Mechanisation: A Radical Approach for Improvement in a Selected Automotive Assembly Organisation in South Africa

Robert Walter Dumisani Zondo,
Associate Professor, Durban University of Technology (DUT), Faculty of Management Sciences, Department of Entrepreneurial Studies and Management, Durban,
Email: dumsaniz@dut.ac.za
http://orcid.org/0000-0003-0214-860X

Abstract:

The increased practice of mechanisation in the execution of tasks in the manufacturing sector, as a method for productivity improvement through standard time achievement and downtime reduction, requires changes in layout and the application of robotics capabilities. In this way, using layout designs for optimum assembly process optimises the assembly process. Hence, this study examines the adoption of mechanisation for quality improvement and downtime reduction in a selected automotive assembly organisation in South Africa.

The study was quantitative in design and examined the production process of the selected automotive assembly organisation that had adopted a mechanised system for quality improvement in its roof process in the weld plant. The company, which operates a three-shift system, is situated in the eThekwini Municipality in KwaZulu-Natal province of South Africa. The study was achieved by collecting pre- and post-quarterly data for product quality, defects per unit and downtime. The results indicate that downtime and product quality improved as a result of mechanisation. Through mechanisation, the organisation has made technological changes in their processes that have led to opportunities for greater flexibilities. This study uncovers the strengths and weaknesses of mechanisation in this automotive assembly organisation in South Africa.

Keywords: automotive assembly organisation, downtime, mechanisation, productivity, product quality, Takt time

INTRODUCTION

The most sophisticated method for articulating the future incorporation of technological advancement can be reviewed through the lens of the fourth industrial revolution (Manyika, 2017). It must be noted that the first industrial revolution was in the 18th century, as steam and water were harnessed to create new machines (Grieco, 2019). The second industrial revolution used electricity and allowed for mass production, while the third has been one that many have experienced in this day and age: the digital revolution. Schwab (2015) alludes to the fact that the fourth industrial revolution comprises of a combination of these systems, combining physical processes with the power of refined digital and cyber technologies. The posited result is a radical reshaping of the economy with the radical reduction of human labour. This view is put forward by technology leaders such as Bill Gates and Elon Musk, as well as politicians such as the UK's Labour leader, Jeremy Corbyn (Corbyn, 2017; Daso, 2017). With increased competition, demands on products of higher quality and with faster delivery time had forced the managers to convert conventional manufacturing practices to computer-controlled manufacturing practices such as flexible manufacturing systems (FMS) and computer integrated manufacturing systems (Villarreal & Alanis, 2011). This signifies the essence and critical role of mechanisation in various business processes.

Generally, the first known practice of grouping equipment, by mechanisation level, to differentiate their respective mechanisation efforts was undertaken in the manufacturing line of an electric company between 1920 and 1925 (Bright, 1958). A diverse range of taxonomies were also developed by researchers to best describe their respective industrial needs. Sheridan and Verplank (1978) developed a 10-level taxonomy for undersea tele-operators' automation assessment that represented ten levels, from manual performance to full automation. This taxonomy was then acknowledged and further enriched by its association with system functions that were translated from models of human information processing (Parasuraman, Sheridan & Wickens, 2000). Endsley and Kaber (1999) also tabulated a 10-level taxonomy, from manual control to full automation, with corresponding roles played by human and/or computer, that applied to a wider variety of domains and task types. Save and Feuerberg (2012) proposed a new level of automation taxonomy based on that of Endsley and Kaber (1999) and Parasuraman *et al.* (2000) for classification and comparison of different types of automation support in air traffic management in the aviation sector. The historical application of mechanisation shows the significant role it has played over a period of time. Thus, mechanisation has been perceived by researchers as having numerous benefits for the industry. One perception is that mechanisation is related to the productivity of industrial activities. It minimises or reduces labour content, so it maximises the performance of the production with less time required (Lamsal, 2018). Thus, the industry gains in productivity along with mechanisation (Fiscor, 2016). Singh (2006) confirmed a positive correlation between productivity and mechanisation. Abbas *et al.* (2017) further asserted that increasing productivity requires more efficient mechanisation. Although it is a type of investment in the industry, mechanisation is essential in increasing the productivity of activities (Kirui and Von Braun, 2018). Hence, this study evaluates the influence of mechanisation on productivity in the selected automotive assembly organisation in South Africa. Herein, productivity will be evaluated in terms of standard time achievements and downtime reduction.

Given the specific and complex nature of mechanisation, enterprises need to undertake appropriate implementation strategies tailored to the individual design of their institutional and process organisation structure (Müller *et al*, 2018b). Yet, thus far, literature provides corporate practice with general and highly aggregated recommendations that are difficult to grasp and that usually disregard company-specific characteristics (Arnold, Kiel & Voigt, 2016). Hence, this study examines the influence of mechanisation on the selected automotive assembly organisation in South Africa.

The rest of the paper discusses the theory that was considered, the methodology used, study results as well as the discussion of results. It deliberates on the implications of results for policy and practice, study limitations, conclusion, as well as future research required.

THEORETICAL CONSIDERATION

This section presents a brief overview of mechanisation, as well as the influence of mechanisation on downtime.

Brief overview of mechanisation

Mechanisation has been defined by Phogat and Gupta (2017) as a process of changing activity from manual completion, either by hand or with animals, to completion with machinery. The associated effects of mechanisation were seen as labour reduction and

labour displacement from one industry or sector to the other (Folts & Jerome, 1935). Williams (1999) regarded mechanisation as a replacement of human and animal muscle power by mission-enabling equipment. He also defined mechanisation as a replacement of human sensory and thought processes with information and control equipment. According to Bock (2015), as mechanisation is machine centred, it should therefore include robotics and equipment with robotic control systems for task completion (Neelamkavil, 2009). Since this paper considers using tools and equipment with various advanced features to replace human effort, mechanisation is used as a term to include both mechanised and automated solutions; this means the mechanisation in this study includes automation. Mechanisation has been perceived by researchers as having numerous benefits for industry. One perception is that mechanisation is related to the productivity of industrial activities. It minimises or reduces labour content, so it maximises the performance of the production with less time required (Lamsal, 2018). Thus, the industry gains in productivity along with mechanisation (Fiscor, 2016). Singh (2006) confirmed a positive correlation between productivity and mechanisation. Abbas et al. (2017) further asserted that increasing productivity requires more efficient mechanisation. Although mechanisation is a type of investment in industry, it is essential in increasing the productivity of activities (Kirui and Von Braun, 2018).
Hence, this study examines the suitability of mechanisation as an appropriate method for the automotive industry in South Africa.

Influence of mechanisation on downtime

It has been established that assembly processes of most manufacturing systems are conducted manually by employees with minor levels of mechanisation, due to complexity and the high cost of automated assembly operations (Grewal, 2011). Industrial managers assess different methods for enhancing productivity, quality and efficiency of the assembly line. There are times when assembly lines employ various methods that have been used in the past to improve the productivity of assembly lines (Villarreal & Alanis, 2011), one of these being the segmentation of the assembly line into sections with embedded buffers that makes it possible to reduce idle times and enhance productivity. In this case, mechanisation has thus been identified as an appropriate strategy (Grewal, 2011), leading to the reduction of human participation in production systems, the introduction of machines for doing repetitive and complex actions, as well as transforming production to make it as continuous as possible (Groover, 2010). With this kind of production system, fewer operators are required. However, downtimes could remain a relevant cause of inefficiency and require focused analysis.

However, efficiencies come with real psychological and physical repercussions (Fiscor, 2016). For example, the New York Committee for Occupational Safety and Health surveyed Amazon warehouse workers and found signs of musculoskeletal disorders attributed to their work; they reported feeling pressured to work harder and/or faster (80 per cent); they experienced psychological stress as a result of their current employment (49 per cent); and they had their sleep negatively impacted as a result of their current employment (63 per cent) (Grieco, 2019). As technology makes it easier to examine human actions and compare them to an algorithmic ideal, these pressures to increase workload and productivity are likely to increase.

However, today's production systems are required to deliver high productivity, resource efficiency and flexibility (Phogat & Gupta, 2017). These requirements will continue to rise in line with the realisation of mechanised manufacturing systems. There is a strong commitment in production personnel to exploit the full potential of current systems, but the complex and highly automated equipment in future mechanised factories is required to deliver even higher levels of performance. However, poor performance in terms of overall equipment effectiveness (OEE) has been reported for over a decade. Ahlmann (1993), Ericsson (1997), and Ljungberg (1998) present numbers between 55 and 60 per cent, and Ingemansson (2004) between 40 and 60 per cent. More recently, by collecting OEE data from 2006 to 2012 in over 90 companies, Ylipää, Harlin & Stahre (2007) present an average number of 51.5 per cent. Consequently, companies are beginning to worry about keeping track of the parameters that affect production performance (Kumar, Galar, Parida, & Stenström, 2013). Nevertheless, the positive influence of mechanisation is recognised at various levels of production. It provides enhancements in both quality and precision, the elimination of potential workplace hazards and decrease in workforce requirements. Hence, this study assesses whether the implementation of a mechanised system leads to a reduction in downtime.

RESEARCH DESIGN AND APPROACH

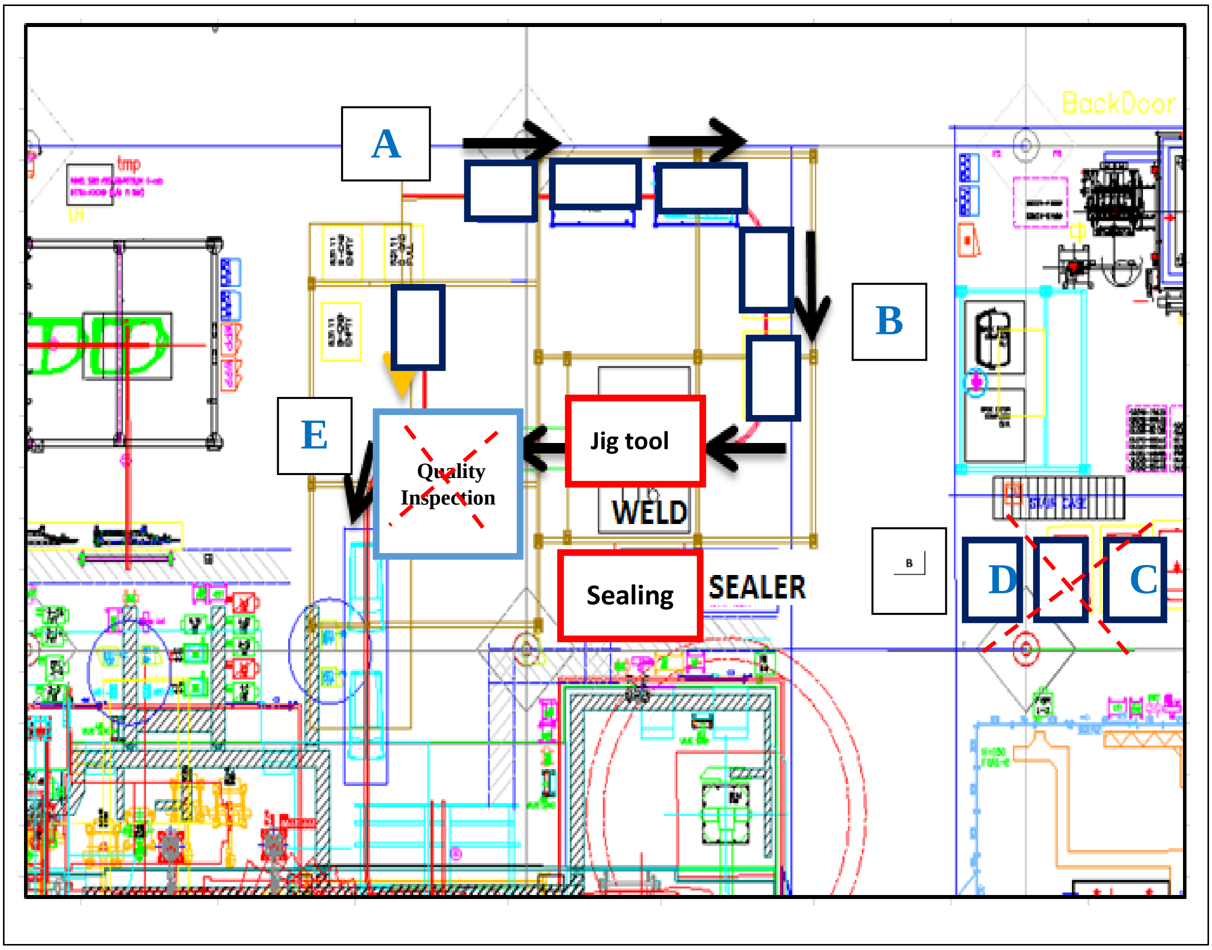
This study was quantitative in nature. It examines the influence of mechanisation on productivity and downtime. Bryman and Bell (2007) explain that the quantitative approach involves the use of statistical procedures to analyse the data collected. Consequently, after the measurements of the relevant variables, the scores were transformed using statistical methods. For this study to achieve its objectives, the pre- and post-mechanisation data were collected over time from one large automotive assembly organisation. The pre-mechanisation results were quarterly data reflecting the company's performance over the three-year period prior to the implementation of a mechanised system. This includes data from the first quarter of 2015 to the final quarter of 2017. The post-mechanisation data reflect the company's performance for three years after a mechanised system was implemented. This includes data from the first quarter of 2018 to the final quarter of 2020.

The organisation is situated within the eThekwini Municipality in the province of KwaZulu-Natal in South Africa. Data were analysed using the descriptive and conclusive designs. Conclusive studies are meant to provide information that is useful in decision-making (Yin, 2008).

PRE-MECHANISATION POSITION OF A COMPANY

The company that agreed to participate in the study had adopted mechanisation in its roof assembly process in the weld plant. Prior to mechanisation, it was unable to achieve the set production target of 87 Takt time due to downtime. Takt time is the rate at which the product is completed in order to meet customer demand (Lebednik, 2012). It therefore implemented mechanisation in its assembly process in order to reduce downtime, thus improving plant productivity through standard time improvement. The mechanised system was directed towards the company's blue-collar employees whose jobs require manual labour. The following Figure 1 presents the layout of the roof process prior to mechanisation.

FIGURE 1: pre-mechanisation of the roof process



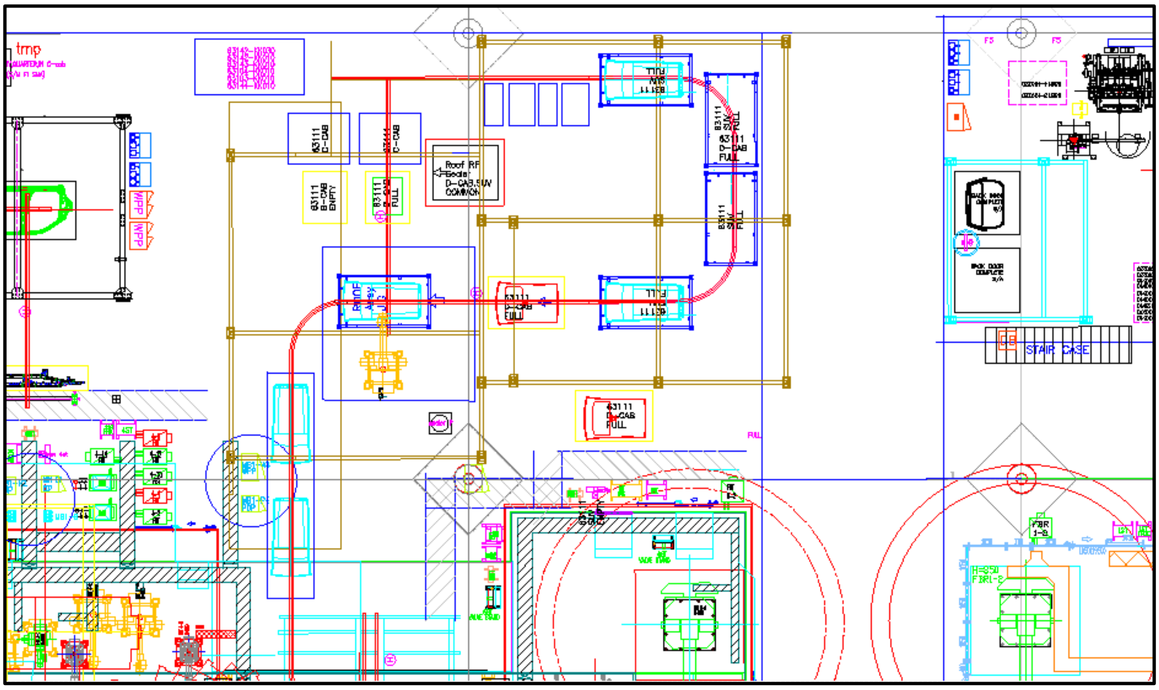
Source: company records (2021)

The process was designed to move the roof component through five stages of the assembly, including stages labelled A to E. Some stages were identified as non-value adding, including C and D. Their inclusion in the process resulted in downtime and low productivity, hence the introduction of mechanisation at the beginning of 2018.

POST-AUTOMATION POSITION OF A COMPANY

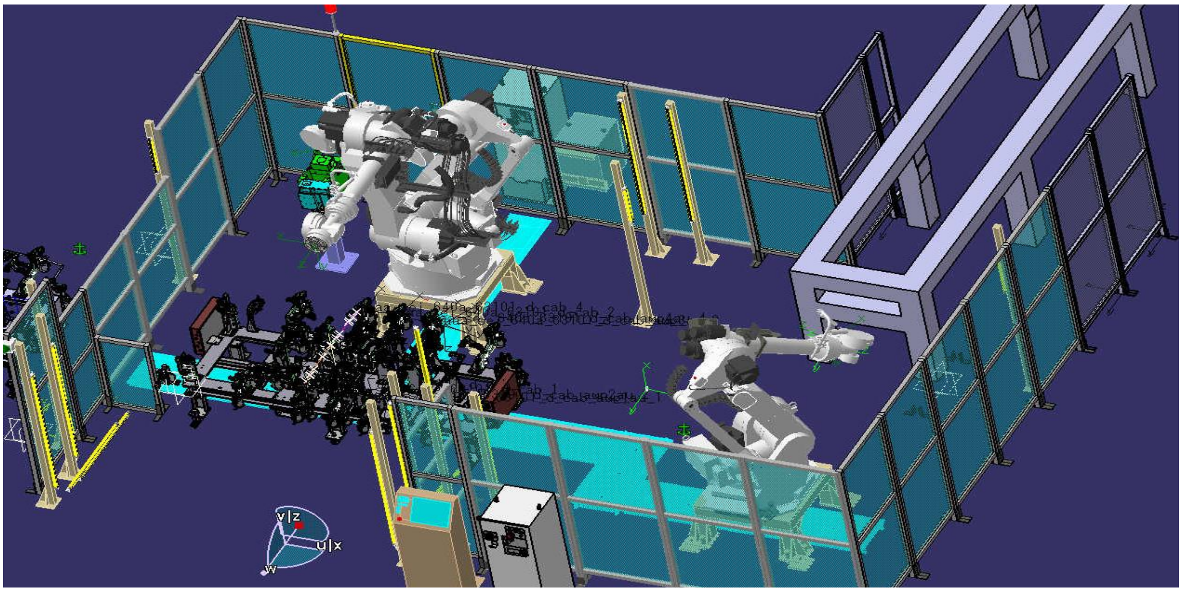
The five-stage assembly process was unproductive and resulted in numerous downtime instances. Management introduced mechanisation into the process, resulting in a shorter assembly process, made possible by the introduction of a robot cell aimed at driving the entire mechanisation process, resulting in workflow reduction. Consequently, the assembly process was reduced to only two stages, labelled as A and B (see Figure 1). The following Figure 2 presents the post-automation two-stage roof process layout.

FIGURE 2: post-automation two stage roof process
Source: company records (2021)



This diagrammatic representation presents an improved two-stage roof assembly process emanating from the introduction of mechanisation (see Figure 2). The introduction of a robot cell aimed at driving the entire mechanisation resulted in the reduction of downtime and, as a consequence, productivity improvement. Figure 3 presents a schematic representation of the roof process post-mechanisation layout.

FIGURE 3: diagrammatic representation of post-mechanisation roof process



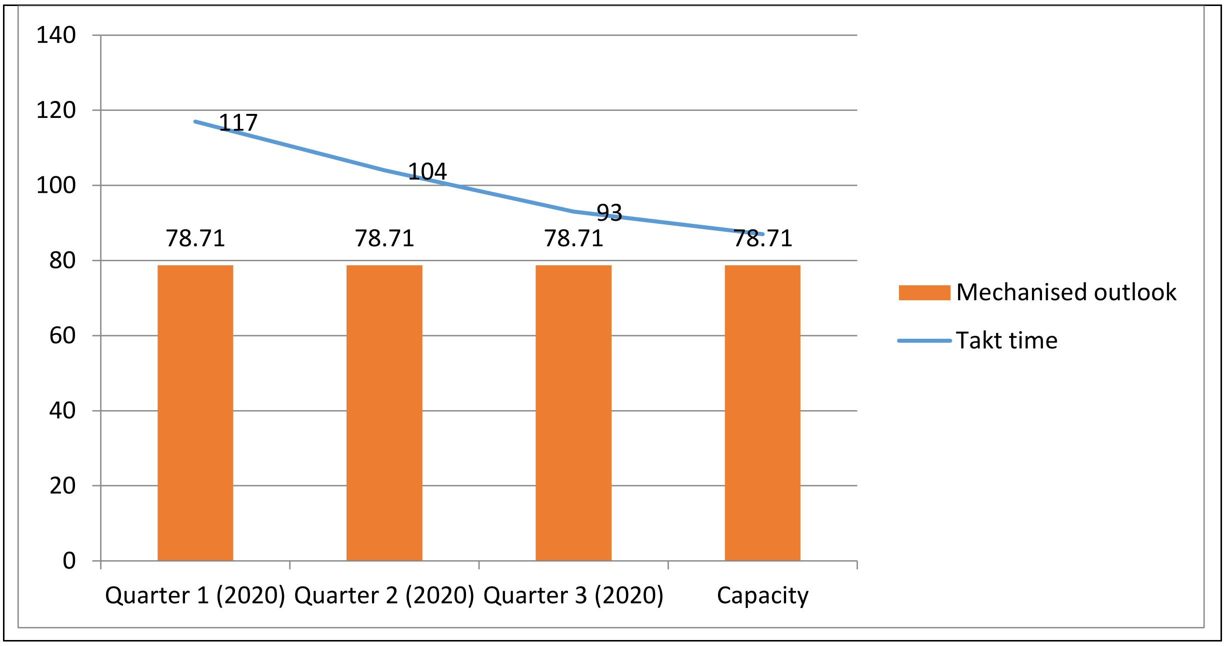
Source: company records (2021)

Having discussed the pre- and post-mechanisation layout of the roof process assembly, the following section presents Takt time results emanating from mechanised process.

Post-mechanisation performance implications

The following Figure 4 shows the extent of Takt time capacity improvements emerging from mechanisation. It shows the progressive improvement in Takt time from 117 minutes in quarter 1; 104 in quarter 2; 93 in quarter 3; and 78.87 in quarter 4, compared with the standard Takt time of 78.71.

FIGURE 4: standard Takt time changes as a result of mechanised process



Source: Author's own work.

SUMMARY OF STUDY RESULTS

This section analyses the results for pre- and post-mechanisation means comparison.

Pre- and post-mechanisation means comparison

Table 1 compares the means (in percentages) for product quality, defects per unit and downtime.

TABLE 1: pre- and post-mechanisation percentage means comparison.

No.	**Variable**	**Pre-mechanisation period (%)**	**Post-mechanisation period (%)**	**% mean difference (post – pre)**
1.	Product quality	80.83	90.50	+9.67
2.	Defects per unit	2.81	2.45	-0.36
3.	Downtime	5.15	2.81	-2.34

Source: Author's own work.

Results in Table 2 indicate that the pre-mechanisation percentage mean data on product quality, defects per unit and downtime are 80.83%, 2.81% and 5.15%; respectively. In addition, the post-mechanisation percentage mean data on the product quality, defects per unit and downtime are 90.50%, 2.45% and 2.81%; respectively. Table 2 shows mixed results of mean values on the three variables (that is, the product quality, defects per unit and downtime) from pre-mechanisation mean data to post-mechanisation mean data. However, they show an increase in mean values on product quality and a decrease on both the defects per unit and downtime when post-mechanisation data is compared with pre-mechanisation periods. This indicates the effect of mechanisation on the organisation that participated in the study.

Equality of pre- and post-sample variances

The Bartlett's test was used to verify whether the variances were equal for all the samples (Curwin & Slater, 2002). The following Table 2 presents a summary of the results from the Bartlett's test for homogeneity of variances.

TABLE 2: Bartlett's test for homogeneity of variances

Variables	**means of transformed data**	**standard deviations of transformed data**	**P-Value**
Product quality	85.667	6.559	0.001
Defect per unit	2.092	1.599	
Downtime	3.980	1.960	

Source: Author's own work.

The p-value in the Bartlett's tests (at p>0.05) shows that homogeneity of variances has occurred, thus rejecting the null hypothesis. The p-value at 0.001 is low when compared with the significant level of 0.05. It can be concluded that there are distribution changes between the two parts of time-series.

DISCUSSION

This study investigates the influence of mechanisation on the improvement of the roof assembly process in the selected automotive assembly organisation in South Africa. It examined the production and related experience of the automotive assembly organisation that has adopted mechanisation in its operations.

The assembly processes of most manufacturing systems are conducted manually by employees with minor levels of mechanisation, primarily because of the complexity and the high cost of automated assembly operations (Groover, 2010). Over the years, the industrial managers have been looking for ways to enhance productivity, product quality and efficiency of the assembly line. This has led to the assembly lines not operating at their maximum capacity (Groover, 2010). There are times when the assembly lines have downtime with the productivity rates being lower than those calculated by the operating manuals. Hence, various methods have been used to improve productivity of assembly lines (Grewal, 2011). For this study to achieve its objectives, pre- and post-mechanisation process layout in the roof assembly was assessed. In addition, quarterly time series data on product quality, defects per unit and downtime were used to analyse data. This includes data on Takt time. The results indicate that mechanisation has an influence on product quality, defects per unit and downtime.

IMPLICATIONS OF RESULTS FOR POLICY AND PRACTICE

The automotive industry relies heavily on robots in their body shop assembly processes (Lamsal, 2018). The amount of welding that is applied in order to connect the different parts of the vehicle requires high efficiency, constancy and precision, which makes it an ideal job for a robot. The robots can be programmed to conduct the same operation the same way every cycle for a very long period of time, with minimum maintenance required (Kirui & Von Braun, 2018). Consequently, the South African automotive assembly organisations should revise their performance management systems and implement mechanised practices that help to achieve new productivity goals and support organisational and cultural change (Grewal, 2011). This must be based on an understanding of the economic factors affecting mechanisation in operations. Besides the achievement of the study objectives, the following conclusions can be made on the adoption of mechanisation:

1) It has a potential for reducing errors, improving quality and augmenting human capacity (Bejakovi & Mrnjavac, 2020).
2) It is associated with increased productivity and a safer worker environment (Müller *et al.*, 2018b)

In order to maximise performance, a comprehensive performance policy must be developed that aligns mechanisation to productivity and product quality in the manufacturing process (Autor, 2015).

STUDY LIMITATIONS

The study was limited to an automotive assembly organisation within the eThekwini Municipality. The investigation was conducted in a single company that has adopted mechanisation in its assembly process. As there are eight registered assembly organisations in South Africa (SAinfo, 2018), the results cannot be extrapolated to other companies within the sector. Future studies ought to use the more advanced Johansen VAR methodology, which relies on large datasets.

CONCLUSION

Mechanisation has been perceived by researchers as having numerous benefits for the industry, one of these being that mechanisation is related to the productivity of industrial activities (Müller *et al*., 2018a). It minimises or reduces labour content, so it maximises the performance of the production with less time required (Lamsal, 2018). Thus, the industry gains in productivity along with mechanisation (Fiscor, 2016). Singh (2006) confirmed a positive correlation between productivity and mechanisation. Thus, Abbas, Yang, Ehsan, Khurram, Riaz, and Tahir (2017) assert that increasing productivity requires more efficient mechanisation. Although mechanisation is a type of investment in the industry, it is essential in increasing the productivity of activities (Kirui & Von Braun, 2018). Hence, the study revealed the relationship between the product quality and the quality of service offered by the organisation after mechanisation.

FUTURE RESEARCH REQUIRED

During the course of this study, issues relating to the long-term survival of mechanisation after implementation were not covered. This includes the applicability of mechanisation to a wider sector of the economic activity, including the public sector. The nature of this research did not allow these areas to be covered in depth, and it is therefore recommended that future research should examine the following issues in greater depth:

- when to use and when not to use mechanisation in the process;
- the applicability of a mechanised approach to other industrial sectors;
- the process followed during the implementation of mechanisation; and
- a more comprehensive investigation should be carried out using a randomised sample of the registered automotive manufacturers that use mechanisation strategy to see if the results can be generalised.

The study investigated the influence of mechanisation on quality in the automotive assembly organisation in South Africa. The pre- and post-mechanisation quarterly data from company records were collected, including the data on Takt time. It established that mechanisation improved productivity and product quality in the selected automotive organisation of South Africa.

REFERENCES:

1. Abbas, A., Yang, M., Ehsan, E., Khurram, Y., Riaz, A. & Tahir, I. (2017). Quantification of mechanisation index and its impact on crop productivity and socio-economic factors. *International Agricultural Engineering Journal.* 26 (3), 59-64.

2. Ahlmann, H. (1993). Increased reliability and efficient maintenance. *Lund Institute of Technology.* Lund (in Swedish).

3. Autor, D.H. (2015). Why are there still so many jobs? The history and future of workplace automation. *Journal of Economic Perspectives*. 29 (3), 3-30.

4. Arnold, C., Kiel, D. & Voigt, K.I. (2016). How the industrial internet of things changes business models in different manufacturing industries. *International Journal of Innovation Management*. 20 (8), 1-25.

5. Bejakovi, C, P. & Mrnjavac, Z. (2020). The importance of digital literacy on the labour market. *Employee Relations: International Journal*. 42 (4), 921-932.

6. Bock, T. (2015). The future of construction automation: technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*. 59 (2), 113-121, doi: 10.1016/j.autcon.2015.07.022, available at: www.sciencedirect.com/science/article/pii/S092658051500165X?via%3Dihub.

7. Bright, J.R. (1958). Automation and management, available at: http://homepages.rpiscrews.us/ simonk/pdf/bright1958.pdf (accessed 27 June 2021).

8. Bryman, A. & Bell, E. (2007). Business Research Methods. *Oxford Press*: USA.

9. Corbyn, J. (2017). Let workers control robots. BBC News, available at: www.bbc.com/news/ uk-politics-41614820.

10. Curwin, J. & Slater, R. (2002). Quantitative Methods for Business Decisions. *British Library Cataloguing Data*: London.

11. Daso, F. (2017). Bill Gates and Elon musk are worried for automation - but this robotics company founder embraces it. Forbes, available at: www.forbes. com/sites/frederickdaso/2017/12/18/bill-gateselon- musk-are-worried-about-automation-butthis- robotics-company-founder-embraces-it/

12. Endsley, M.R. & Kaber, D.B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics*, 42 (3), 462-492, doi: 10.1080/ 001401399185595.

13. Ericsson, J. (1997). Störningsanalys av tillverkningssystem: Ett viktigt verktyg inom Lean Produktion., PhD thesis, Lund University (in Swedish).

14. Fiscor, S. (2016). Miners make significant productivity gains during WWII: developments during the 1940s usher in a new era of mechanisation and labour issues (Accessed 12 July 2021), available at: www.e-mj.com/features/miners-make-significant-productivity-gains-during-wwii/

15. Folts, F.E. & Jerome, H. (1935). Mechanisation in industry. *Journal of the American Statistical Association*. 30 (192), 756-758, doi: 10.2307/2277740.

16. Grewal, S. (2011). Manufacturing Process Design and Costing: An Integrated Approach. *Springer*, London.

17. Grieco, E. (2019). US newsroom employment has dropped a quarter since 2008, with greatest decline at newspapers. Pew Research Center, available at: www.pewresearch.org/fact-tank/ 2019/07/09/u-s-newsroom-employment-hasdropped- by-a-quarter-since-2008/

18. Groover, M.P. (2010). Fundamentals of Modern Manufacturing: Materials, Processes, and Systems. 4th ed., Wiley, Hoboken, NJ.

19. Ingemansson, A. (2004). On reduction of production disturbances in manufacturing systems based on discrete-event simulation. PhD thesis, Lund University, Lund.

20. Kirui, O.K. & Von Braun, J. (2018). Mechanisation in African agriculture: a continental overview on patterns and dynamics. Available at: www.zef.de (accessed 18 July 2021).

21. Kumar, U., Galar, D., Parida, A. & Stenström, C. (2013). Maintenance performance metrics: a state-of-the-art review. *Journal of Quality in Maintenance Engineering*. 19 (3), 233-277.

22. Lamsal, E. (2018). Mechanisation and its level. Ekendra Online, available at: https://ekendraonline. Com/engg/economics/mechanisation-and-its's-level/ (accessed 18 July 2021).

23. Lebednik, C. (2012). Tools and Techniques for Quality Control in the Automobile Industry. Available at: http://www.ehow.com/list_7559133_tools-quality-control-automobile-industry.html (Accessed: 17 July 2021).

24. Ljungberg, O. (1998), Measurement of overall equipment effectiveness as a basis for TPM activities. *International Journal of Operations & Production Management*. 18 (5), 495-507.

25. Manyika, J. (2017). A future that works: AI automation employment and productivity. McKinsey Global Institute Research, Tech. Rep, available at: www.mckinsey.com/ featured-insights/digital-disruption/harnessingautomation-for-a-future-that-works.

26. Müller, J.M., Kiel, D. & Voigt, K.I. (2018a). What drives the implementation of industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*. 10 (1), 247-271.

27. Müller, J.M., Pommeranz, B., Weisser, J. & Voigt, K.I. (2018b). Digital, social media, and mobile marketing in industrial buying: still in need of customer segmentation? Empirical evidence from Poland and Germany. *Industrial Marketing Management*. 73 (2), 70-83.

28. Neelamkavil, J. (2009). Automation in the prefab and modular construction industry. *Proceedings of the International Symposium on Automation and Robotics in Construction*. pp. 299-306, doi: 10.3892/ol.2016.4893.

29. Parasuraman, R., Sheridan, T.B. & Wickens, C.D. (2000). A model for types and levels of human interaction with automation", *IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans*, 30 (3), 286-297, doi: 10.1109/3468.844354.

30. Phogat, S. & Gupta, A.K. (2017). Identification of problems in maintenance operations and comparison with manufacturing operations: a review. *Journal of Quality in Maintenance Engineering*. 23 (2), 226-238, doi: 10.1108/JQME-06-2016-0027.

31. SAinfo. (2018). South Africa's automotive industry. Accessed 14 July 2021, from http://www.southafrica.info/doing_business/economy/key_sectors/ motorindustryboost.html.

32. Save, L. & Feuerberg, B. (2012). Designing human-automation interaction: a new level of automation taxonomy. p. 978, available at: http://hfes-europe.org (accessed 24 July 2021).

33. Schwab, K. (2015). The fourth industrial revolution. Foreign Affairs, available at: www.foreignaffairs.com/articles/2015-12-12/ fourth-industrial-revolution.

34. Sheridan, T.B. & Verplank, W.L. (1978). Human and computer control of undersea teleoperators. Man Machine Systems Lab Department of Mechanical Engineering, December, p. 343, Cambridge, MA, doi: 10.1080/02724634.1993.10011505.

35. Singh, G. (2006). Estimation of a mechanisation index and its impact on production and economic factors: a case study in India. *Biosystems Engineering*. 93 (1), 99-106, doi: 10.1016/j. biosystemseng.2005.08.003.

36. Villarreal, B. & Alanis, M.R.A. (2011). Simulation approach to improve assembly line performance. *The International Journal of Industrial Engineering: Theory, Application and Practice*. 18 (6), 283-290.

37. Yin, R.K. (2008). Handbook of Applied Research: California. Sage. Thousand Oaks.
38. Ylipää, T., Harlin, U. & Stahre, J. (2007). Production disturbances in Swedish Production industry: a survey study. Working paper, Chalmers University of Technology, Gothenburg.

39. Williams, T.J. (1999). Establishment of the place of the human in enterprise integration. *IFAC Proceedings Volumes*. 32(2), 157-162, doi: 10.1016/S1474-6670(17)56029-2.