the assembly operation.

inverted state so that brackets and other attachments can be welded on easily. Similar to the underframe, the various parts of the railcar bogie will be brought together in a series of jigs for assembly.

9. Welding of the bogie frame and assembly of its components parts.
10. Pre assembly. At this stage, the underframe, other components and fittings are pre-assembled before being brought together in the assembly area.
11. Final assembly. The manufactured bogie parts, and the preassembled parts as sub-assemblies are fitting together as a whole assembly.
12. Finishing operation: This may involve straightening, painting etc.

The breakdown of the activities which characterizes the assembly operation of a railcar bogie and the average time taken are presented in Table 1.

3.4. Business case

For effective process performance and product quality improvement in the organisation, there is a need to achieve improvement in the process efficiency as well as reduction in the manufacturing wastes, lead and takt times. This will promote the accomplishment of the organisation's bottom-line goals of profitability, sustainability, market share and competitiveness. This necessitates the engagement of Lean Six Sigma approach to assess the present state of assembly operation. The LSS team composed of postdoctoral researchers, with specialization in quality management with Black Belt certification. The team engaged in organisation's document review, interview and brainstorming sessions with some designated customers and staff of the production department. Furthermore, self-observation was carried out on the production floor for three months to assess the production processes.

3.5. Problem definition phase (define)

At this phase, the problem to be solved is clearly identified and defined (Snee, 2010; Sokovic et al., 2010). The problem involves job tardiness during the assembly process of the bogie of a railcar which brings about an increase in the lead time with resulting low process efficiency. The problem definition phase is in line with the aim of this study, which is to troubleshoot the assembly process, identify the root cause of the waste generated and improve the assembly process with the use of the LSS approach. The VSM was employed to provide an overview of the assembly process which provides an insight into the value-added and non-value-added activities as well as the requirements necessary for meeting the benchmark.

The data necessary for the development of the VSM of the assembly operations of the railcar are summarized in Table 2.

The VSM of the assembly process show the activities which characterise the various stages of operations. The data employed for the development of the present VSM is presented in Table 2 with other necessary information such as the number of operators (O) and number of robots (R). The summary of the railcar bogie development activities as well as the time required are highlighted in Table 1 while Table 2 also summarizes the highlighted activities including the data necessary for the development of the VSM of the assembly operations for 15 railcar bogies.

The present VSM of railcar assembly line indicate the flow of information, labour, raw materials, as well as the value-added and non-value-added times. These information are necessary for the computation of the required process cycle efficiencies. The investigation of the present VSM of the assembly operation, number of labour required at each unit, value added and non-value added times and the necessary improvement measures are necessary to determine the future Process Cycle Efficiency (PCE) and the manufacturing lead time. Figure 2 shows the present VSM of assembly operations. As shown in the Figure, there are many non-value added times revealed from each unit of the assembly line which are computed to a total of 497,691.19 and a total lead time of 623519.97. The total number of operators were 31 while the total number of robots used were 11. The implementation of the LSS is expected to eliminate the wastes and non-value-added times.

Table 1. The assembly operation of the railcar bogie.

Pre assembly 1	
Operation	Time (min)
Welding of bogie frame	1545
Welding of components such as shoes, hangers and brake levers	1037
Assembly of the brake cylinders	1343
Assembly of the centre rubbers	1147
Assembly of the links, brake hangers and shoes	1121
Assembly of the brake pipe	1034
Other welding and fitting operations	1300
Finishing Operation	
Honing or buffing	1023
Painting	1142
Other finishing operations	616
Pre assembly 2	
Assembly of the brake liners	1622
Assembly of the centre frame rubbers	2886
Assembly of the traction motor/wheel to the frame	1433
Assembly of the axle blocks and springs	1543
Assembly of the axle block brackets	1443
Assembly of the brake blocks	1765
Assembly of the traction motor cable clamp	2470
Assembly of the sand pipes and brackets	3874
Assembly of the motor nose rubbers	2754
Assembly of the wicks	2765
Assembly of the snubbers	2087
Assembly of the centre frame	3082
Other assembly or fitting operations	2008
Pre-Assembly 3	
Fitting of other sub components	1000
Loading the assembled bogie to railcar wagon	550
Total	42590

The present PCE of the assembly line is expressed as Eq. (3).

$$\text{Present Lead Time} = \text{Value Added Time} + \text{Non-Value-Added time} \quad (3)$$

$$\text{Process Cycle Efficiency} = \frac{ValueAddedTime}{LeadTime} \times 100\% \quad (4)$$

From the data presented in Table 2, the estimated average PCE is 19.9 % which relatively falls below the minimum benchmark of 25 % (Ying, 2011). The present manufacturing lead time was also observed to be high. This has implication of high inventory in the system as well as the low productivity and efficiency of the overall assembly process, hence, the need for the implementation of the LSS for process improvement.

3.6. Measurement phase (measure)

At this phase, primary data were collected which provide the necessary information regarding the lead time and process cycle time for the major activities such as design, parts procurement, jig development, assembly of the underframe, bogie frame and component assembly, pre assembly, overall assembly, finishing and inspection operations. The descriptive statistical analysis of the lead times were carried out in order to estimate the magnitude of variations and deviations from the mean lead time. In addition, interviews were conducted with some personnel

Table 2. The value added and non-value-added time of the assembly operation.

S/N	Activities	No of operators	No of robot	Value added time (min)	Non value added time (min)	Total lead time (min)	Up time (min)	Down time (min)	Total cycle time (min)	Process cycle efficiency (%)
A	Contract, design, materials and parts procurement	2	-	7776.00	31104.00	38880	17280	4320	21600	20.00
B	Jig development	4	1	10724.40	43275.60	54000	1800	1200	30000	19.86
C	Parts manufacturing	4	1	10125.00	34875.00	45000	16250	8750	25000	22.50
D	Assembly of the underframe	4	1	8514.00	27486.00	36000	12984	7016	20000	23.65
E	Bogie frame and components assembly	2	1	6521.25	34518.74	41040	15960	6840	22800	15.89
F	Pre assembly	5	2	20841.40	100118.59	120960	63936	22464	86400	17.23
G	Overall assembly	5	2	40352.25	141087.74	181440	96768	24192	120960	22.24
H	Finishing operation	4	1	13652.10	49347.90	63000	27169	12206	39375	21.67
I	Inspection, testing, delivery and commissioning	1	2	7322.40	35877.60	43200	19200	4800	24000	16.95
Total		31	11	125828.8	497691.17	623520	271347	91788	390135	

and based on this, further information in respect of the value added and non-value added times as well as the equipment up and down time were obtained (Table 2). In addition, the Pareto chart was used to compare the PCE for the various assembly operations with the benchmark set for 85%. This is necessary to quantify the percent improvement required via the use of the continuous improvement process.

The analysis phase was performed with the use of Pareto chart. The Pareto chart compares the process PCE for various assembly operations for the bogie in relation to the benchmark set at maximum of 85% and minimum of 25% (Ying, 2011). This gives an indication of the percent improvement in the efficiency of the process cycle which will bring about significant improvement in the overall assembly operation for the railcar bogie. Figure 3 shows that improvement ranging between 70-75% in the PCE for the assembly operations is required before the process could meet up with the PCE benchmark (between 25-85%) for each of the identified operations as the PCE for the operations falls below the minimum 25%.

3.7. Analysis phase (analyse)

At this phase the assembly process is troubleshot to uncover the root cause of low process cycle efficiency and variations in the lead time. This involves collaboration, discussion and brainstorming sessions between the study team and the personnel as well as the managers. The identified possible causes of the low PCE and variations in the lead time are represented using a fish bone diagram. The analysis of the possible root causes of the problems and their effects are necessary for design improvement and subsequent control (Michel 1985; Roriz et al., 2017). From the brainstorming sessions engaged with the production managers and the personnel, the five why's iterative interrogative tool was employed to explore the underlying root and cause effect which underlie the identified challenges. The use of the five why's is to enable the determination of the root cause of organisation's challenges that are possibly responsible for the PCE falling below the benchmark. Questions were asked on why the problem occurred to identify its root cause. The identified challenges and the possible root causes were documented. From the analysis and brainstorming session carried out, it could be inferred that the behaviour of some of the operators may be a contributing factor to the challenges. Other causes were grouped into five main categories, namely: work organisation, machine, method, materials and man and this is depicted using a fish bone diagram as presented in Figure 4. It was observed that the work layout could increase the non-value added time and the total

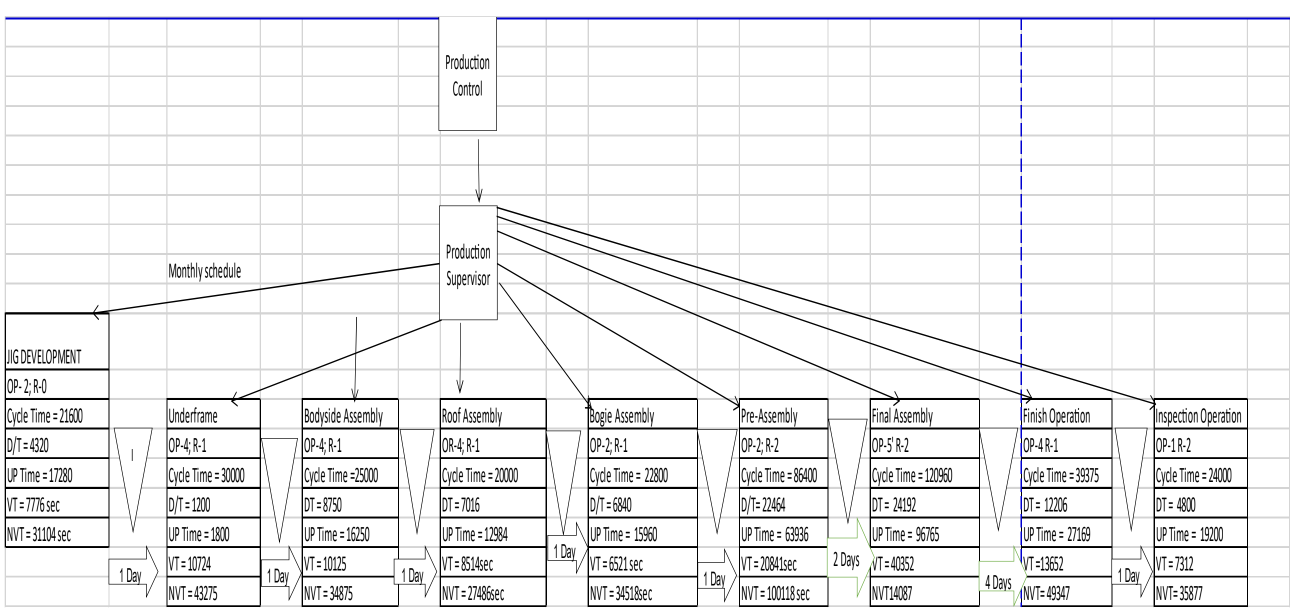

Figure 2. Present value stream of the assembly operation.

manufacturing lead time of the assembly process. This is because the arrangement of some of the equipment used are not sequential to permit continuous flow of the assembly operations. Furthermore, the components handling and transportation involving disproportional handling or movement can trigger unexpected damages and deterioration of product's quality. The causes could be linked to poor plant layout, long manufacturing lead times and inefficient process flow. One of the ways suggested to mitigate this challenge is to design the plant layout such that all the necessary machines required for the assembly operations are arranged sequential. This will ease the flow of component and ensure that the subsystems are delivered to the next stage of assembly operation without any interruption. Also cases of inventory imbalance were cited due to interruption of the supply chain. The concept of Lean manufacturing and the Just-in-time approach were introduced to enhance effective coordination of the supply chain in order to reduce complexities, non value added time while promoting flexibility, adequate inventory and less product defect (Szauter et al., 2015; Ducruet and Lugo, 2013). The concept of modularity was also introduced which involves the division of the various stages of assembly into different independent sub assembly was also suggested (Péter, 2012; Kopeček and Pinte, 2014). This is to promote flexibility, cost efficiency and simplification of the assembly process. The low level of technology and process automation were also part of the contributing factors to the reduction in the PCE and increase in the manufacturing lead time. This was evidenced in the number of robots which were 11 at the initial stage (before the implementation of the LSS). The number of robots were increased to 28 following the implementation of the LSS. Also lack of real time process monitoring and control was also observed which makes it difficult to detect error resulting from the deviation from the ideal process and adjust to cancel the effect of such error. The use of highly automated system and the development of human capacities in this regard will promote process efficiency during the assembly operations.

3.8. Improvement phase (improve)

The improvement phase was carried out using the Kaizen approach. The Kaizen approach is a systematic approach to ensure that the movement of materials and parts during the assembly process is achieved in an orderly, gradual and continuous manner. This is to promote significant improvement in inventory and reduction in the number of defective parts during assembly operation. This phase is aimed at balancing the assembly schedules in order to effectively utilize resources and produce the right product quantity (Improta et al., 2020).

3.8.1. Implementation of the lean tools in the assembly line

Figure 5 presents the improved VSM of assembly line with some significant improvement points.

To proffer solution to the major problem of high inventory and low PCE, linked to high setup time, the implementation of Single Minutes Exchange of Die (SMED) and 5S techniques were proposed and implemented.

3.8.1.1. SMED implementation. This method was proposed and implemented following the preliminary assessment of the assembly process and setup time with the aid of work measurement and time study techniques. The aim of this approach is to assess and group all the production, assembly and machines setup into value adding and non-value adding activities. The non-value adding activities comprising of waste generated in terms of time and resources, therefore, must be eliminated. Furthermore, the value adding activities were grouped into internal activities (activities involving machine set-up carried out when the production is stopped) and external activities (activities carried out before the machine is shut down). The aim is to convert all the internal activities to external. This is to reduce the frequency of setup times and in the process, waste generated are eliminated. Other improvement approach necessary to increase PCE and reduce the manufacturing lead time in the assembly process include the training of the operators working with the machines on effective management of the assembled parts. Work standardization was also proposed for implementation. Following the implementation of total productive maintenance approach, the overhauling of the machines for maintenance is not limited to the maintenance department alone. The operators of these machines were trained on the principles of corrective and preventive maintenance. This is necessary to reduce the equipment down time.

3.8.1.2. 5S technique. Finally, the 5S technique was also employed, to effectively eliminate the errors capable of causing frequent down time. This is attributed to machine break down and non-available of the operators in the production floor (Antoniolli et al., 2017). The 5S acronym stand for the following:

i. Sort: Inspect and eliminate all the parts, tools and instruction that are not needed.
ii. Set in order: This entails the arrangement of tools and machine parts for easy visibility of the ones needed.
iii. Shine: This is to make the entire workplace clean and void of any dangerous or hazardous materials.

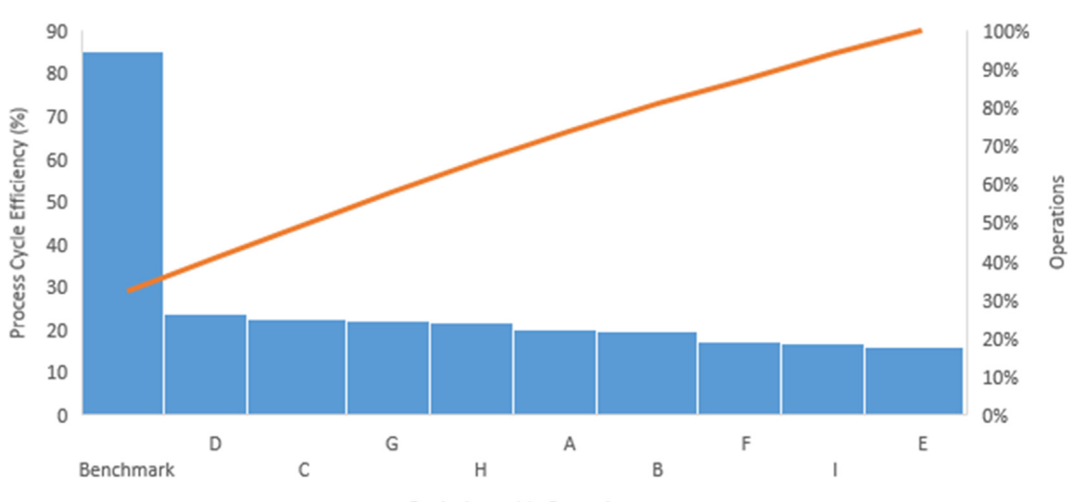

Figure 3. The Pareto analysis of the present PCE for the assembly operations.

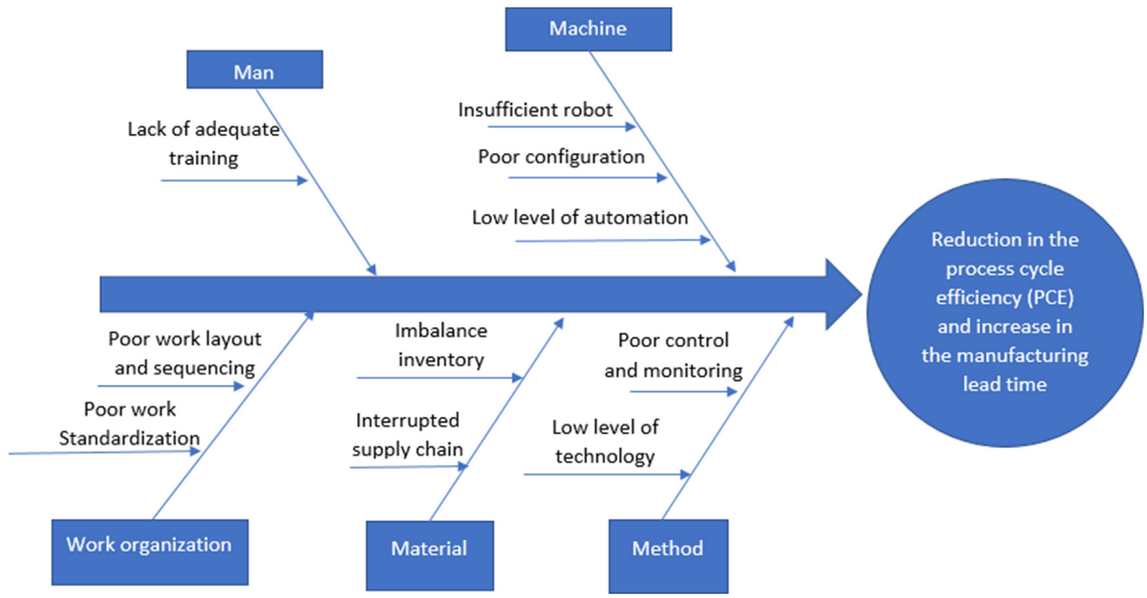

Figure 4. The fish bone diagram for the cause effect.

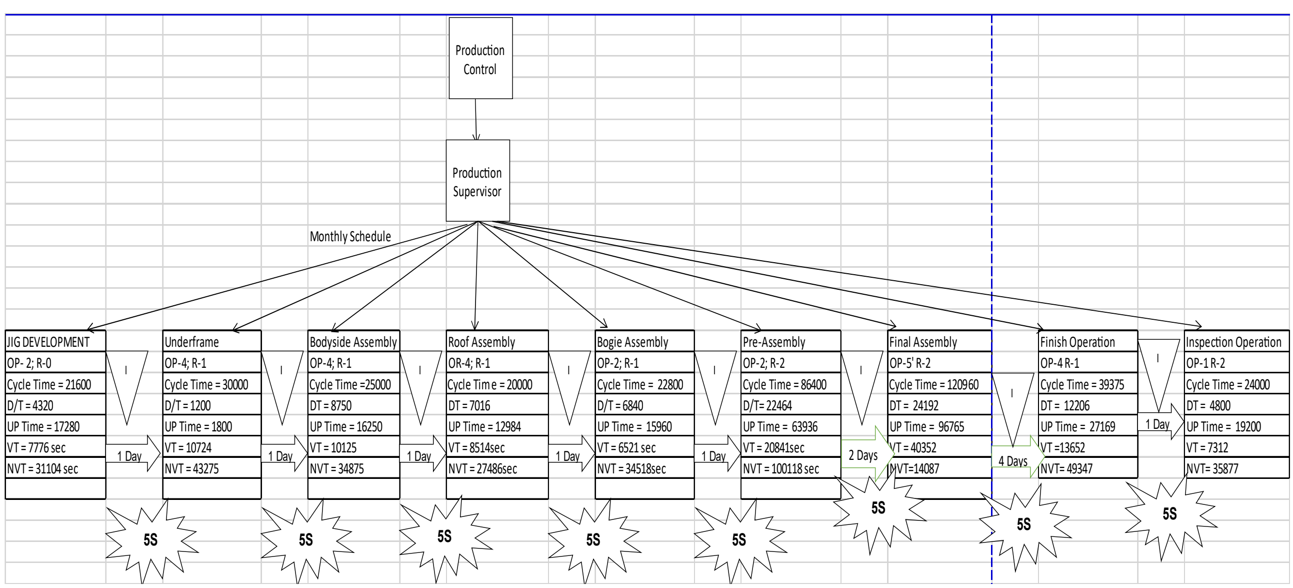

Figure 5. Improved VSM of the assembly line with improvement point.

iv. Standardize: This is to initiate a standard or general work procedures for the various kinds of activities which characterise the assembly process.
v. Sustain: This is to achieve an optimum way of maintaining and reviewing the established standard.

3.8.2. Improved VSM of the assembly line

The future VSM of the assembly line, after the implementation of some Lean appropriate tools reflected in the improvements of the value added time and reduction in non-value-added time. This is presented in Table 3.

From Table 3, there is an increase in the value added time from 125828.8 min to 309600 min which accounts for approximately 59.3% increase in the value added time (Figure 6). In addition, there was significant decrease in non-value-added time from 497691.17 min to approximately 139680 min which accounts for about 71.9% reduction in the non-value added time (Figure 7). The non-added value time is the non-productive time during the assembly operation. A decrease in the non-added value time implies an increase in the productive time and vice versa. The total number of human operators has been reduced to 15 (50 %) and now replaced by robots. This will reduce wastages and part defects, with increase in assembly speed, precision and accuracy as well and reduction in the assembly cycle time. This is because human operators are prone to drudgery and assembly error with an increased likelihood for defects or wastages and non-value added time due to fatigue. The total number of robots used on the assembly line has increased to 28. Figure 8 presents the future value stream of the assembly operations.

3.8.3. Future process cycle efficiency of the assembly line

The lead time is the time interval between the period of ordering and delivery of the component, subassembly or the final product assembly. The total initial lead time was 623519.97 min but upon the application of the LSS there was significant reduction in the value of the total lead time to 449280 (Figure 9). This accounts for 27.9% reduction in the lead time.

The lower the lead time the more productive and efficient the process and vice versa.

This lends credence to the fact that there was significant improvement in the assembly process upon the application of the LSS tool. It is estimated that the improved production cycle efficiency (PCE) is 66.7 % as opposed to the initial value of 19.9%. A PCE value of 66.7 % is above minimum benchmark of 25 % (Ying, 2011), which accounts for approximately 46.8% % improvement in the efficiency of the assembly process cycle. This accounts for 27.94% reduction in the lead time (Figure 10).

The increase in the PCE was achieved through the implementation of Kaizen (continuous improvement) approach for the various activities which characterise the assembly process. Th Kaizen approach is a systematic approach aimed at improving the efficiency and quality through gradual process (Albliwi et al., 2015; Costa et al., 2017a,b; Das and Patnaik, 2015). The implementation of Kaizen minimised unnecessary inventory and production lead time. Furthermore, periodic training and re-training of the operators for skills acquisition on the jobs was achieved. The operators were also to acquainted with the importance of team work. The work standardization Lean tool was also implemented to improve the PCE in the assembly line. It was employed to organise the production processes such that the required tasks are implemented effectively through accurate line balancing, minimization of unnecessary work in process and reduction in non-value-added activities (Fled, 2000; Ahmed et al., 2018).

3.8.4. Analysis on process cycle efficiency (PCE)

The results obtained indicate that the PCE before implementation of LSS (19.9%) increased to 66.7% after the LSS implementation. This can be attributed to the elimination of many non-value-added activities during the assembly processes. The elimination of the excessive non-value-added time reduced the production lead time and invariably impacted the PCE. The initial challenge of low PCE can be attributed to inefficient process method and work organization. It was observed that operators handling the assembly process employed inefficient methods due to lack of experience on the job. Figure 11 shows the Pareto analysis of the improved PCE for the assembly operations. Comparing Figure 11 with Figure 3, it is clear that there is significant improvement in the PCE for the assembly operations as activity D (assembly of the underframe) had already meet up with the required PCE benchmark set at 85% while other activities still needs to be improved upon requiring improvement in the PCE between 5-45% to meet up with the benchmark (85%) although the minimum benchmark is already exceeded.

3.8.5. Validation of the improvement obtained

Table 4 presents the descriptive analysis of the present and improved lead time for the assembly operations highlighted in Table 3. From Table 4, comparing the present and improved lead times, it is clear that there are significant reduction in the magnitude of the standard error, standard deviation and variance. This further lends credence to the fact that significant $0.006 < 0.05$ process improvement had taken place as a result of the application of the continuous improvement tools. Further reduction in the variations and deviation from the mean lead time can be achieved with the continuous implementation of the continuous improvement tools. Furthermore the Kolmogorov-Smirnov (K–S) non-parametric test was used to test whether or not the present and improved lead time test samples falls within the same population and to validate the process improvement achieved in this study [42]. At 95% confidence level the Asymp. Sig (2-tailed) otherwise known as the p-value was statistically significant. This implies that the present lead time falls within the population where the data was taken from. For the improved lead time, the p-value was statistically insignificant $0.053 > 0.05$. This implies that there is a significant difference between the values obtained for the improved lead time and the initial population of the lead time. The significant difference is attributed to reduction to the magnitude of the lead time following the application of the continuous improvement tool. Hence, based on the statistical analysis of the K–S test carried out, it can be established that there is significant reduction in the lead time and improvement in the assembly process.

3.9. Control phase

The control phase ensures that the scope of the long-term objectives are not compromised by measuring the system performance and comparing it with the benchmark. This stage witnessed the implementation of the plans for monitoring the system's performance and taking corrective action in situations where deviations of deviations from the idea are detected. This phase is necessary for process improvement and future process performance**.** There is a need for the improvement achieved to be sustained. This can be achieved by implementing control measures such as the Standard Operating Plan (SOP) where all necessary especially the assembly of the underframe, bogie frame and components assembly/sub assembly. The periodic documentation and review of the assembly process by the compliance team was also ensured. Training and re-training of staff on the improvement tools used like 5S and SMED should be a continuous exercise. Figures 12 and 13 present the average and the standard deviation control chart for the activities which characterize the railcar bogie assembly.

The essence of this charts is to observe and keep the variations in the total lead time within the permissible limit.

Figure 14 presents the visual representation of the frequency of the data for the improved process using a histogram. From the plot, the sigma level was obtained as 3.95. The sigma level is an indicator, which provide an insight into the level of the process improvement achieved via the application of LSS tool. The sigma level of 3.95 obtained for the improved process implies that significant improvement had taken place in the

Table 3. Future value added and non-value-added time of the assembly line.

S/N	Activities	No of operators	No of robot	Value added time (min)	Non value added time (min)	Total lead time (min)	Process cycle efficiency (%)
A.	Contract, design, materials and parts procurement	1	1	8640	17280	25920	33.333
B.	Jig development	2	3	27360	15840	43200	63.333
C.	Parts manufacturing	2	3	28800	7200	36000	80.000
D.	Assembly of the underframe	2	3	24480	4320	28800	85.000
E.	Bogie frame and components assembly	0	3	14400	12960	27360	52.631
F.	Pre assembly	2	5	57600	28800	86400	66.666
G.	Overall assembly	2	5	93600	36000	129600	72.222
H.	Finishing operation	2	3	40320	10080	50400	80.000
I.	Inspection, testing, delivery and commissioning	2	2	14400	7200	21600	66.666
	Total	15	28	309600	139680	449280	

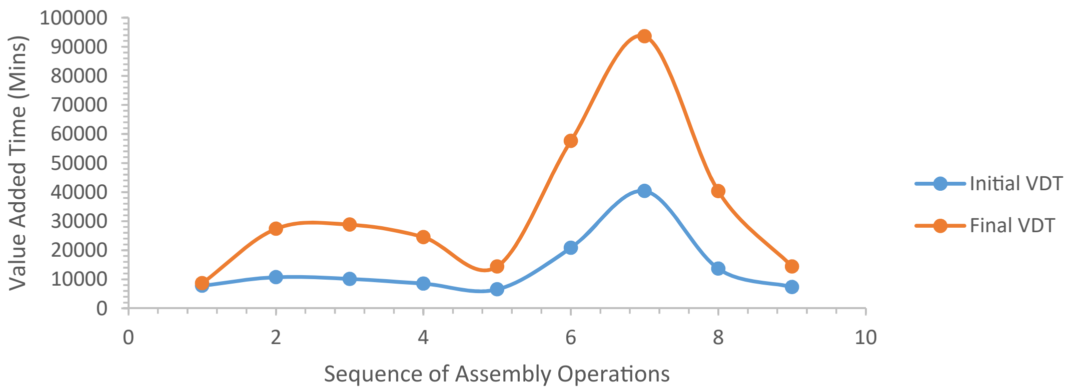

Figure 6. The initial and final VDT.

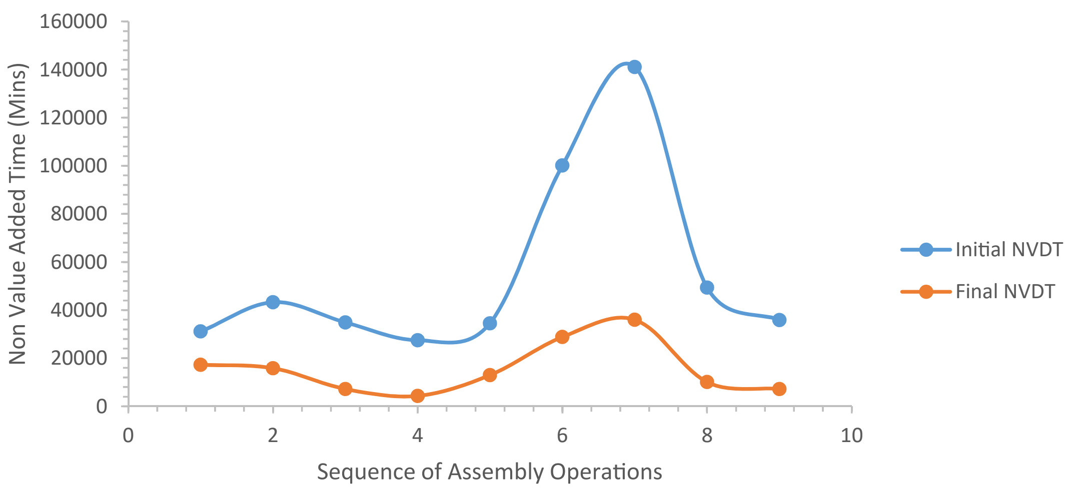

Figure 7. The initial and final NVDT.

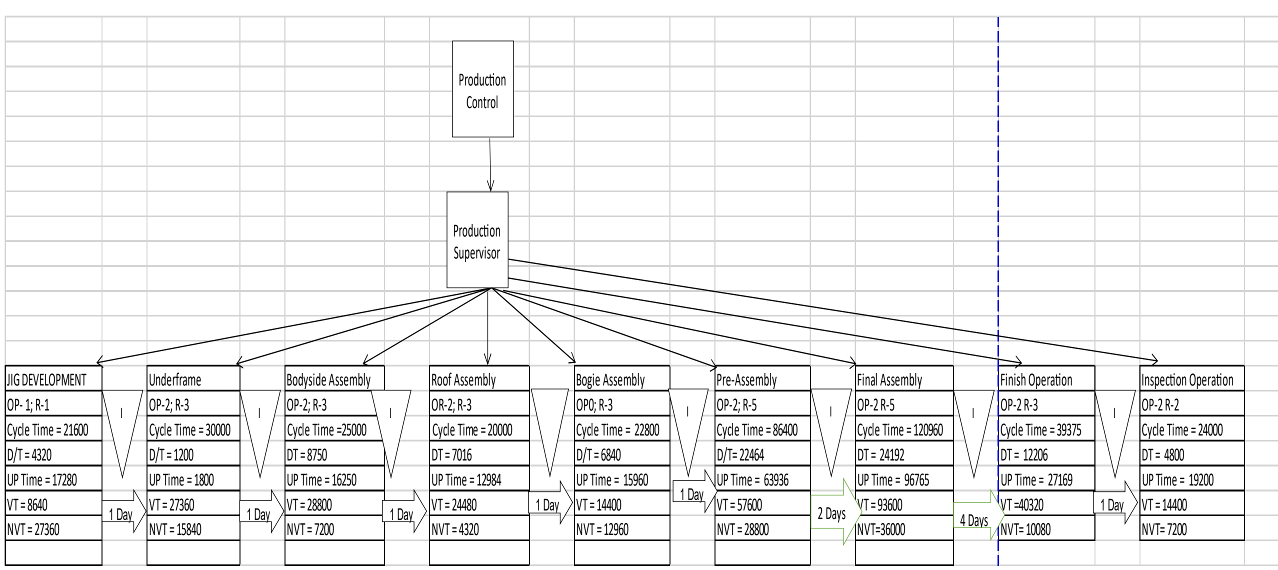

Figure 8. Future value stream of the assembly operations.

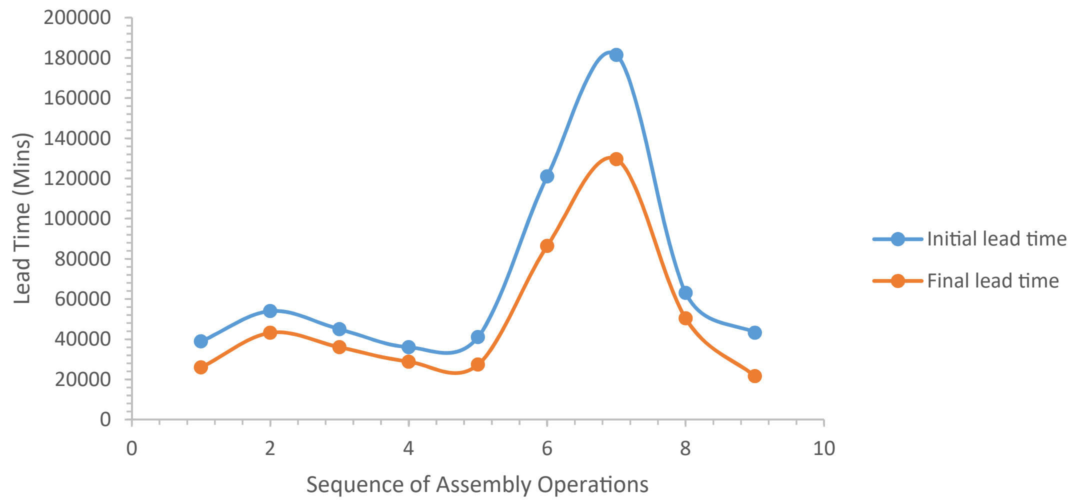

Figure 9. The initial and final lead time.

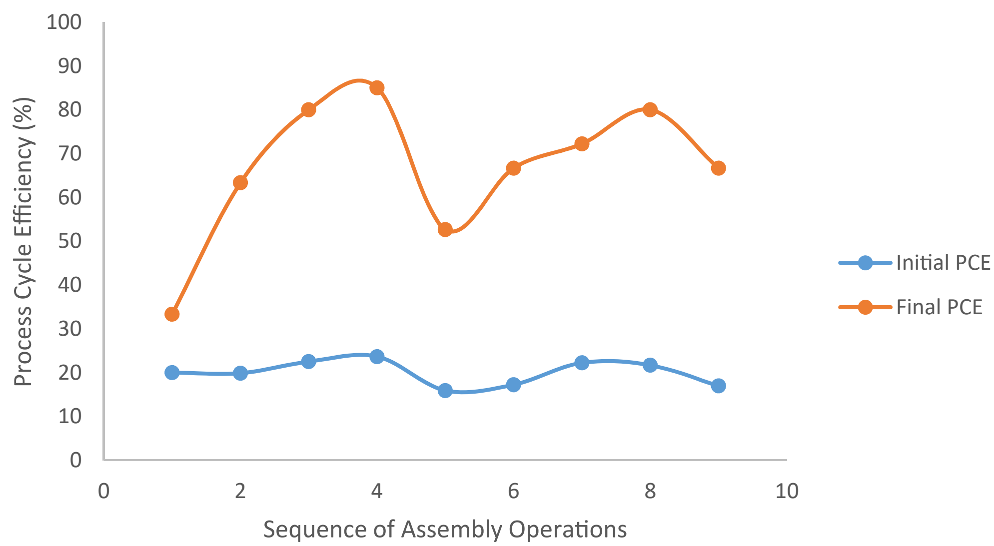

Figure 10. The initial and final process cycle efficiency.

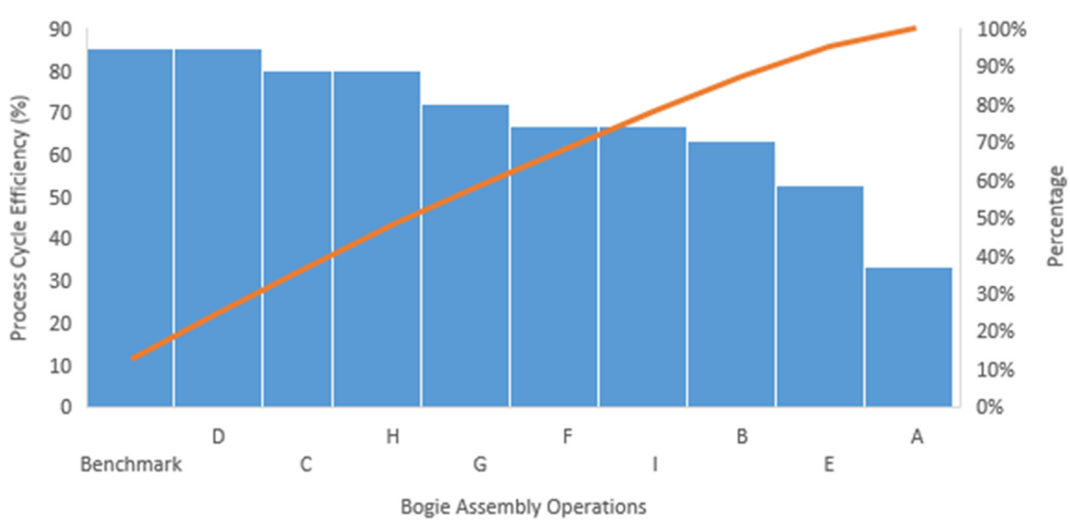

Figure 11. The Pareto analysis of the improved PCE for the assembly operations.

Table 4. The statistical analysis of the lead time.

Lead time	Mean	Standard error	Standard deviation	Variance	K–S statistics	P-value (2-tailed)
Present lead time	6.93×10^4	1.65×10^4	4.95×10^4	2.45×10^9	0.328	0.272
Improved lead time	4.99×10^4	1.19×10^4	3.58×10^4	1.28×10^4	0.006	0.053

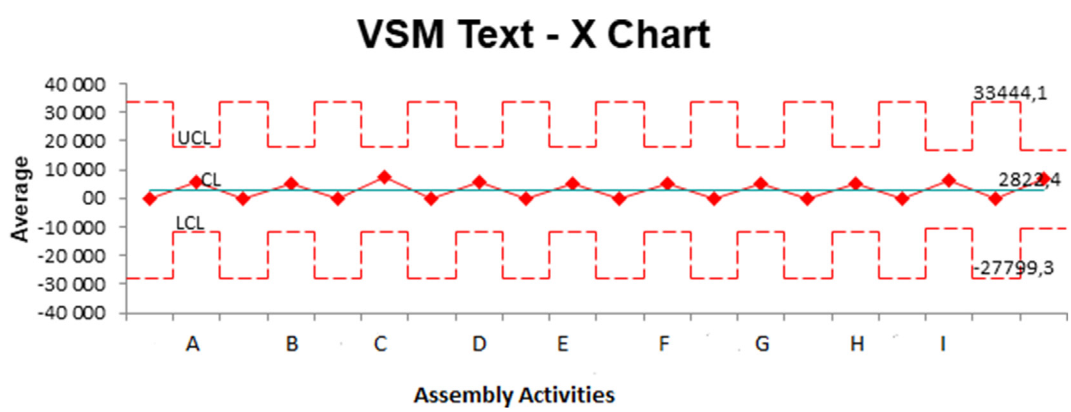

Figure 12. The average control chart for the lead time for the assembly operations.

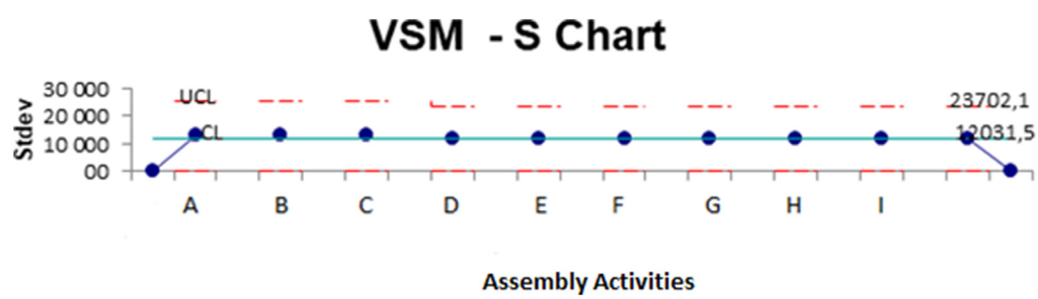

Figure 13. The standard deviation control chart for the lead-time for the assembly operations.

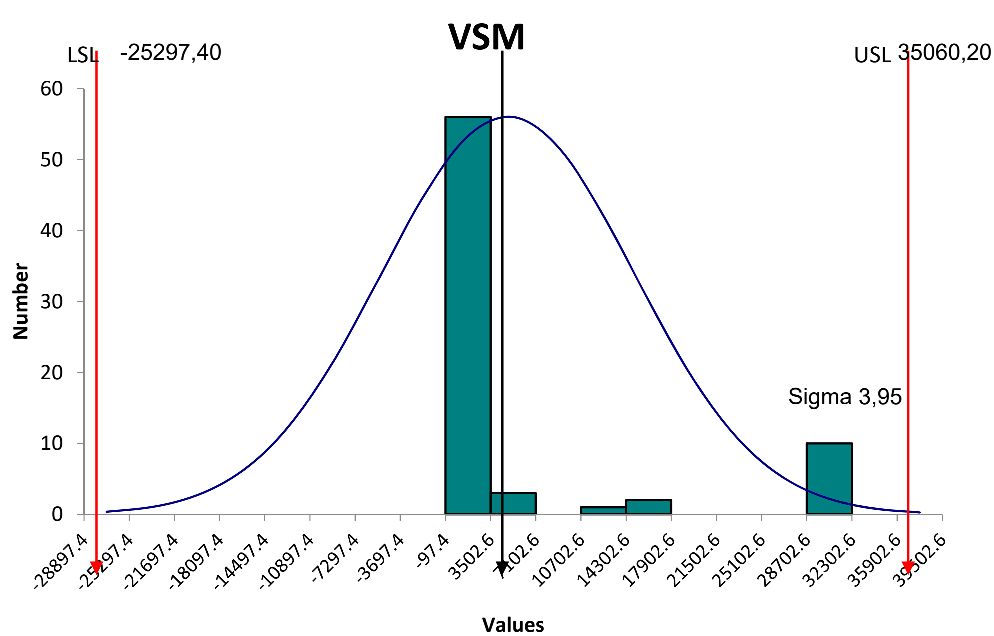

Figure 14. Histogram showing data distribution and Sigma level.

process A Sigma level that is less than three is usually not desirable (QiMacros User guide, 2020).

4. Lesson learnt and limitation of study

This study contributes to the body of knowledge in the field of LSS to improve assembly process efficiency in a manufacturing industry using Lean Six Sigma DMAIC approach. The study has demonstrated that some challenges in the industry can be solved through effective academia-industry collaboration. Existing studies encourage the collaboration of this sort for LSS implementation (Sunder and Mahalingam, 2018; Sunder and Antony, 2018) for building academic-industry synergy. The study highlights the successful implemntation of LSS for process improvement during railcar bogie assembly. The study indicated that the implementation of LSS for waste elimination and process improvement is a continuous improvement process approach that is achievable ovr a period of time rather than one-off improvement (Schroeder et al., 2008; Kwak and Anbari, 2006; McAdam and Lafferty, 2004; Coronado and Antony, 2002). In addition, the implemntation of the LSS make effective changes in the organisation productive as part of the continuous improvement process (Trader-Leigh, 2002; Huy and Mintzberg, 2003).

The limitations of this study are as follow:

i. This implementation of LSS with focus on assembly operation in the railcar manufacturing sector was successfully demonstrated. However, the study is limited to a single organisational case study which is insufficient to draw a general conclusion.
ii. Due to the nature of data available, some Lean based simulation software were not considered for validation.
iii. This work is limited to the assembly operations of the railcar bogie in a railcar industry. The consideration of a single unit in the production department is to reduce the complexity of the continuous improvement process. The use of multi-criteria decision model approach demonstrated in the work of Daniyan et al. (2020a) is also recommended for the selection of the most appropriate method of assembly in order to improve the overall process efficiency and performance of the assembled system while the consideration of predictive based approaches will enhance equipment reliability and availability (2020b).

5. Conclusion and implication

The aim of this study was to demonstrate the use of the Lean Six Sigma (LSS) for improving the efficiency of the assembly operation of rail car bogie in terms of lead-time and process cycle efficiency. This study has presented some theoretical and empirical findings by with the development of a successful LSS frame work for the manufacturing industries for waste elimination and process improvement. The following conclusions were drawn from this study:

i. The problem of poor process cycle efficiency or productivity was solved as evidenced in the PCE which increased from 19.9% to 66.7 % by implementation of Kaizen and work standardization. This accounts for approximately 46.8% improvement in the efficiency of the assembly process cycle.
ii. There was significant reduction in the lead-time from 623519.97 min to 449280 which accounts for 27.9% reduction in the lead time.
iii. There was an increase in the value added time from 125828.8 min to 309600 min which accounts for approximately 59.3% increase in the value added time.
iv. There was significant decrease in non-value-added time from 497691.17 min to approximately 139680 min which accounts for about 71.9% reduction in the non-value added time.
v. The application of LSS in the presented case-study is an indication that it can be successfully employed to solve other challenges relating to process metrics such as quality, and total turnaround time etc. The findings from this work establishes the suitability of the LSS for achieving process improvement and operational excellence in an organisation. The integration of Lean and Six Sigma tools (Lean Six Sigma) can assist the manufacturing industries to achieve zero defects, optimum production performance, improved product's quality and fast delivery at optimum cost.

Declarations

Author contribution statement

Ilesanmi Daniyan, Adefemi Adeodu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Khumbulani Mpofu, Rendani Maladzhi, Mukondeleli Grace Kana-Kana Katumba: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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