MIXED MODEL LINE BALANCING FOR MANUAL ASSEMBLY SYSTEM

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ABSTRACT

It is imperative for organisations in the automotive industry to adopt a culture of continuous improvement due to a highly competitive market environment. An automotive manufacturer had adopted a takt time of 60 minutes but has been facing challenges in meeting the daily target of vehicles produced per day. The challenges were attributed to the imbalance of the assembly line and waste generated from non-value adding activities. The focus of this work is to improve a manual automotive assembly system. Time studies were conducted, a list of tools and shovel-ware components was compiled, and work stations were allocated to all the operations. After line balancing, the bus trailer was moved from the sub-assembly bay to the production line leading to more productivity. Additionally, the centralisation of bus trailer allowed for the optimal use of the tools, and the savings that were derived amounted to R350 000 per year.

Keywords: Line balancing, Manual assembly system, Mixed model

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1 INTRODUCTION

The global landscape is characterised by an inflationary environment where wages have failed kept pace with the increased cost of living. It has become increasingly vital for firms to adopt a culture of continuous improvement, especially in a market as competitive as the automotive industry [1]. In South Africa, the automotive industry's localisation ambitions are retarded and it is difficult to create sustainable jobs or attract investment opportunities to grow the South African economy due to loadshedding which is the prevailing biggest inhibitor [2]. The case study organisation is a leading manufacturer of medium, heavy and extra-heavy trucks, as well as buses and coaches, based in South Africa. The assembly plant is basically made up of 15 workstations; which are divided into 3 zones and at the end of the assembly line, there is a quality inspection bay where all vehicles produced on the line are inspected for faults. The scope of the study was improve the manual assembly efficiency through the deployment of mixed model assembly line analysis with focus on the DBC bus train chassis assembly and XLA truck. The XLA was the most difficult vehicle to assembly due to the nature of its design. The studied manual automotive component assembly system was characterised by a bus chassis that was built on the bus assembly line, while the chassis extension or trailer is built separately on a pre-assembly station next to the assembly line. The preliminary study of the manual assembly line demostrated inherent waste in terms of ineffective space and manpower utilisation. The study focused on improving process effectiveness by integrating the two chassis and assembling them on the assembly line while concurrently keeping the daily target the same.

2 RELATED LITERATURE

Lean philosophy fundamentally targets identifying and eliminating waste from production processes, fousing on maintaining the product value wihile using less work [3, 4]. A manual assembly line consists of a sequence of consecutive workstations where assembly tasks are performed by human workers as the product moves along the line, with the workers performing a subset of assigned assembly tasks within a specified time range [5]. The factors that favour the use of manual assembly lines include identical or similar products, high or medium demand for product, total work content that can be divided into work elements, and when it is economically infeasible or technologically impossible to automate the assembly operations [6].

Arising from the complexity of necessary tasks that must be accomplished manually, manual assembly line may be characterised by inefficient processes that are inherently wasteful. Waste from assembly processes is basically caused by inefficient processes, unnecessary delays, costs and human errors [7]. The fundamental seven forms of waste that characterise manual assembly systems include transportation, overproduction, processing, motion, inventory, waiting and defects. Yerasi [8], in improving the overall performance of a production line, re-configured an assembly system from two manual assembly line configurations and the results demonstrated that the operator productivity was improved when the existing assembly method was changing over to a single-stage assembly line configuration.

Correia et al. [9] posited that despite the notion that manual assembly lines are generally studied heavily before implementation, numerious challenges emanate if the product needs some modifications. The product design modifications sometimes create huge problems for the already installed manual assembly line, creating line imbalances and other forms of waste. In such circumstances, visual management techniques and value stream mapping can be deployed to fully comprehend the different tasks and operations. Lean line balancing can be used to reduce the line bottlenecks by balancing the workstation task times to reduce delays, and even out worker taskloads resulting in better line efficiency and production rate [9].

To cope with the excessive information flow, Aljinović et al. [10] developed a procedure to aid decision-makers in selecting the most applicable Industry 4.0 technology to integrate into a prevailing assembly line to enable the transformation of production towards smart production. The proposed production paradigm was aligned with the expected organisation's strategic goals since the procedure took into consideration the current production plans, scheduling, throughput, value from the end-user perspective and other related production metrics. The results were validated through a real assembly line providing a decision support system that enabled the decision-makers to express preferences through criteria weights and preference functions [10].

Scheduling decisions in assembly lines can be multi-objective, using seven different products, Ostermeier [11], while modelling human learning and deterioration effects explicitly, simulated a real unpaced mixed-model assembly line to analyse the effect of different sequence types on the desired objectives. The results demonstrated that sizeable trade-offs existed as different sequence types were preferred for several scheduling objectives.

3 RESEARCH METHODS

3.1 Background

Figure 1 shows a schematic for the research methods that were deployed to reduce waste and improve the manual automotive component assembly system.

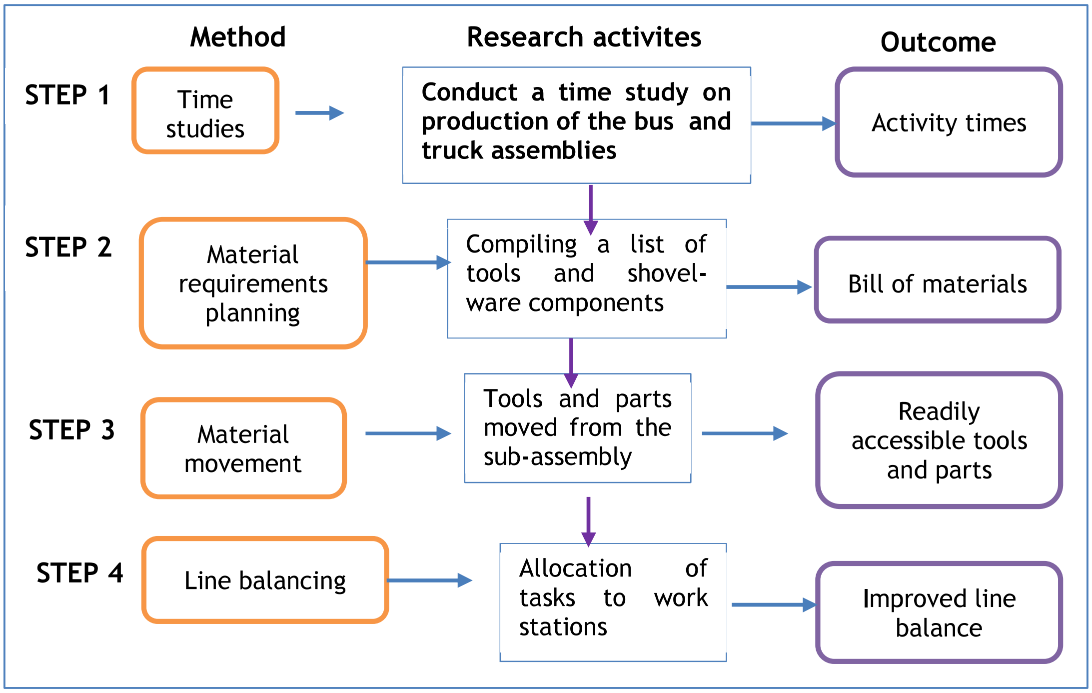

Figure 1: Schematic for research methods

Figure 2 shows a schematic for process flow manual automotive component assembly system, characterised by 15 workstations and a quality inspection bay.

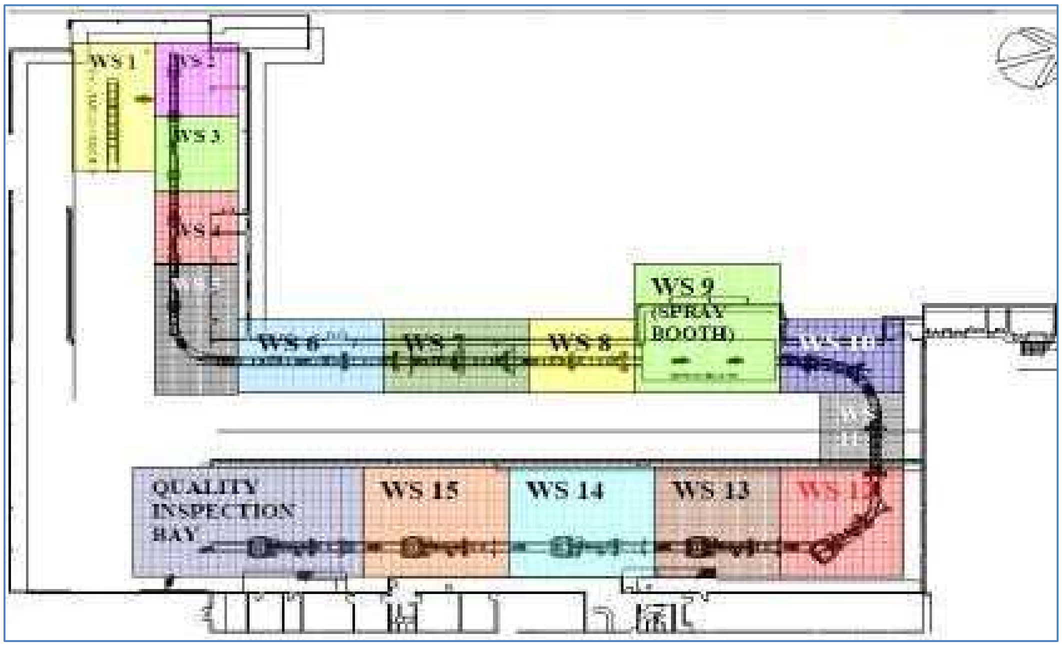

Figure 2: Process flow manual automotive component assembly system

The bus train shown in Figure 3 (the bus with a chassis extension is one of the vehicles built on the line (bus assembly line). Currently the actual chassis was built on the assembly line while the chassis extension (hereafter referred to as the trailer) is built separately on a pre-assembly station next to the assembly line, the assembly line only makes bus chassis without a body.

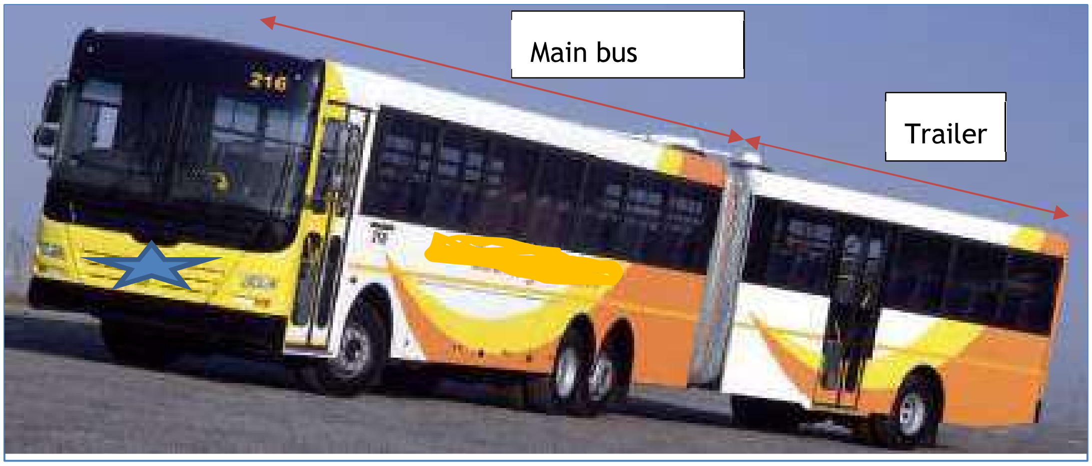

Figure 3: A completed bus train

3.2 Time and work study

Table 1 shows the time study results for DBC main bus chassis assembly as well as for the sub-assembly. A time study was conducted for production of the trailer on the sub-assembly work station to get the total assembly time required to produce a complete trailer and it was found that the trailer chassis took 6 hours and 6 minutes to make. The data showing all the operations required to assemble the trailer was also collected. The next step was to compile a list of all the tools and shovel-ware components that are required to assemble the trailer. It was crucial to ensure that all the tools and parts are available on the assembly line before commencing the bus trailer integration project so that the activities would be executed smoothly without stoppages. All the tools were moved from the sub-assembly work station to the main assembly line and placed at the work stations for easy access by the operator.

Table 1: Time study results for DBC bus chassis main an sub-assembly

Work element	Description	DBC bus chassis		XLA truck
		Duration (mins) main assembly	Duration (mins) for sub-assembly	
1	Chassis ladder assembly	30	28	68
2	Peripheral mounting and chassis coupling	25	25	30
3	Brake valves sub assembly mounting	52	50	45
4	Chassis electric system connection and air brake pipe mounting	60	58	60
5	Axle sub assembly	53	50	46
6	Axle mounting	60	58	56
7	Chassis turning	30	25	28
8	Preparation for chassis painting by masking of paint sensitive parts	20	20	25
9	Chassis painting	15	15	20
10	Wheel mounting and exit the assembly line	50	50	45

3.3 Allocation of operations to work stations for mixed model assembly line

Using the time and work study data for the vehicles produced on the line and functions performed every day, the next step was to allocate work stations to all the operations. The Kilbridge & Wester rule, where assignment of work elements to stations is grounded on the time that is required each work element, was used as a line balancing algorithm.

With regards to determining the number of workers, ***w***, for a mixed model assembly line:

$$w = \frac{WL}{AT} \tag{1}$$

and

$$WL = \sum_{j=1}^{P} R_{pj} T_{wcj} \tag{2}$$

where ***WL*** is workload to be accomplished over a scheduled period of time, and ***AT*** is the available time per worker in the period. ***P*** is number of models to be produced and ***j*** is denoting the model.

The objective of mixed model assembly line balancing was to distribute the total work content on the assembly line as uniformly as possible among the operators.

The objective function was expressed as:

$$Minimise(wAT - WL) \text{ or } Minimise \sum_{i=1}^{w}(AT - TT_{si}) \qquad \textbf{(3)}$$

where w is number of workers assuming that *Mi =1*, so that *n* = *w*. The available time (AT) during the period of interest in minutes, and TT_{si} was total service time at station *i* to perform its assigned portion of the workload in minutes.

$$WL = \sum_{j=1}^{P} R_{pj} T_{wcj} \qquad \textbf{(4)}$$

Total time per element, TT_k is:

$$TT_k = \sum_{j=1}^{P} R_{pj} T_{ejk} \qquad \textbf{(5)}$$

Total service time at each station is computed as:

$$TT_{si} = \sum_{k \varepsilon i}^{P} TT_k \qquad \textbf{(6)}$$

where TT_{si} is total service time at station *i*

Balance efficiency, E_b is computed as

$$E_b = \frac{WL}{w(Max\{TT_{si}\})} \qquad \textbf{(7)}$$

where $Max\{TT_{si}\}$ is the maximum value of total service time among all stations.

4 RESULTS AND DISCUSSION

4.1 Allocation of bus trailer sub-assembly functions to main assembly line

The study focused on improving process effectiveness by integrating the two chassis and built both of them on the assembly line. The bus trailer was initially assembled on its own small bay; with all the tools and shovel ware components required to build a trailer available on that small bay and the dates on which the DBC bus trailer was completely assembled was different from the date on which the trailer was produced because of the fact that they are built on “different” production lines. Due to poor planning of shovel-ware, in some cases, it took just over two shifts to produce the DBC bus chassis on the assembly line and just over 6 hours to produce a trailer, so this means that a completed trailer chassis have to wait for over 1 shift to be coupled with its DBC bus. The aim was therefore to keep the daily target (the daily number of vehicles expected to be produce every day) the same (8 vehicles per shift), so that meant the bus trailer was not going to be counted as a unit. An operator was assigned to assemble the bus trailer with the help of the operators on the line in some instances. This operator would follow the chassis around the production line until it goes into the spray booth (work station 9) for chassis painting. To move this small trailer around the line it was crucial to couple it to the DBC bus train which is part of the goofy using a specially designed coupling. The main reason for coupling this trailer to another vehicle was to avoid counting it as a complete unit, and eliminate unnecessary pre-assembly station and centralise production.

4.2 Mixed mode assembly line balancing

After the allocation of bus trailer sub-assembly functions to main assembly line, it was imperative to ensure that the line was well balanced. The automotive manufacturer had adopted a takt time of 60 minutes but has been facing challenges in meeting the daily target of vehicles produced per day. The two models, the DBC bus train chassis assembly and XLA truck were to be assembled on a mixed model manual assembly line, taking into consideration, their work elements, element times, and precedence constraints. Given the target of 60-minute takt time, that would cascade to one DBC bus train chassis assembly per 2 hours and one XLA truck chassis per 2 hours. The bus trailer elemental times were integrated into main bus chassis so that a bus chassis and trailer chaiss would be counted as one unit, hence the mixed model analysis considered the the DBC bus train chassis assembly and XLA truck. Assuming an ideal efficiency of 100%, repositioning efficiency of 100%, and average manning level of 2 workers per station, the ideal minimum number of workstations that were required to realise the required production rate was computed and thereafter the Kilbridge & Wester method was deployed to solve the line balancing problem.

Table 3 shows the totals for the product of elemental times and production rates (R_p) that were used to derive the minimum number of workstations that were required to achieve production rates the DBC bus train chassis assembly and the XLA truck chassis.

Table 2: Workloads for production rates the DBC bus train and the XLA truck chassis

Work element	Description	R_p x DBC bus chassis duration	R_p x XLA truck chassis duration	Sum
1	Chassis ladder assembly	30	34	64
2	Peripheral mounting and chassis coupling	13	15	28
3	Brake valves sub assembly mounting	26	23	49
4	Chassis electric system connection and air brake pipe mounting	30	28	58
5	Axle sub assembly	27	23	50
6	Axle mounting	30	24	54
7	Chassis turning	15	14	29
8	Preparation for chassis painting by masking of paint sensitive parts	10	13	23
9	Chassis painting	8	10	18
10	Wheel mounting and exit the assembly line	25	23	48
Total				418 mins

Given the available takt time of 60 min, total service time at each station was 60 min and the minimum number of work stations required was found to be 7 stations.

Table 3 shows the line balancing results by using the Kilbridge & Wester method.

Table 3: Allocation of elements to workstations

List of elements by column		
Element	TT_k (mins)	Column
1	64	I
2	28	II

Allocation of elements to workstations			
Station	Element	TT_k (mins)	TT_{si}
1	1	64	64 min
2	2	28	28 min

3	49	III
4	58	IV
5	50	V
6	54	VI
7	29	VII
8	23	VIII
9	18	IX
10	48	X
	418min	

3	3	49	49 min
4	4	58	58 min
5	5	50	50 min
6	6	54	54 min
7	7	29	
	8	23	52 min
8	9	18	18 min
9	10	48	50 min
			418 min

Given that maximum {TTsi} = 60 min, balance efficiency,

$$E_b = \frac{WL}{w(Max\{TT_{si}\})} = \frac{418.0}{9(60)} = 0.774 = \mathbf{77.4}\%$$

It is worth noting that the XLA is one of the trucks produced on the assembly line, the XLA is the most difficult vehicle to assembly because of its design; hence the need to introduce a sub-assembly concept for XLA truck on station 1 (TT_{si} = 64 minutes).

5 CONCLUSION

Without compromising efficiency, assembly lines nowdays must be as flexible as possible. The engineers of today need to embrace diverse physical tools such as flexible workstations, flow racks, pick-to-light systems and visual work instructions in complementing the deployment of lean tools on mixed-model assembly lines. Mixed model assembly line balancing ensured the distribution of the total work content on the manual assembly line as uniformly as possible among the operators. The automotive manufacturer was able to meet the daily target of vehicles produced per day from the adopted takt time of 60 minutes. After implementing the mixed model line balancing solution for manual assembly system, extra space was created at the trailer static bay and this could be used for sub-assembling other models. The centralisation of bus trailer enabled effective manpower and time utilisation as well as the optimal use of the tools since the same tools and jigs used for all the other vehicles were used for the trailer.

6 REFERENCES

[1] D. Soares, F. J. G. da Silva, S. C. F. Ramos, K. Kirytopoulos, J. C. Sá, and L. P. Ferreira, "Identifying Barriers in the Implementation of Agile Methodologies in Automotive Industry," *Sustainability,* vol. 14, no. 9, p. 5453, 2022.

[2] R. Hartley and R. Morrow, "A Special Economic Zone Masterplan for Gauteng," 2021.

[3] A. Anvari, Y. Ismail, and S. M. H. Hojjati, "A study on total quality management and lean manufacturing: through lean thinking approach," *World applied sciences journal,* vol. 12, no. 9, pp. 1585-1596, 2011.

[4] A. M. R. da Silva, M. E. dos Santos, D. B. de Alencar, M. F. Junior, I. L. R. Rodriguez, and M. H. R. Nascimento, "Applying the Lean Concept through the VSM Tool in Maintenance Processes in a PIM Manufacture," *International Journal of Advanced Engineering Research and Science,* vol. 6, no. 7, 2019.

[5] A. Adeppa, "A Study on Basics of Assembly Line Balancing," *International Journal on Emerging Technologies,* vol. 6, no. 2, p. 294, 2015.

[6] B. Rekiek and A. Delchambre, *Assembly line design: the balancing of mixed-model hybrid assembly lines with genetic algorithms*. Springer Science & Business Media, 2006.

[7] P. Arunagiri and A. Gnanavelbabu, "Identification of major lean production waste in automobile industries using weighted average method," *Procedia engineering,* vol. 97, pp. 2167-2175, 2014.

[8] P. Yerasi, "Productivity improvement of a manual assembly line," Texas A & M University, 2012.

[9] D. Correia, F. Silva, R. Gouveia, T. Pereira, and L. P. Ferreira, "Improving manual assembly lines devoted to complex electronic devices by applying Lean tools," *Procedia Manufacturing,* vol. 17, pp. 663-671, 2018.

[10] A. Aljinović, N. Gjeldum, B. Bilić, and M. Mladineo, "Optimization of Industry 4.0 Implementation Selection Process towards Enhancement of a Manual Assembly Line," *Energies,* vol. 15, no. 1, p. 30, 2021.

[11] F. F. Ostermeier, "On the trade-offs between scheduling objectives for unpaced mixed-model assembly lines," *International Journal of Production Research,* vol. 60, no. 3, pp. 866-893, 2022.

FMEA/FMECA APPLICATION FOR THE SAFER INDUSTRY - SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Despite astronomical investments in plant safety, poor plant uptime and accidents continue to prevail. The objective of this study was to explore the application of FMEA/FMECA cases in the literature. FMEA/FMECA articles (52) were identified from 2010-2022 studies. This was done by applying a general systematic literature review research methodology and the Thematic Analysis Framework. Risk Priority Number determination was found to be based on subjective data (Severity, Occurrence, and Detectability), this had a negative effect on the apparatus results and ultimately on plant maintenance strategy. A computerised maintenance management system was identified as the most common source of data. The integration of mathematical tools and data analytics into the tool framework offered promise in improving risk assessment by providing objective estimations and reducing subjectivity. Practitioners were provided with a list detailing the limitations of this tool and areas that need further improvement. Research output in this sector had positive growth in the application of this tool.

Keywords: FMEA, FMECA, RPN, Safety, Maintenance.

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