Improvement of production process variations of bolster spring of a train bogie manufacturing industry: a six-sigma approach.

Item Type	Article
Authors	Daniyan, Ilesanmi;Adeodu, Adefemi;Mpofu, Khumbulani;Maladzh, Rendani;Kanakana-Katumba, Grace Mukondeleli
DOI	https://doi.org/10.1080/23311916.2022.2154004
Publisher	Taylor and Francis Group
Rights	Attribution-NonCommercial-ShareAlike 4.0 International
Download date	2025-05-21 07:35:25
Item License	http://creativecommons.org/licenses/by-nc-sa/4.0/
Link to Item	https://hdl.handle.net/20.500.14519/744

Cogent Engineering

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaen20

Improvement of production process variations of bolster spring of a train bogie manufacturing industry: a six-sigma approach

Ilesanmi Daniyan, Adefemi Adeodu, Khumbulani Mpofu, Rendani Maladzhi & Grace Mukondeleli Kanakana-Katumba

To cite this article: Ilesanmi Daniyan, Adefemi Adeodu, Khumbulani Mpofu, Rendani Maladzhi & Grace Mukondeleli Kanakana-Katumba (2023) Improvement of production process variations of bolster spring of a train bogie manufacturing industry: a six-sigma approach, Cogent Engineering, 10:1, 2154004, DOI: 10.1080/23311916.2022.2154004

To link to this article: https://doi.org/10.1080/23311916.2022.2154004

Daniyan et al., *Cogent Engineering* (2023), 10: 2154004
https://doi.org/10.1080/23311916.2022.2154004

cogent engineering

PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Improvement of production process variations of bolster spring of a train bogie manufacturing industry: a six-sigma approach

Ilesanmi Daniyan[1]*, Adefemi Adeodu[2], Khumbulani Mpofu[1], Rendani Maladzhi[2] and Grace Mukondeleli Kanakana-Katumba[2]

Received: 06 July 2022
Accepted: 29 November 2022

*Corresponding author: Ilesanmi Daniyan, Department of Industrial Engineering, Tshwane University of Technology, Pretoria, South Africa
E-mail: afolabiilesanmi@yahoo.com

Reviewing editor:
Zude Zhou, Wuhan University of Technology, Wuhan, China

Additional information is available at the end of the article

Abstract: The need for improved productivity without sacrificing quality, which is in line the prime target of many manufacturing industries. The aim of this study is to investigate the causes of production variation: a case study of the rail manufacturing industry, South Africa. In this study, the six-sigma Define, Measure, Analyse, Improve and Control (DMAIC) phases were applied to enhance the process capability (long term) in the production of bolster compression springs in the main line of bogie secondary suspension system. In every phase of DMAIC method, a combination of both qualitative and quantitative techniques was utilized. First, process capability index Cpk of the current process was computed which was found less than 1. The results obtained indicated that the process capability index values were found to be 1 after the improvement phase. Hence, significant improvement was achieved in the area of reduction in process variation and product quality after taking corrective actions. From outcomes of the study, it can be concluded that process performance of a train manufacturing plant can be improved significantly by implementing six-sigma DMAIC methodology. The novelty of this study lies in the fact that the implementation of the six-sigma DMAIC phases to enhance the process capability (long term) and minimise variations in the production of bolster compression springs has not be sufficiently highlighted by the existing literature.

Subjects: Mechanical Engineering; Manufacturing Engineering; Systems & Control Engineering

Keywords: DMAIC; process capability index; process variation; six-sigma

1. Introduction

The dynamic and the increasing competitive nature of the market has continued to intensify pressure on the manufacturing industries to adopt sustainable manufacturing practices. Sustainable manufacturing practices ensure a balanced production rate with healthy social economic and environmental performances. The duo of optimum productivity and good product quality are central to the survival of any manufacturing industry in this era of emerging technologies, globalization, changing customers' requirements and increasing market competitiveness (Rosa et al., 2017). An optimum productivity is one which meets the target production throughput and satisfies the need of customers in a time and cost effective manner without any compromise to the quality and environment. The quest for improved productivity without sacrificing quality has continued to be the prime target of many manufacturing industries. To ensure an optimum production, the manufacturing industries need to be more responsive to the market and customers' trends, while ensuring the development of a value added supply chain. Many manufacturing industries have deployed several approaches to keep their production activities with a realistic forecast to avoid the challenges related to under or over production. Furthermore, for manufacturing industries to comply with the manufacturing standards, delivery deadlines and remain competitively healthy, the root cause of all the failures and wastes during the production process must be identified and mitigated (Costa et al. 2017). However, the manufacturing industries are still seeking for ways to optimize productivity, improve product's quality and manufacturing cycle time, optimize inventory, reduce lead time, and eliminate manufacturing waste. Prominent among such approach that can be used to achieve effective production performance is the Lean manufacturing approach; a systematic approach aimed at identifying and eliminating waste through continuous improvement by ensuring a consistent flow of products in line with the demand requirements (Das & Patnaik, 2015). The manufacturing resources have been categorized as: human, time, material, physical, and financial resources and the effectiveness of the production process is a function of the production method and machines employed, human personnel, supply chain, a carefully balanced inventory, amongst others. The effective balance of the manufacturing resources is critical to production sustainability and reduction in waste generation. Wastes are generated whenever the manufacturing resources are not optimally harnessed for the development of quality products and provision of value added services. This is consequential in the sense that it affect the turnover, integrity, profitability, competitiveness and sustainability of the manufacturing industries. According to Das and Patnaik (2015), manufacturing wastes can results from the following: over or under-production, waiting or tardiness, ineffective handling and transportation, wrong or poor processing, poor inventory control, and product's defect. In the case of under production, the production rate is usually lower than the benchmark thus failing to meet the customers' demand. On the other hand, over-production is marked with a high rate of production which exceeds the optimum thereby exceeding the customers' demands (quantitative production) or the development of products before orders are placed (early production). Over-production in manufacturing is termed "just-in-case" as opposed to the ideal manufacturing concept of "just-in-time" (Das & Patnaik, 2015). Under-production is vastly costly to a manufacturing industry because it can diminish the competitiveness of the industry, results in the loss of organisation's goodwill and customers' trust as well as poor turn over. Over-production can obstructs the even flow of materials and the supply chain and degrade the quality of products and the overall productivity. The causes of under-production have been traced to low level of automation and technology, ineffective production planning, unbalanced work load and schedules, ineffective supply chain, poor inventory control, natural disaster, redundancy or long process set up, poor maintenance and management culture, poor manufacturing resource control, lack of suitable framework for the implementation of continuous and process monitoring and improvement (Calvo et al., 2007). On the other hand, overproduction can be as a result of misappropriation of automation and technology, application of "just-in-case" logic, redundant inspections, poor inventory control, unreliable production forecast or ineffective production planning (Calvo et al., 2007). Waiting or tardiness is another identified challenge which contributes to waste generation capable of offsetting the balance of manufacturing resources and production rates. The challenge is peculiar to the traditional mass production due to misappropriation of manufacturing resources, ineffective application of automation, upstream challenges, unleveled scheduling, and poor communication. Furthermore, material handling and transportation involving disproportional movements and handling can cause damages and deterioration of product's quality. The causes could include poor plant layout, poor process flow, large sizes of production batches, long lead times, and large storage areas. One of the ways to mitigate this challenge is to design the plant layout such that all the necessary machines required for the manufacturing of a product are arranged sequential. This will ease the flow of material movement and ensure that materials should be delivered to its point of use, only when needed. Another contributing factor to waste generation is wrong or poor processing which could breed production error as a result of negligence or taking unnecessary steps during production which may increase the manufacturing lead time and the overall production cost. Sometimes, when the production plan is not clearly defined with vague demand or customer requirements, manufacturers may add unnecessary processing steps, which could affect production schedules and generate wastes. Wrong or poor processing can also be as a result of product variation with inflexible manufacturing systems to accommodate such changes or as a result of poor communication during the production cycle. Poor inventory control has also been identified as another major cause of waste generation. A carefully balanced inventory is the one which eliminates or reduces raw materials, which does not add value to the product development phases. Insufficient inventory could lead to underproduction and increase the time of man and machines while excess inventory can use up the production floor space and results in longer lead times, obsolescence of stocked up goods, product defect, transportation and storage related challenges. Poor inventory control could stem from the need to compensate for inefficiencies and unexpected production challenges, unbalanced scheduling, and poor market forecast. In addition, product's defect can be as a result of production defects or service errors. Product defect could increase reverse logistics, expensive and time consuming rework thus, constituting a significant portion of total manufacturing cost. Product defects could be traced to product's birth, ineffective manufacturing or process control, poor or inconsistent quality standards as well as lack of the required expertise or inadequate training and work instructions. Other sources of waste generation are: poor man or machine efficiency, ineffective or inconsistent work methods, poor facility or cell layout, and other ergonomics related issues such as the psychology or the overall employee well-being or the overall condition of the work place and environment. The primary aim of waste reduction or elimination is to achieve lean manufacturing which improves the manufacturing process and maximizes customers' value in order to achieve manufacturing excellence through the optimum production and creation of more value with fewer resources (Albliwi et al., 2015; Costa et al., 2017; Singh & Rathi, 2018; Sanchez-Marquez et al., 2020).

Based on these requirements, the Just In Time (JIT), Kanban system, Kaizen approach, production smoothing, and Value Stream Mapping are suitable approaches for achieving lean manufacturing (waste reduction; Das & Patnaik, 2015).

The models of the Six Sigma are the DMAIC (Define, Measure, Analyze, Improve, Control) (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, & Oda, 2019; Jones et al., 2014).

The JIT is a management concept aimed at waste elimination via the production of the right component part in the right place and at the right time while the Kanban systems is an information lean manufacturing tool for controlling the logistic and supply chain which is usually employed to establish that production takes place as soon as the demand is created downstream. The Kaizen approach is a systematic approach to ensure a gradual, orderly, and continuous movement of materials and parts. The significant improvement in inventory and reduction in the number of defective parts during manufacturing using the Kaizen tools, which involve the 5S (sort, set in order, shine, standardize or systemize, and sustain). The production smoothing is another concept aimed at balancing the production schedule to effectively utilize manufacturing resources and produce the right product quantity (Antoniolli et al., 2017). The Value Stream Mapping (VSM) is a lean manufacturing tool suitable for the analysis and design of the flow of materials and information that is required to deliver high-quality products with significant waste reduction during production (Belokar et al., 2012). On the other hand, the Total Quality Management (TQM), and Six Sigma etc. are techniques suitable for improving production performance and product's quality (Chen et al., 2015).

The TQM tool is suitable for monitoring the overall production process and continuous process improvement. Some of the TQM tools are: check sheets, histogram, Pareto charts, control charts, cause-effect diagram, scatter charts, Stratification (Flow charts, fish bone diagram, run charts, etc.). These tools investigate the root causes manufacturing challenges such as production variation in order to eliminate them. They are helpful in troubleshooting problems related to quality and production variation (Roriz et al., 2017). The six sigma tool is a systematic, scientific, statistical, and smarter approach suitable for the enhancing product's quality, innovation, and improving customers' satisfaction (Gupta et al., 2018; Hekmatpanah et al., 2015; Krueger et al., 2014). The models of the Six Sigma models are the DMAIC (Define, Measure, Analyze, Improve, Control), which is usually deployed to improve an existing process, and the DMADV (Define, Measure, Analyze, Design, Verify), which is employed for the development of new products. To eliminate waste and manufacturing challenges, a proper approach is required to achieve a lean manufacturing by identifying value adding and non-value adding activities through an optimum feasible process mapping. The lean manufacturing is a set of principle embraced by industrial organizations in order to eliminate waste while the six sigma tools are aimed at improving the production performance, and product's quality in order to enhance customer's satisfaction (Madsen et al., 2017; Mwacharo, 2013). The integration of Six Sigma and lean tool (lean Six Sigma) will assist the manufacturing industries to achieve zero defects, optimum production performance, improved product's quality and fast delivery at optimum cost. A more detailed description of this integration is needed in order for organizations to succeed in exceeding future customer demands. Many works have been reported on the use of lean Six Sigma (LLS) approach for achieving the following: aligning organization's goals and strategy, better product quality, reduction in the amount of waste generated and number of reworks, process, and production performance improvement, as well as customer satisfaction. The successful implementation of the LSS approach for achieving the aforementioned have been demonstrated in various sectors such as health, manufacturing, education, banking sectors etc. (Furterer & Elshennawy, 2005; Laureani & Antony, 2010; Edgeman, 2010; Shahada & Alsyouf, 2012; Meza & Jeong, 2013; Ben Ruben et al., 2017; Bazrkar et al., 2017; Ahmed et al., 2018; Sunder & Mahalingam, 2018; Gijo et al., 2018; Adeodu et al., 2021; Srivastava et al., 2021; Sodhi et al., 2022).

The occurrence of variations in the bolster spring during manufacturing could affect the performance of the rail vehicle. Pandey and Bhattacharya (2020) stated that improperly designed bolster suspension system can affect the dynamic response of the carbody. It may trigger excitations in the vertical and lateral directions of the rail track. This is due to the fact that the damping force exhibited by the railcar to load or rail disturbances is a function of the stiffness of the bolster springs, the stiffness of the friction control spring (snubber springs) and the frictional coefficient between the surface of the wedge block and the side frame or bolster (Pandey & Bhattacharya, 2020).

The objective of this study is to employ the six-sigma Define, Measure, Analyse, Improve and Control (DMAIC) phases to enhance the process capability (long term) in the production of bolster compression springs in the main line of bogie secondary suspension system. This is geared towards providing a continuous improvement approach to solving an identified problem of variations in the diameter and free height of the bolster compression springs produced during a specific period.

Although this work considers only the six-sigma DMAIC approach, however, the findings from this work establishes the suitability of the six sigma for minimising process variation and achieving quality improvement in a manufacturing industry. The novelty of this study lies in the fact that the implementation of the six-sigma DMAIC phases to enhance the process capability (long term) and minimise variations in the production of bolster compression springs has not be sufficiently highlighted by the existing literature. It is envisaged that the findings of this work will assist manufacturing industries to minimise process variations and achieve operational excellence during manufacturing operations.

2. Methodology

In this study, the six-sigma DMAIC phases were applied to enhance the process capability (long term) in the production of bolster compression springs in the main line of bogie secondary suspension system. In every phase of DMAIC method, a combination of both qualitative and quantitative techniques was utilized. The DMAIC steps followed in the current research are as follows:

2.1. Define

The first phase of goals definition is to improve the current process. The voice of customer (VOC) method was used to achieve the most critical goals. Thus, the goals will positively impact on the defect level and increase the overall output of the process. VOC is important because customers are the major decider of the product's value and quality. The successful implementation of LSS for continuous process improvement through the understanding of customers' need and requirements. At this stage, some selected customers who are knowledgeable about the production of bolster springs were asked about their expectations (the ones currently met and the ones that are not met). This provides an opportunity for the LSS team to fully understand the opportunities for improvement. Customers were also asked about the market performance, product-line analysis, and the manufacturing lead time.

2.2. Measure

Measuring the performance attributes of the production will provide the improvement route. Therefore, measure phase is targeted to establish a good measurement system to measure the process performance. Process capability index Cpk was selected to measure the process performance. To compute the process capability index, observations of bolster compression springs variation were taken and Qi Macros embedded in Excel was used for analysis.

2.3. Analyze

In the analysis phase, the process was analyzed to identify possible ways of bridging the gaps between the present quality performance of the process and the goal defined. In addition, it was started by determining the existing performance statistics obtained with the help of six-sigma quality tools (process capability index). The further analysis of these data was done for finding root cause of the problem using Ishikawa diagram.

2.4. Improve

In improvement phase, the objective is to find an alternative way to achieve better performance at no or minimized cost. Different approaches like project management, other planning and management tools were used. Also, statistical methods were proposed for continuous improvement.

2.5. Control

The improvement gained through the previous steps need to be maintained for continuous non-defect production. Control phase was used to maintain these improvements in process. The new process/improved process was proposed for sustaining the quality control in the organization.

Figure 1 presents the activities and the period for the implementation of the LSS project. The figure is grouped into five major activities, namely: formation of LSS team, survey, implementation of LSS DMAIC approach, establishment of continuous improvement and review.

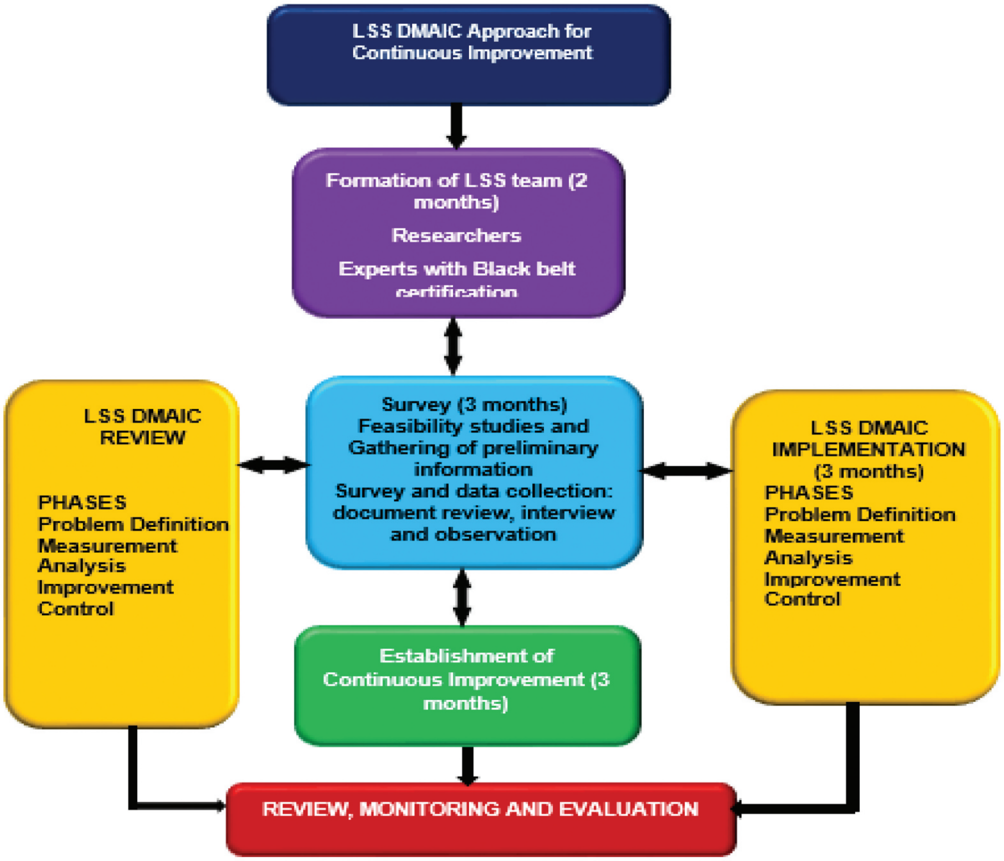
The LSS team carried out the review of some of the company's document provided and also conducted interview with some selected staff and customers who are knowledgeable about the production of bolster spring and continuous improvement processes. Furthermore, observations were made on the production shop floor. It took a total of three months for the completion of the review, interview, and observation. Thereafter, the LSS DMAIC was introduced and implemented for three months. The review of the implementation and the outcome was carried out after another three months. This takes the total time for the execution of the LSS project to 11 months.

3. Case study

3.1. Company profile

Company X formed as a black economic empowerment company, has contract with the South African government to manufacture passengers' trains for the Passenger Rail Agency of South Africa (PRASA).

Figure 1. Activities and the period for the implementation of the LSS project.



The scope of the contract includes train maintenance, technical support and the manufacture and supply of spare parts. Today, state-of-the-art X'trapolis MEGA commuter trains are rolling off the production line at Company X.

3.2. Implementation of DMAIC methodology

3.2.1. Problem definition

Train bogies are classified based on the structure of the suspension gear, which are of two types, namely: swing hanger type and the small lateral stiffness bolster springs type. The focus of this study is the production of the bolster helical compression spring. This springs are found in the secondary suspension system of the main line bogie. They are made up of chrome vanadium or chrome molybdenum steel. The study identified problem of variations in the diameter and free height of the bolster compression springs produced during a specific period. The problem was identified via Voice of Customer basis (VOC). Customers interviewed complain of wastage of materials due to the defects, which have serious negative financial, implication of the organization if not properly managed. The customers also complained about variation in the manufacturing lead-time, which is an indication of the presence of wastes due to the existence of non-value activities.

Table 1 shows the standard specification of the product while Table 2 presents the diameter and free height variation data of the produced bolster springs.

3.2.2. Measurement phase

The focus of the measurement phase is to create an overall baseline for the system to assess its performance according to the necessary improvement areas noted in the define phase. The

Table 1. Specifications of the product

Description	Specification (mm)
Main specification of Diameter	324 ± 10
Average Diameter of the Bolster Spring	330.19
Main specification Free Height	380 ± 10
Average Free height of the Bolster Spring	383.81
Acceptable free height rang under test load	301–307

Table 2. Diameter and free height variation data of the produced bolster springs

S/N	Diameter (mm)	Free height (mm)
1	331.04	387.04
2	334.22	390.22
3	333.07	387.07
4	330.32	386.32
5	323.63	389.36
6	328.29	384.92
7	330.08	386.01
8	333.88	388.98
9	330.08	388.06
10	326.40	384.20
11	328.76	375.53
12	331.02	372.95
13	329.51	385.51
14	330.63	383.63
15	329.69	370.47
16	328.01	375.60
17	333.75	389.57
18	330.07	387.06
19	331.11	381.17
20	330.24	382.46

Figure 2. Normal probability plot for diameter variation.

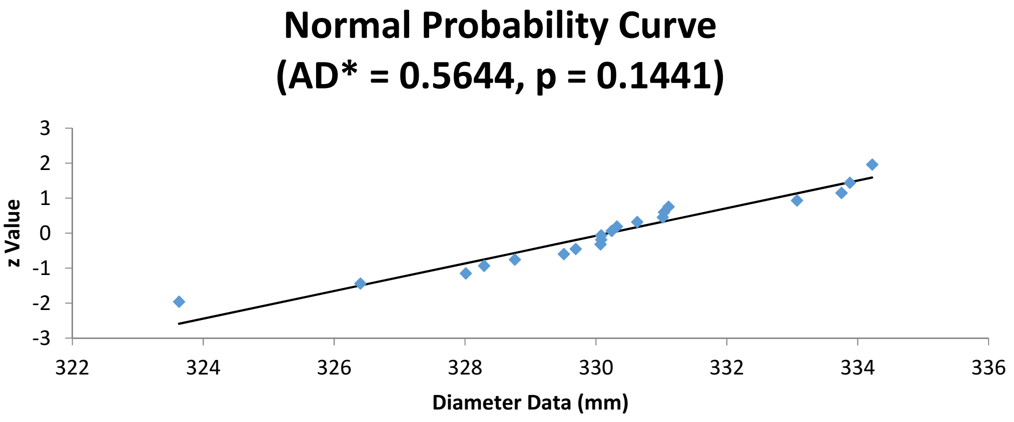
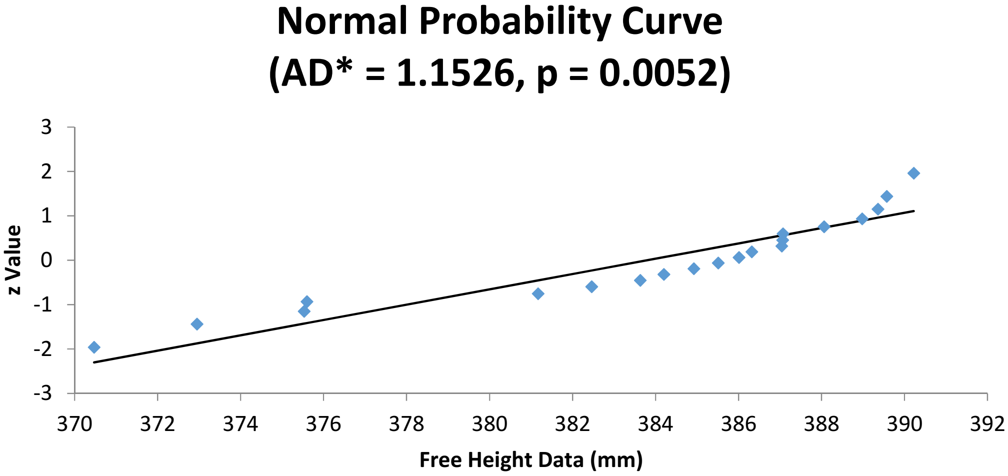


Figure 3. Normal probability plot for free height variation.



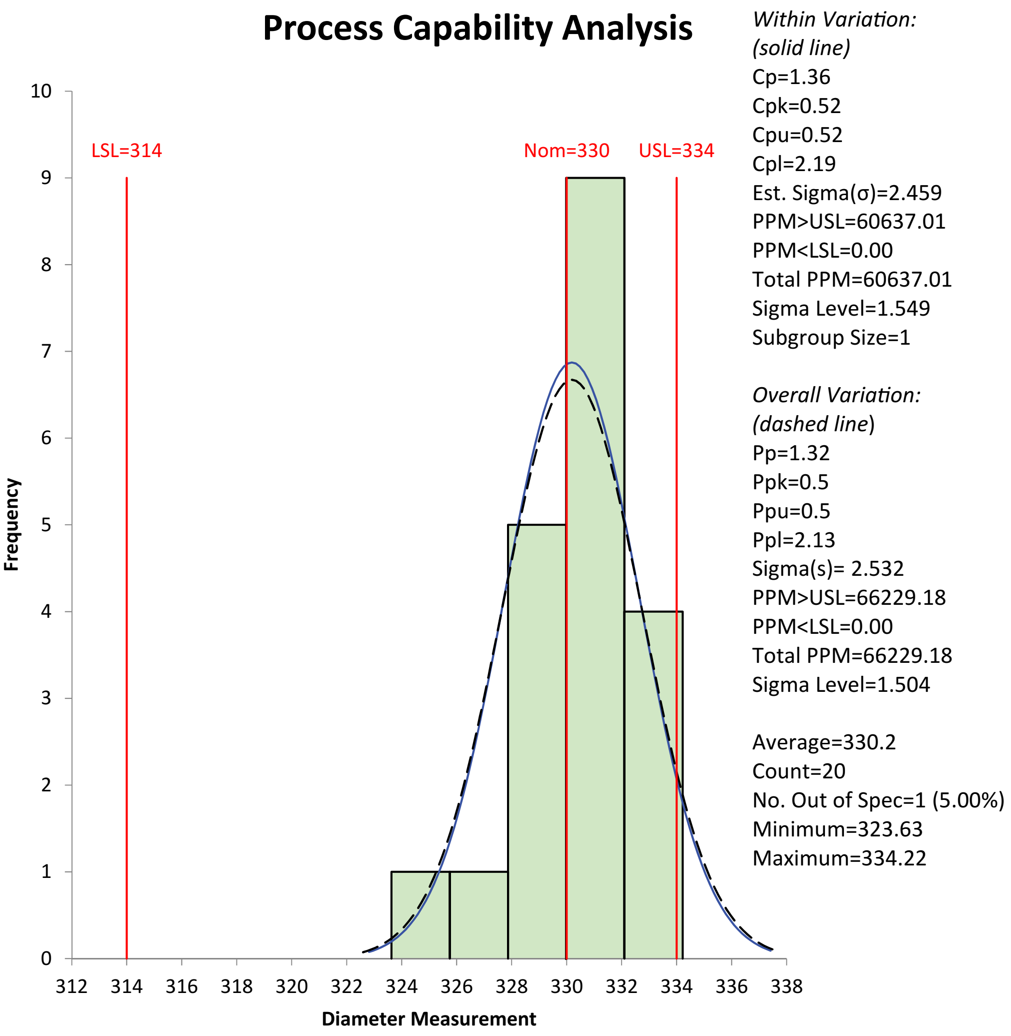
normality test for the diameter and free height data of the bolster compression spring was performed as presented in Figures 2 and 3 using normal probability curves. After passing the normality test, process capability indices Cpks were estimated to measure the present process performance using the produced diameter and free height variation data (Table 2).

Figures 4 and 5 show that the values of process capability index Cp_{ks} for the diameter and free height are 0.52 mm and 0.49 mm, respectively, before the application of the Six-Sigma DMAIC approach. Figures 4 and 5, it is clear that the Cp_{ks} for diameter variation and free height variation before improvement were less than 1; hence, the process is not capable and as such needs improvement. This implies that there are evidences of variation in the manufacturing process which can affect the overall process performance as well as the quality of the product.

3.2.3. Data analysis phase

In this phase, the data were analyzed and control charts were constructed. Figures 5 and 6a show the X-bars and mR-charts for the diameter and free height data, respectively. The combination of the X and mR charts shown in Figures 6a and 6b is known as the X-mR chart which i**s to** track process variations based on the data collected over a period of three months. Manufacturing usually employ both the pair of X-bar and R-chart to visualize continuous data. While the X-bar can assist in monitoring the changes in the magnitude of the average or the mean of the process over time, the R-chart presents the statistical range of the sample (i.e. the difference between the highest and lowest value in each sample). Both the X-bar and R-charts provide a visualisation of data assumed to be normally distributed and displays the control limits. The essence of the X-bar and R-charts is for manufacturing industries to monitor and identify any points outside the control limits as the “out-of-control processes”. This will further assist in locating the origins of the process variables and variations so that control actions can be implemented. Both the X-bar and R-charts are used as a pair to standardize the manufacturing process, visualise the areas where improvement are needed, analyse improvement by comparing improvement results in historical performance and to measure the overall process performance. This chart helps to trouble shoot the indications of any possible causes in the process that can cause product variation and measures the process performance before and after the implementation of continuous improvement.

Figure 4. Process capability index for diameter variation before the improvement phase.



From Figures 7a and 7b, show clearly that there is a datapoint, which lie outside the lower control limit. This implies that the process is statistically out of control and that there is evidence of variation within the process.

The Ishikawa diagram was used for finding the root cause of the problem, which is shown in Figure 8. The identified causes of the problem are categorized as follows:

3.2.3.1. Environment. Environmental factors like weather fluctuation may have contributed to the bolster spring variation in the sense that the rise and fall of temperature during production affected the linear expansivity of the former causing variations in the formation of the spring. Also, poor lightning of the environment impacted on the calibration of the CNC machine used for the product fabrication by the technician.

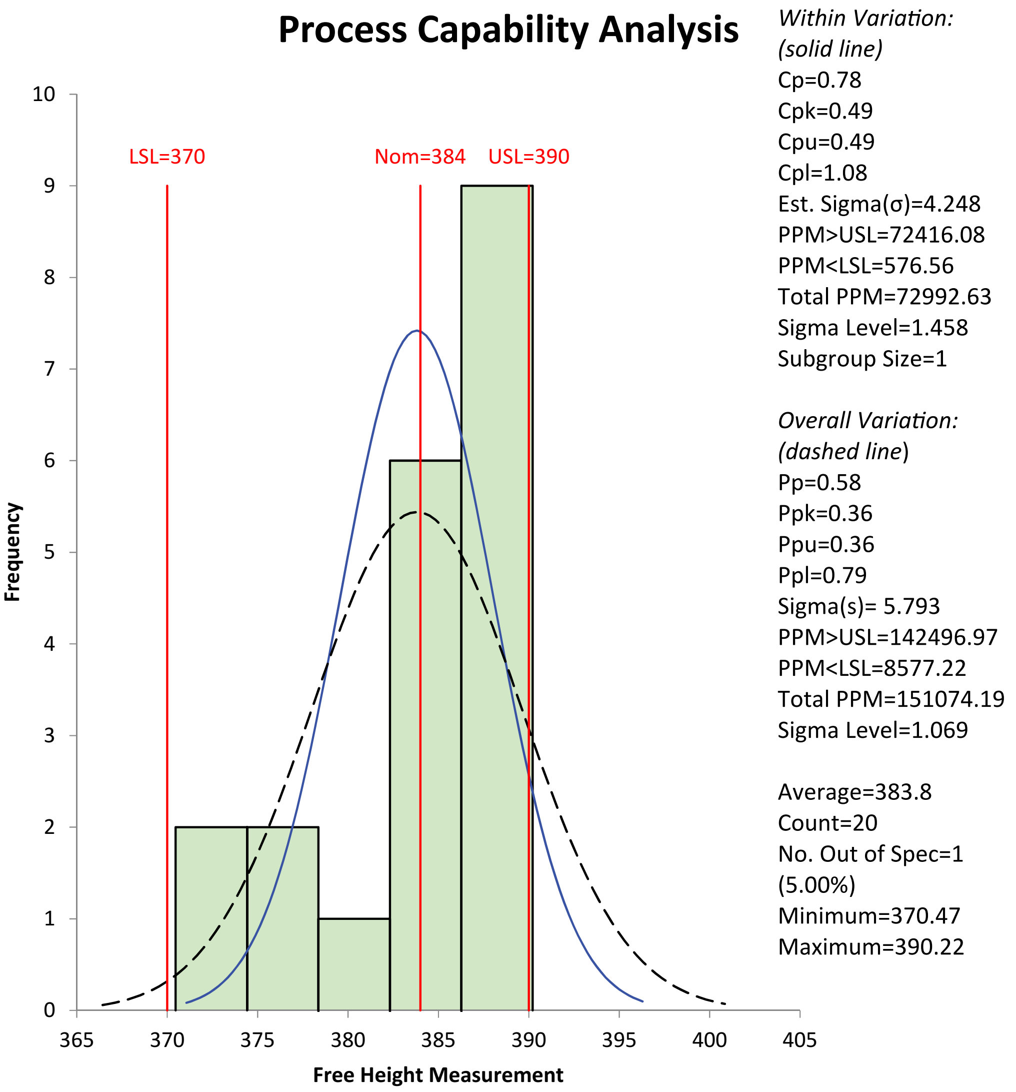


Figure 5. Process capability index for free height variation before the improvement phase.

3.2.3.2. Material. The second category of the causes of variation is the material employed for product development. Insufficient wiring, wrong materials, and bad powdered coating were some of the potential causes of variations in the production of the bolster spring.

3.2.3.3. People. The third category was people. Factors like inexperience due to inadequate training of the technician, lack of motivation, poor finishing, and human errors due to poor calibration of machine were some of the identified possible causes of variations.

3.2.3.4. Method. The fourth category is the method. Under this category, wrong feed, insufficient heat treating, faulty coiling, poor grinding were traced as the possible causes of variation in the spring.

Figure 6a. X-Chart of the diameter before the improvement phase.

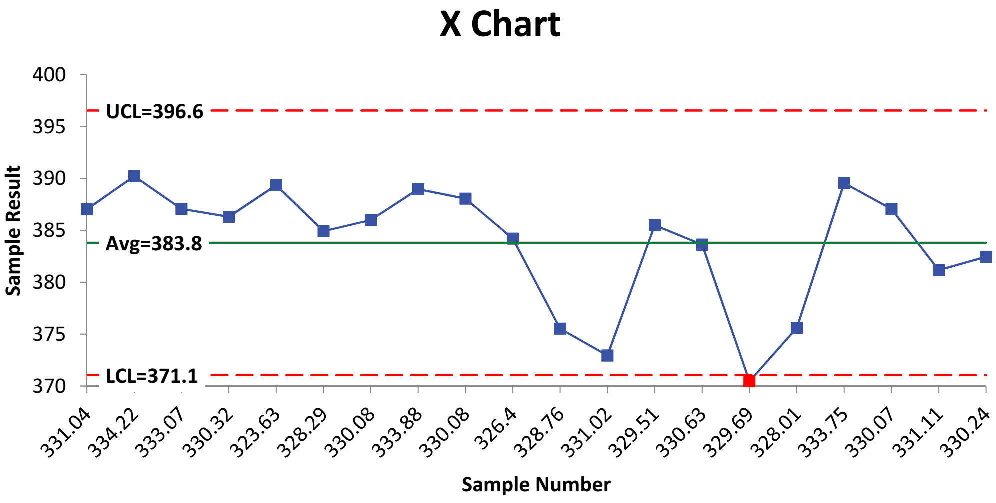
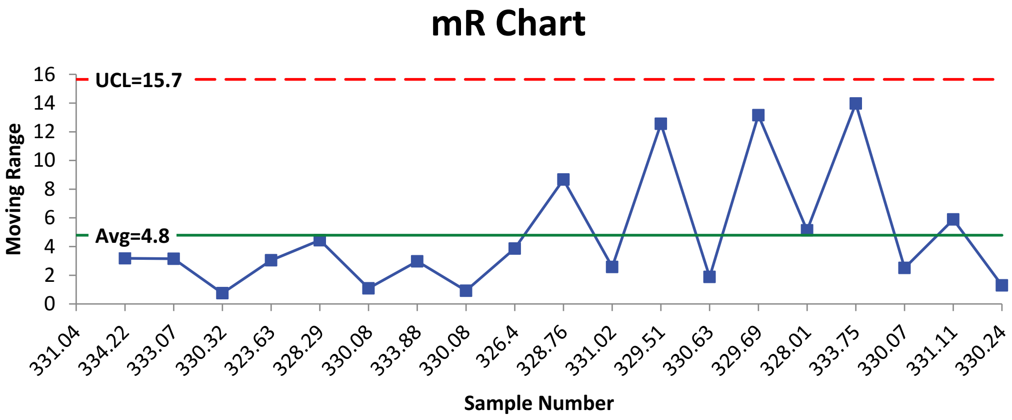


Figure 6b. R-Chat of the diameter before the improvement phase.



3.2.3.5. Measurement. Measurement is the fifth category and causes like wrong dimensioning, poor calibration of machine and worn-out spring dish were traced as possible causes of variation. Machine: The last category is the machine. Some faulty machines due to aging such as the grinding and coiler, as well as worn-out threading and wrong machining were the possible causes of the variation in the produced bolster springs

3.2.4. Improvement phase

Improvement actions were implemented in line with the cause and effect analyzed, which are presented in Table 3. After implementing these improvement actions, observations were taken to measure the process performance. The comparative analysis of the measurements before and after the improvement phase is presented in Table 4.

The X bar-R charts for diameter and free height of Bolster springs variation were drawn for the observations taken after the improvement actions and presented in (Figures 9a and 9b) and (10a and 10b), respectively. After the improvement phase, the data points of the X bar-R charts were

Figure 7a. X-Chart of the free height before the improvement phase.

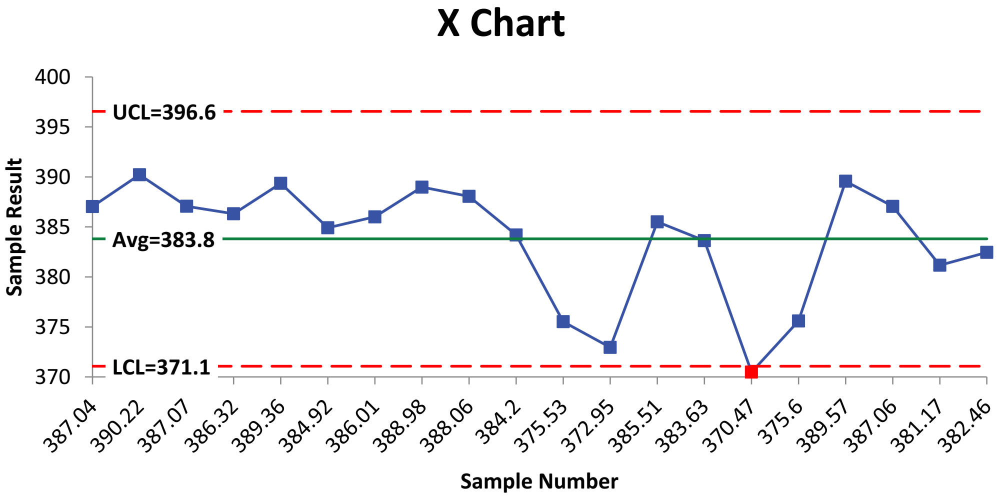
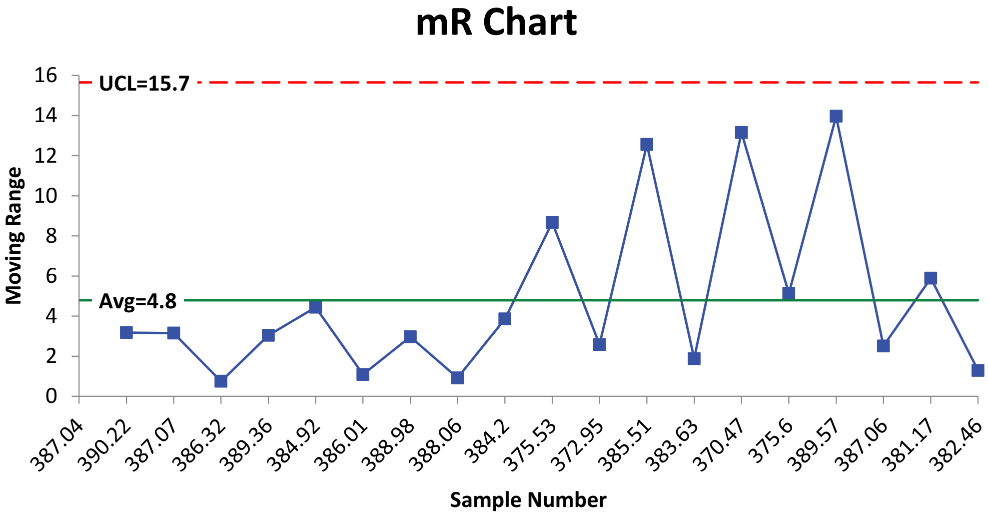


Figure 7b. R-Chat of the free height before the improvement phase.



found to be within the control limits unlike the data points obtained before the improvement phase. From Figures 9a and 10a, we show clearly that all data points lie within the upper and lower control limits. This implies that the process is statistically in control and that there is no evidence of variation within the process.

The process capability index was also computed after implementing improvement actions. Figures 11 and 12 show that the capability of the process has improved. Unlike the Cp_{ks} obtained before the improvement phase (which were less than 1), the indices of the Cp_{ks} values obtained after the improvement phase for the both diameter and free height, respectively, were 1. This shows that the process is now capable. It also implies that there are no evidences of variation in the process or product quality, which signals an improvement in the manufacturing process.

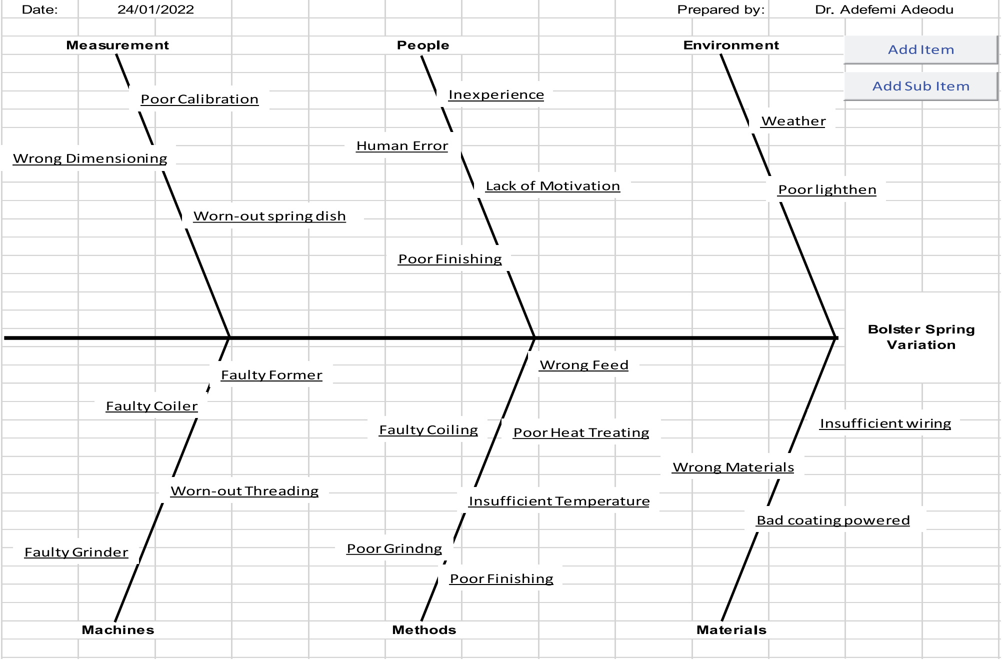


Figure 8. Cause and effect diagram of the variations in the bolster spring.

3.2.5. Control phase

To maintain the achieved process performance of the six-sigma quality level, the above four steps of DMAIC methodology must be reviewed periodically. Table 5 presents the statistical measures of process quality. The process capability (Cp) measures the closeness of the process to the specification limit relative to the process variability. The larger the process capability index (CpK) the less likely the process variation and vice versa. The process performance (Pp) measures how the process meets the required specifications while the process performance (Ppk) is an index that evaluates the performance of the process against the required specification. It is obvious from Table 5 that the implementation of the LSS as a continuous improvement tool has brought about significant improvement in the process capability and performance with an overall improvement in the sigma level. The increase in the value of the six-sigma is an indication that there was continuous improvement in the bolster spring manufacturing process (Magodi et al., 2022).

The essence of the control phase is to ensure that the process capability and performance are not compromised. This can be achieved by measuring and comparing the performance of the system with the benchmark (Daniyan et al., 2022). The control phase ensures that the implementation of the plans for monitoring the system's performance and taking corrective action where deviations are detected. This is aimed at further improving the process or sustaining the improved process. This phase is also necessary for process improvement and enhancing future process performance. The control activities implemented during this phase include the Standard Operating Procedure (SOP) where all necessary especially the assembly of the underframe, bogie frame and components assembly/sub assembly. With the SOP, regular documentation and review of the manufacturing process by the compliance team was ensured. The SOP provides a procedural step for repetitive process to minimise stress, errors, and communication gaps. The use of SOP will ensure process and production efficiency, and reliability, with improvement in product for routine

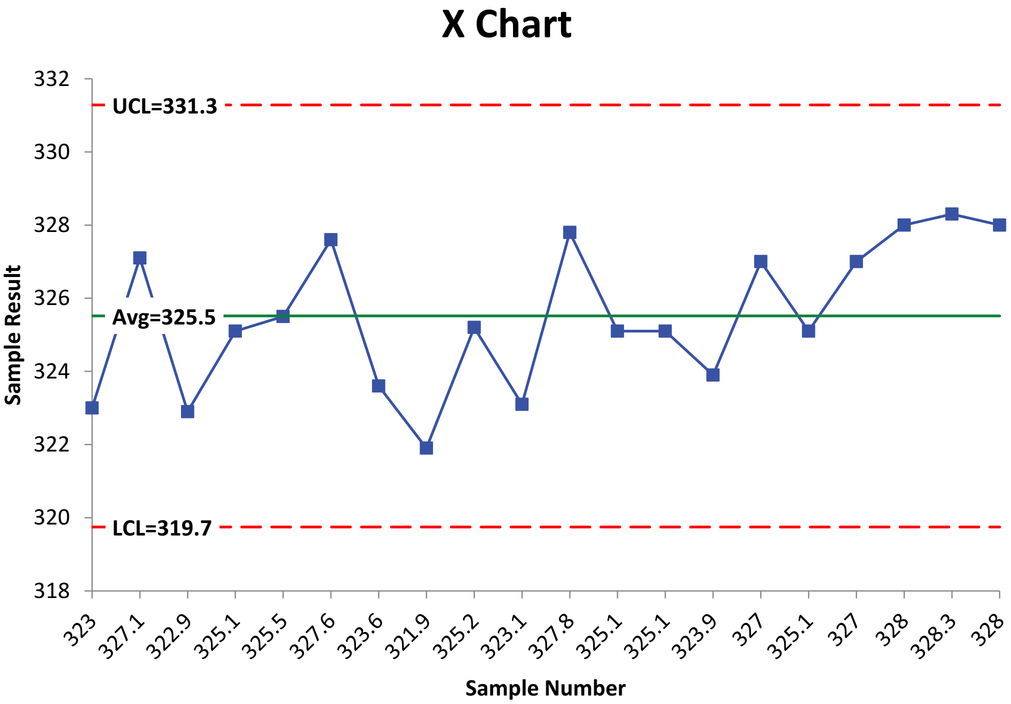


Figure 9a. X-Chart of the diameter after the improvement phase.

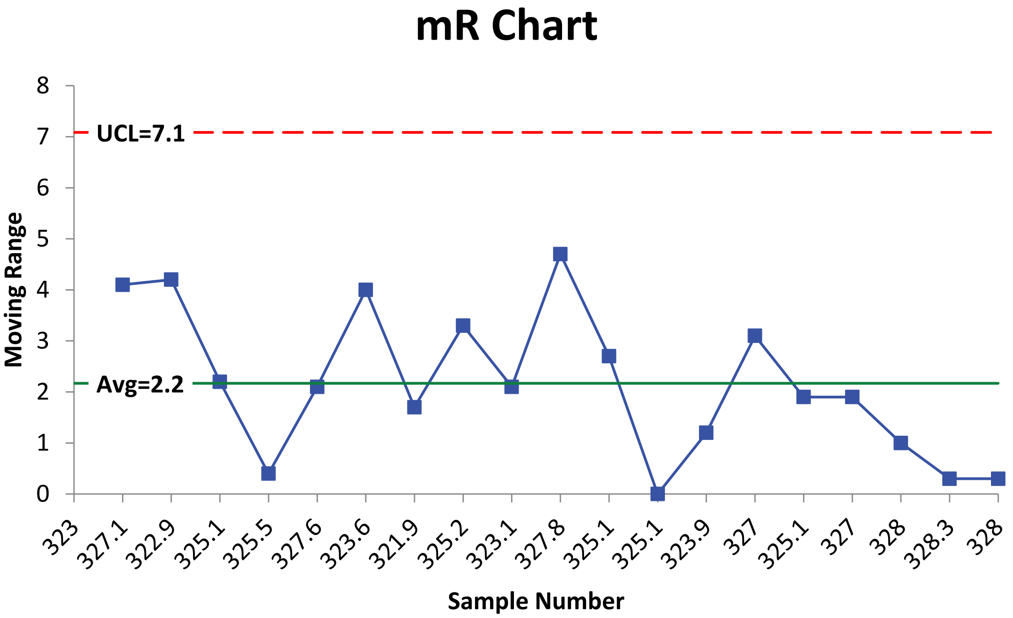


Figure 9b. R-Chat of the diameter after the improvement phase.

Figure 10a. X-Chart of the free height the improvement phase.

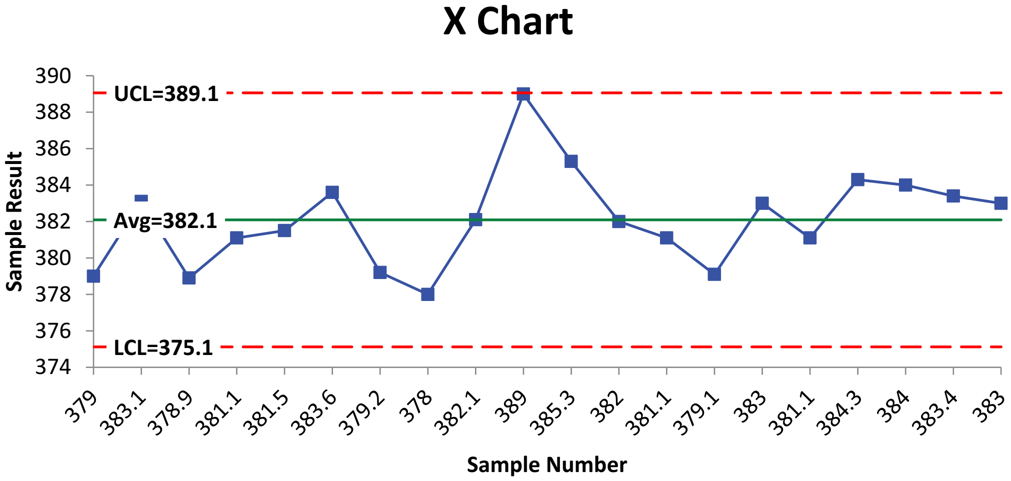
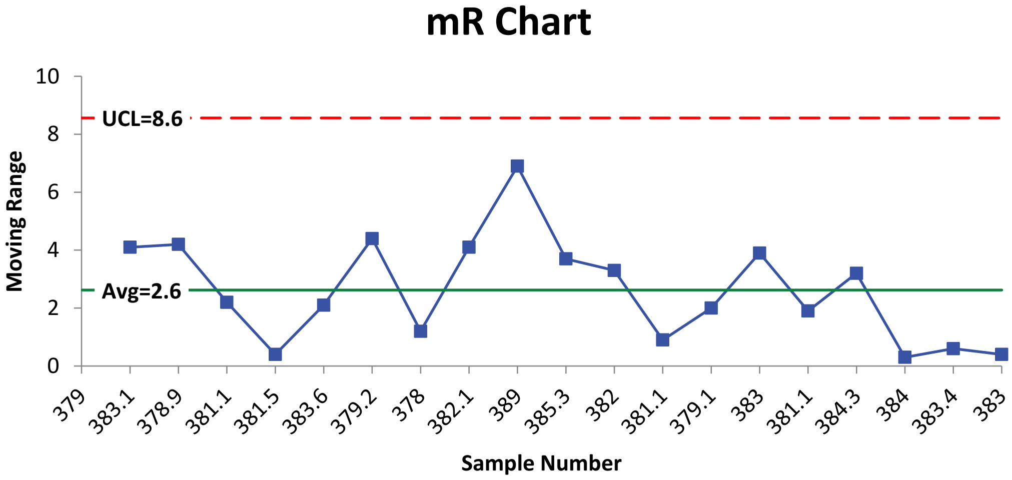


Figure 10b. R-Chat of the free height after the improvement phase.



activities. The 5S (sort, set in order, shine, standardize, and sustain) was also implemented to minimise the rate of defective product.

The results obtained in this study agree significantly with the findings of some recent studies such as Adeodu et al. (2021), Magodi et al. (2022), and Daniyan et al. (2022) that the implementation of the LSS as a continuous improvement technique can solve real-time problems relating to productivity and manufacturing wastes reduction with improvement in product quality, process efficiency, and customer's satisfaction.

Table 3. Improvement actions against variation

S/N	Causes of Variation by Category	Improvement Actions
1	Environment	(i) Stability in the temperature of the former should be noted before operation. (ii) Adequate lightning should be put in place in the machine floor.
2	Materials	(i) Sufficient spring wire should be fed into the coiler and machines. (ii) There should be proper check to ensure consistency in the material grade and type before processing. (iii) Coating of the spring after grinding should be done with correct specification of powder.
3	Man	(i) Adequate training should be given to the machine operators before allowing them to mount machine. (ii) The operators should be adequately motivated to work effectively.
4	Method	(i) There should be consistency in the feed level by inscribing mark on the former to show standard. (ii) Right specification and type of heat treatment should be ensured. (iii) Right tools and calibration should be ensured during grinding.
5	Measurement	(i) Proper check of the machine parts to replace the worn-out before operation. (ii) Calibration and dimensioning of the tools should be done by an experienced operator to avoid human errors.
6	Machine	(i) Adequate periodic maintenance of the machines should be carried out by the senior supervisor. (ii) Total preventive maintenance should be in place instead of corrective maintenance.

Table 4. Diameter and free height data before and after the improvement phase

	Before Improvement		After Improvement	
S/N	**Diameter (mm)**	**Free Height (mm)**	**Diameter (mm)**	**Free Height (mm)**
1	331.04	387.04	323.0	379.0
2	334.22	390.22	327.10	383.10
3	333.07	387.07	322.90	378.90
4	330.32	386.32	325.10	381.10
5	323.63	389.36	325.50	381.50
6	328.29	384.92	327.60	383.60
7	330.08	386.01	323.60	379.20
8	333.88	388.98	321.90	378.0
9	330.08	388.06	325.20	382.10
10	326.40	384.20	323.10	389.0
11	328.76	375.53	327.80	385.30
12	331.02	372.95	325.10	382.0
13	329.51	385.51	325.10	381.10
14	330.63	383.63	323.90	379.10
15	329.69	370.47	327.0	383.0
16	328.01	375.60	325.10	381.10
17	333.75	389.57	327.0	384.30
18	330.07	387.06	328.0	384.0
19	331.11	381.17	328.30	383.40
20	330.24	382.46	328.0	383.0

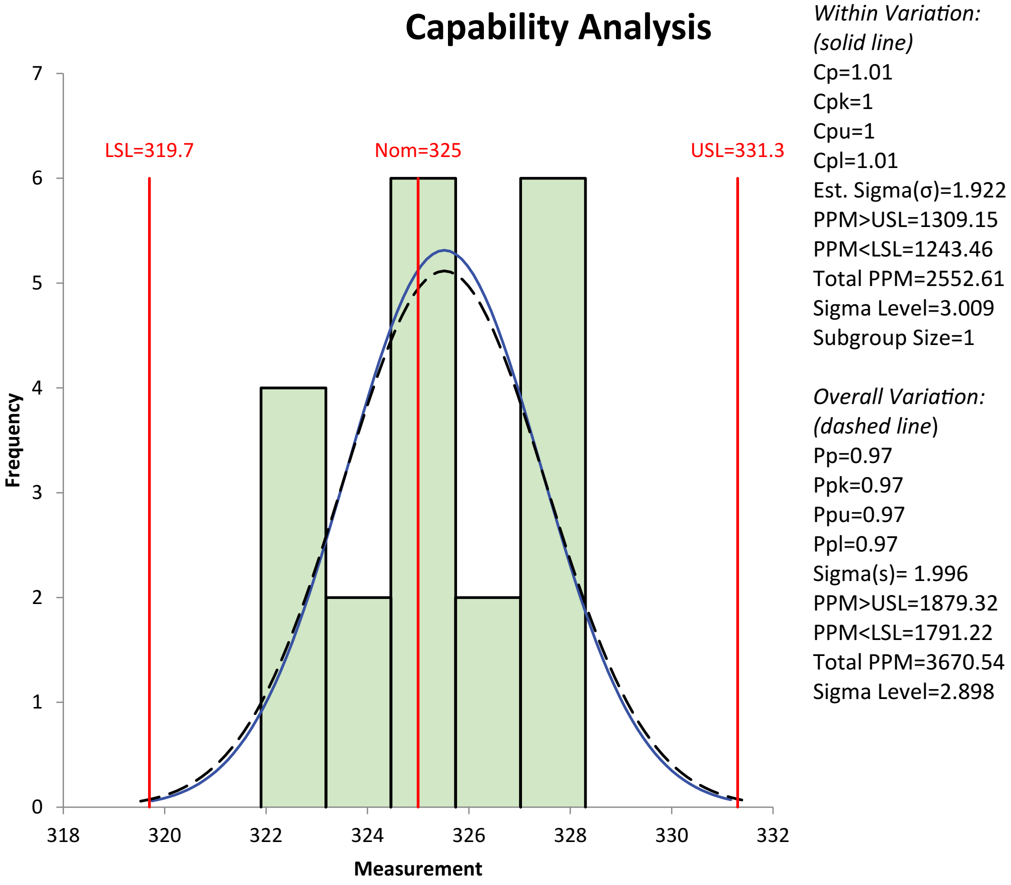
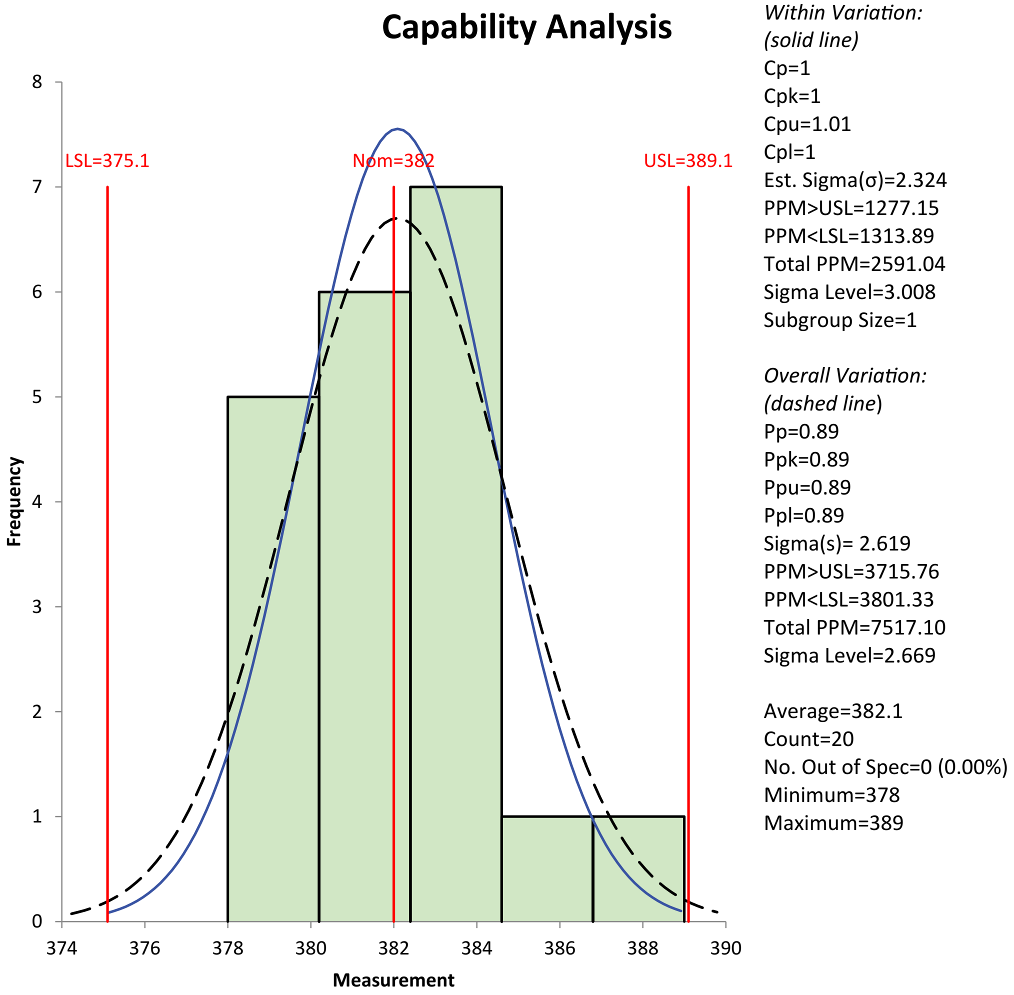


Figure 11. Process capability index for diameter after the improvement phase.

Table 5. Statistical measures of process quality

		Before Improvement		After Improvement	
S/N	**Parameter**	**Diameter (mm)**	**Free Height (mm)**	**Diameter (mm)**	**Free Height (mm)**
1	Process capability (Cp)	1.36	0.78	1.01	1.00
2	Process capability index (Cpk)	0.52	0.49	1.00	1.00
3	Process performance (Pp)	0.52	0.49	1.00	1.01
4	Process performance index (Ppk)	2.19	0.18	1.01	1.01
5	Sigma level	1.504	1.458	2.898	2.669

Figure 12. Process capability index for free height after the improvement phase.



4. Conclusion

In this research, DMAIC approach was implemented for process improvement in train bogie manufacturing industry considering production variation in bolster compression spring diameter and free height. First, process capability index Cpk of the current process was computed which was found less than 1. Therefore, to improve the value of process performance, the root causes of problem were determined with the help of cause and effect diagram. In addition, substantial analysis of existing system was done for finding the solution of root cause identified. Finally, in the improved phase, statistical analysis was done for identifying the process capability index values. The process capability index values were found to be 1 after the improvement phase. This signals an improvement in the process after taking corrective actions. It also implies that there are no variation in the process or product quality, which signals an improvement in the manufacturing process. Furthermore, the sigma level of the diameter of the bolster spring increased from 1.504 to 2.898 while that of the free height measurements increased from 1.069 to 2.669. The increase in the value of the six-sigma is an indication that there was continuous improvement in the bolster spring manufacturing process.

From outcomes of the study, it can be concluded that the process performance of a train manufacturing plant can be improved significantly by implementing six-sigma DMAIC methodology. Future work will consider the use of the Lean Six Sigma approach for the elimination of wastes generated in the process and for maintaining the achieved process performance of the six-sigma quality level.

Funding
The authors received no direct funding for this research.

Author details
Ilesanmi Daniyan[1]
E-mail: afolabiilesanmi@yahoo.com
ORCID ID: http://orcid.org/0000-0002-7238-9823
Adefemi Adeodu[2]
Khumbulani Mpofu[1]
Rendani Maladzhi[2]
Grace Mukondeleli Kanakana-Katumba[2]
[1] Department of Industrial Engineering, Tshwane University of Technology, Pretoria, South Africa.
[2] Department of Mechanical Engineering, University of South Africa, Florida, South Africa.

Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: Improvement of production process variations of bolster spring of a train bogie manufacturing industry: a six-sigma approach, Ilesanmi Daniyan, Adefemi Adeodu, Khumbulani Mpofu, Rendani Maladzhi & Grace Mukondeleli Kanakana-Katumba, *Cogent Engineering* (2023), 10: 2154004.

References

Adeodu, A. O., Kanakana-Katumba, M. G., & Maladzhi, R. (2021). Implementation of lean six sigma for production process optimization in a paper production company. *Journal of Industrial Engineering and Management*, *14*(3), 73–89. https://doi.org/10.3926/jiem.3479

Ahmed, S., Manaf, N. F., & Islam, R. (2018). Measuring Lean Six Sigma and Quality Performance for Health care Organization. *International Journal of Quality and Service Science*, *10*(3), 267–278. https://doi.org/10.1108/IJQSS-09-2017-0076

Albliwi, S. A., Antony, J., & Lim, S. A. H. (2015). A systematic review of lean six sigma for the manufacturing industry. *Business Process Management Journal*, *21*(3), 665–691. https://doi.org/10.1108/BPMJ-03-2014-0019

Antoniolli, I., Guariente, P., Pereira, T., Ferreira, L. P., & Silva, F. J. G. (2017). Standardization and optimization of an automotive components production line. *Procedia Manufacturing*, *11*, 1120–1127. https://doi.org/10.1016/j.promfg.2017.09.173

Bazrkar, A., Iranzadeh, S., & Farahmand, N. F. (2017). Total quality model for aligning organization strategy, improving performance, and improving customer satisfaction by using an approach based on combination of balanced scorecard and lean six sigma. *Cogent Business & Management*, 4(1), 1390818. https://doi.org/10.1080/23311975.2017.1390818

Belokar, R. M., Kumar, V., & Khars, S. S. (2012). Application of value stream mapping in automobile: A case-study. *International Journal of Innovative Technology and Exploring Engineering*, *1*(2), 152–157.

Ben Ruben, R., Vinodh, S., & Asokan, P. (2017). Implementation of lean six sigma framework with environmental considerations in an Indian automotive component manufacturing firm: A case study. *Production Planning & Control*, *28*(15), 1193–1211. https://doi.org/10.1080/09537287.2017.1357215

Calvo, R., Domingo, R., & Sebastián, M. A. (2007). Operational flexibility quantification in a make-to-order assembly system. *International Journal of Flexible Manufacturing Systems*, *19*(3), 247–263. https://doi.org/10.1007/s10696-008-9037-9

Chen, C., Lu, I., Wang, K., Jang, J., & Dahlgaard, J. J. (2015). Development of quality management in Taiwan the past, present and future. *Total Quality Management & Business Excellence*, *26*(1–2), 3–13. https://doi.org/10.1080/14783363.2014.981071

Costa, T., Silva, F. J. G., & Ferreira, L. P. (2017). Improvement of the extrusion process in tire production using Six Sigma methodology. *Procedia Manufacturing*, *13*, 1104–1111. https://doi.org/10.1016/j.promfg.2017.09.171

Daniyan, I. A., Adeodu, A. O., Mpofu, K., Maladhzi, R., & Kana-kana Katumba, M. G. (2022). Application of lean six sigma methodology using DMAIC approach for the improvement of bogie assembly process in the railcar industry. *Heliyon*, *8*(2022), e09043, pp. 1–14. https://doi.org/10.1016/j.heliyon.2022.e09043

Das, S., & Patnaik, A. (2015). *Production planning in the apparel industry*. *Garment Manufacturing Technology*. Woodhead Publishing Series. 81–108.

Edgeman, R. L. (2010). Lean Six Sigma in service: Applications and case studies. *Total Quality Management & Business Excellence*, *21*(10), 1060–1061. https://doi.org/10.1080/14783360903491977

Furterer, S., & Elshennawy, A. K. (2005). Implementation of TQM and lean six sigma tools in local government: A framework and a case study. *Total Quality Management & Business Excellence*, *16*(10), 1179–1191. https://doi.org/10.1080/14783360500236379

Gijo, E. V., Palod, R., & Antony, J. (2018). Lean six sigma approach in an Indian auto ancillary conglomerate: A case study. *Production Planning & Control*, *29*(9), 761–772. https://doi.org/10.1080/09537287.2018.1469801

Gupta, V., Jain, R., Meena, M. L., & Dangayachi, G. S. (2018). Six-sigma application in tire manufacturing company: A case study. *Journal of Industrial Engineering International*, *14*(3), 511–520. https://doi.org/10.1007/s40092-017-0234-6

Hekmatpanah, M., Sadroddin, M., Shahbaz, S., Mokhtari, F., & Fadavinia, F. (2015). Six Sigma process and its impact on the organizational productivity. *World Academy of Science, Engineering and Technology*, *43*, 2070–3740.

Improta, G., Balato, G., Romario, M., Ponsiglione, A. M., Raiola, E., Russ, O. M. A., Cuccaro, P., Scantillo, L. C., & Caserelli, M. (2017). Improving Performances of the Knee Replacement Surgery Process by Applying DMAIC Principles. *International Journal of Public Health Policies and Health Research*, *23*, 1401–1407. https://doi.org/10.1111/Jep.12810

Jones, E. C., Parast, M. M., & Adams, S. G. (2014). A Framework for Effective six sigma Implementation. *Total Quality Management and Business Excellence*, *21*(4), 415–424. https://doi.org/10.1080/14783361003606720

Krueger, D. C., Parast, M. M., & Adams, S. (2014). Six sigma implementation: A qualitative case study using grounded theory. *Production Planning & Control*, *25*(10), 873–889. https://doi.org/10.1080/09537287.2013.771414

Laureani, A., & Antony, J. (2010). Reducing employees' turnover in transactional services: A lean six sigma case study. *International Journal of Productivity and Performance Management*, *59*(7), 688–700. https://doi.org/10.1108/17410401011075666

Madsen, D. Q., Risvik, S., & Stenheim, T. (2017). The diffusion of lean in the Norwegian municipality sector: An exploratory survey. *Cogent Business & Management*, 4(1), 1,1411067. https://doi.org/10.1080/23311975.2017.1411067

Magodi, Y., Daniyan, I. A., & Mpofu, K. (2022). Application of lean six sigma to a small enterprise in the Gauteng Province: A case study. *South African Journal of Industrial Engineering*, *33*(1), 190–204. https://doi.org/10.7166/33-1-2504

Meza, D., & Jeong, K. Y. (2013). Measuring efficiency of lean six sigma project implementation using data envelopment analysis at NASA. *Journal of Industrial Engineering and Management*, *6*(2), 401–422. https://doi.org/10.3926/jiem.582

Mwacharo, F. K. (2013). *Challenges of lean management - Investigating the challenges and developing a recommendation for implementing lean management techniques*. Bachelor. HAMK University of Applied Sciences.

Pandey, M., & Bhattacharya, B. A. (2020). A parametric study analysing the effect of bolster suspension parameters on the carbody dynamic response in a freight wagon with three-pice bogie. *Journal of Vibration Engineering Technology*, *8*(5), 625–641. https://doi.org/10.1007/s42417-019-00105-4

Ricciardi, C., Sorrentino, A., Improta, G., Abbate, V., Latessa, I., Perrone, A., Fraissi, A., & Traisi-Orobona, G. D. (2020). A health technology Assessment between two Pharmacological Therapies through Six sigma: The Case Study of Bone Cancer. *The TQM Journal*. https://doi.org/10.1108/TQM01-2020-0013

Roriz, C., Nunes, E., & Sousa, S. (2017). Application of lean production principles and tools for quality improvement of production process in a cartoon company. *Procedia Manufacturing*, *11*, 1069–1076. https://doi.org/10.1016/j.promfg.2017.07.218

Rosa, C., Silva, F. J. G., & Ferreira, L. P. (2017). Improving the quality and productivity of steel wire-rope assembly lines for the automotive industry. *Procedia Manufacturing*, *11*, 1035–1042. https://doi.org/10.1016/j.promfg.2017.07.214

Sanchez-Marquez, R., Guillem, J. M. A., Vicens-Salort, E., & Vivas, J. J. (2020). A systemic methodology for the reduction of complexity of the balanced scorecard in the manufacturing environment. *Cogent Business & Management*, *7*(1), 1,1720944. https://doi.org/10.1080/23311975.2020.1720944

Shahada, T. M., & Alsyouf, I. (2012). Design and implementation of a lean six sigma framework for process improvement: A case study. In: *2012 IEEE International Conference on Industrial Engineering and Engineering Management*, IEEE, pp. 80–84.

Singh, M., & Rathi, R. (2018). A structured review of lean six sigma in various industrial sectors. *International Journal of Lean Six Sigma*, *10*(2), 622–664. https://doi.org/10.1108/IJLSS-03-2018-0018

Sodhi, H. S., Singh, D., & Singh, B. J. (2022). Implementation of lean six sigma model for scrap reduction in machining sector. *International Journal of Business Excellence*, *27*(1), 110–124. https://doi.org/10.1504/IJBEX.2022.123032

Srivastava, P., Alrasheedi, M., Kaushik, P., & Sharma, S. (2021). Reducing the cost of poor quality and improving process output by adopting a six sigma DMAIC tool: A case study. *International Journal of Six Sigma and Competitive Advantage*, *13*(1–3), 195–216. https://doi.org/10.1504/IJSSCA.2021.120222

Sunder, M. V., & Mahalingam, S. (2018). An empirical investigation of implementing Lean Six Sigma in higher education institutions. *International Journal of Quality & Reliability Management*, *35*(10), 2157–2180. https://doi.org/10.1108/IJQRM-05-2017-0098

Uluskan, M., & Oda, E. P. (2019). A thorough six sigma DMAIC application for household appliance manufacturing systems: Oven door Panel alignment case. *The TQM Journal*. https://doi.org/10.1108/TQM06-2019-0171

© 2023 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:
Share — copy and redistribute the material in any medium or format.
Adapt — remix, transform, and build upon the material for any purpose, even commercially.
The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:
Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.
You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
No additional restrictions

You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

***Cogent Engineering* (ISSN: 2331-1916) is published by Cogent OA, part of Taylor & Francis Group.**

Publishing with Cogent OA ensures:

- Immediate, universal access to your article on publication
- High visibility and discoverability via the Cogent OA website as well as Taylor & Francis Online
- Download and citation statistics for your article
- Rapid online publication
- Input from, and dialog with, expert editors and editorial boards
- Retention of full copyright of your article
- Guaranteed legacy preservation of your article
- Discounts and waivers for authors in developing regions

Submit your manuscript to a Cogent OA journal at www.CogentOA.com