Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

Article

Productivity Improvement using Simulated Value Stream Mapping: A Case Study of Truck Manufacturing Industry

Fikile Poswa [1]*, Khumbulani Mpofu [1] and Olukorede Tijani Adenuga [1],

[1] Department of Industrial Engineering: Tshwane University of Technology Staatsartillerie Rd, Pretoria West, Pretoria, 0183; mpofuK@tut.ac.za (K.M.); adenugaOT@tut.ac.za (O.T.A.)
* Correspondence: fposwa44@gmail.com; Tel.: +27728063045

Abstract: The accumulation of process waste in production line cause fluctuations, bottlenecks, and increased inventory in workstations disrupting process flow. In this paper, the aim is the use a simulated value stream mapping (SVSM) as lean assessment tools for decision making in continuous improvement process to influence and provide consideration and consistency on productivity improvement in the production system. The proposed methodology applied discrete event simulation for production process operations improvement to eliminate non-value adding times and provides good quality products at the lowest cost and highest efficiency. The results are the analysis of the current state of the production system in a South African truck manufacturing industry small and medium enterprise (SMEs) as a potential solution for production system future state. The identified non-value adding times in 6 most critical workstations was eliminated by SVSM that resulted to a productivity improvement of 4%, most importantly bringing the productivity to 95% and total cycle time improvement to 451 for small units and 466 for large units. The results proposed combined VSM and Simulation techniques which enhances LEAN application by DES to increase productivity and performance improvement to remain competitive in the global economy.

Keywords: simulated value stream mapping; small and medium enterprise

1. Introduction

Companies seek strong methodologies to increase productivity and performance improvement to remain competitive in the global economy. Process optimisation focuses on quality, productivity improvement and cost reduction with most companies focusing on competitiveness and continuous improvement to achieve sets key performance indicators (KPIs) targets. Productivity is one of the key elements to measure how well the company is doing in the marketplace. Production flow is one of the factors taken into consideration when measuring and improving the productivity. This is based on the contributing factors that make a success of the applied tools [1]. New models are developed to ensure success and competitive advantage in the marketplace, which are complementary model to other continuous improvement tools and the existing paradigms in place to monitor the dynamics of the marketplace. Lean manufacturing tools are used in the 21st century to ensure that companies perform at their maximum. The selection of an ideal tools in continuous improvement and productivity improvement projects has been a challenge for in SMEs automotive till date [2]. Most researcher ignores these challenges because lean manufacturing failure are rarely reported and yet they are required to serve as guideline to a sustainable production line. The lack of suitable framework on how to use lean manufacturing tools for the success of each project continuous improvement support has been a major issue that are not address by researchers [3]. There are emerging technologies and collaborative robotics that are required to keep up with the pace of competitiveness for productivity improvement [4]. The issues with these emergent technologies are the non-empirical evidence to show the effectiveness of these of these approaches. Lean manufacturing has played a huge role in making sure that all levels of production and manufacturing are

© 2022 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

capable of delivering their optimal processes. Simulation has been around for decades but not taken as effective tool in production and manufacturing environment because of its stochastic nature. Efficiency is one of the most important aspect of productivity, which needs to keep it at its maximum all the time. Value Stream Mapping has been an effective tool in recent years to visualise the production and manufacturing system [5]. This shows how non-value adding operations disrupt most of the production lines mostly in automotive manufacturing system, because non-value adding are considered as value adding times [6]. Productivity improvement happens when there are systems ensure that all the KPI's involve are monitor to fulfil all the demands. This article aims to a simulate value stream mapping (SVSM) as lean assessment tools for decision making in continuous improvement process to influence and provide consideration on productivity improvement in the production system. Section 1 discussed the review of the current production state challenges and potential solution for future state of the production system. Section 2 discussed the literature reviews on how the production system behaves, and how the methods are applied in production to seek improvement opportunities. The methodology in section 3 discusses how the type of the applied data is ideal to the study. Section 4 presents the results that show the study application was to improve productivity of the truck manufacturing industry, while the last section presents the conclusion.

2. Literature Review

Lean manufacturing system has been a drive force for productivity improvement in an automotive industry, which extend from long-time leader the Toyota Production System (TPS), known for changing how things are done in the automotive industry. To be competitive in a sustainable environment, different techniques are used to eliminate waste that result in creating non-value adding times in the production system [7]. These non-value adding times contributed to more complex process when classification of the process is not done properly because of the nature and dynamics of the process that are not visible enough [8]. Value Stream Mapping is the commonly used tool in waste reduction project where it provides the visualisation of the entire production system. This helps to identify waste and classification done based on the nature of the waste for a well-defined decision-making. VSM is tool that enhance the use of other waste reduction techniques to enhance core functionality support using VSM in waste reduction and proper strategies on how to reduce the time wasted on the system [9]. Non-value adding is the time wasted by not adding value to the product and translated to not adding any value to the customer because the customer is not willing to pay for that time. Despite the VSM, capabilities there are shortcoming when the production system shows the characteristics of being dynamic. VSM can be complemented by the use of digitalisation to bring flexibility that will overcome these short comings [10]. Though digitalisation have different elements and application that might be costly when applied to enhance VSM, simulation have been around for quite some time and there is new application designed to complement VSM. VSM is a lean manufacturing technique that align with other tools used for process optimisation and continuous improvement projects. This application paves a way to apply those techniques in a way that will be less costly and more effective. The implementation of lean manufacturing is more expensive when everything has to undergo a trial or assurance before it can be up and running and this is a time constraint to a project [11]. Time consumption happens when appropriate lean manufacturing tools are not used properly, which happens when the uncertainties of the process have not been identified properly. Identifying the cause of these uncertainties become difficult when the production system has the characteristics of dynamic production system.

Simulation in production environment provide stability by assuring that real time use of simulation identify the hidden cause of uncertainties in decision-making [12]. Simulation in business practice pro-vide assurance to the production system. Performance and high expectation are the key driver of a successful production system [13]. This drives the determination of seeking a production system that continuously improving and aiming to use lean as the assessment tool [14]. The use of lean manufacturing and simulation

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

models is to effectively apply business strategy to be competitive and efficient [15]. Most automotive industries use discrete manufacturing systems where queuing takes place, causing delays in the process workstations. Too many delays increase waiting time. In a production environment, waiting times are recorded as idle time that a customer is unwilling to pay for, thereby decreasing productivity. Insufficient process reliability, supply chain, and an inactive workforce cause idle time in the system. In this kind of manufacturing system, some disruptions are caused by dynamics in the production system, which can be evaluated using Discrete Event Simulation (DES) [16]. Simulation provides management with different alternatives compared and trailed for better decision-making in the application of lean manufacturing. Lack of automation (process variability) in SME operations and for the entity to become accustomed to a high demand that requires complex structures in their production system has become a challenge. This makes it hard to complete a feedback loop to analyse the system behaviour and enable performance improvement in a manufacturing system. The ap-plication of simulation models can minimise these challenges by analysing these complex structures [17]. Simulation is a good tool to assess a production system without any physical intervention on the system. This approach gives an overview of the system compared to manual operation intervention. The emerging use of information communication technology (ICT) and information technology (IT) in the manufacturing sector has increased information transparency across all functional areas of the organisation. This transparency helps improve the supply chain and just in time (JIT), deliveries to production, minimising the dynamic disruption and uncertainty in the production pro-cesses. Proper alignment of every aspect that contributes to production improves efficiencies, thus improving productivity ([18]. The industrial revolution has shifted the emphasis on a production system that focuses on quality to one that focuses on both quality and production efficiency. This forces business efficiency to pull in the direction of global competitiveness by using advanced technological innovation to improve productivity [19].

The application of cyber physical system (CPS) in manufacturing systems has improved production systems and enhanced the use of digital simulation to improve real times and cost-effectiveness in the production system. A simulation-based approach in a production system has brought about significant advancement, especially in processes involving human manpower [20]. Production visibility is essential in production improvement because it brings about the overall flexibility of the production system. SMEs in automotive industry apply lean manufacturing in an advanced manner by keeping its original principle but applying computer-based simulation to optimise the production process. Lean manufacturing is famous for production system improvements, but it is difficult for dynamic processes where visibility is critical. Simulation is a complementary tool for the difficulties of production process dynamics [21]. Evaluating the environmental impact in a dynamic production process needs more visibility to sup-port decision-making. VSM is a reliable tool in process visibility, making it the most used tool in lean thinking and implementation. It is a vital tool in developing knowledge and understanding of the production value. Simulation complements VSM by utilising and analysing the data collected from dynamic processes [7]. It is a good practice in discrete sequence production systems where resources such as facility layout, tool location, and part supply set the pace from the warehouse and process complexity, rather than the machine setting the pace. Processes are executed when the production system has adequate facility layout to allow the process to be performed at maximum best [22; 23; 24]. VSM can only analyse one product at a time, which is different from simulation models. Although VSM visualises the process by showing the cycle and changeover times, it fails when the process is dynamic. Mixed production systems cannot be studied with VSM alone; multiple projects would have to be implemented to accommodate all the model/products produced in that system [25; 26; 27]. Value stream mapping visualises the data collected from the process by plotting each component on the map. VSM is bounded by symbols used to represent the components in the process; however, some information is not displayed in the VSM map to visualise how the process is doing. VSM is a tool that supports the improvement process

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

analysis in manufacturing system. The results displayed by VSM are of great use when line balancing is applied to validate how each process contributes to process reliability and capability. A reliable process improvement is based on the characteristics required to perfect multiple activities and provide flexibility where necessary [28, 29].

3. Materials and Methods

3.1 Materials

The use of quantitative research approach in this paper was to determine the relationship between the processes in the production system for SMEs in the automotive industry. Quantitative research is a descriptive approach, based on time measurement and was used to gather data on time measurement in all stations involved in the truck production system. Secondary data of the time study was obtained from South Africa truck manufacturing company.

3.1.1 Current state VSM

The current state VSM is the logical representation of how the production system behaves, where the VSM schematic diagram is filled with times that coordinate the production system. When the current state is completely plotted, all the measurements are in place to do the analyses, the visualisation of every aspect of the production system is clear, and the waste can be identified. The logical diagram of VSM shows how the waste is accumulated in the production system, and suggestions for improvement are observed and proposed based on this logical presentation. VSM visualises the process waste, mainly focusing on times that do not add value to the system output. This is measure by reducing the process times and increasing the units produced in the time allocated for the shift. The VSM used in this research study is design from Microsoft Visio because the software is efficient and easily transferable to any document format.

Yamazumi diagram was developed to determine the current state as a tool used to do line balancing based on the characteristics of the VSM and DES process evaluation. The individual work tasks of the two process elements detailing the time taken are the critical characteristics required for productivity improvement. The importance of TAKT time in the process is to stabilise the process and provide daily information for production throughput. It is a good tool for production-based process on what is planned for the day. Having TAKT time in place for all the products will determine the response to customer demand. The process flow in VSM seems to flow smoothly because everything is within the TAKT time. When everything falls within the TAKT time, it is regarded as perfect execution in the manufacturing industry. In lean manufacturing, TAKT time is used to test a proposed pace to improve productivity. It also acts as a boundary to determine the process flow to ensure no disruptions in the process. It also monitors fluctuation in the process and becomes a signal when these fluctuations exceed the boundary (TAKT time) set to meet customer de-mand. This technique is used in VSM mainly and is different for each unit produced, depending on size and type. The Yamazumi diagram presented in Table 1 shows the current situation for the truck manufacturing assembly, where all the parameters used in this study are plotted to visualise the current situation. Orders come from the customer from the sales department and are shared with the planning department. The information is evaluated and filtered based on the available material stock, and the information is shared with different stakeholders to prepare to produce the product. All the processes involved are prepared accordingly; the flow of material starts from planning by distributing information.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

Table 1. The truck manufacturing assembly current state plotted to visualise current situation.

Station	Process	No. of Op	FKI	NVA	VA	PO2	NVA	VA	JU3	NVA	VA
1	CA	4	28	10.08	17.92	30	10.8	19.2	24	8.64	15.36
2	PE	3	27	12.15	14.85	23	10.35	12.65	28	12.6	15.4
3	FS	4	27	10.8	16.2	32	12.8	19.2	37	14.8	22.2
4	ROU	3	27	11.34	15.66	23	9.66	13.34	30	12.6	17.4
5	R&F	4	36	13.32	22.68	25	9.25	15.74	31	11.47	19.53
6	ASS	3	24	10.56	13.44	18	7.92	10.08	23	10.12	12.88
7	ASL	5	39	14.04	24.96	32	11.52	20.48	31	11.16	19.84
8	CM	4	34	15.64	18.36	32	14.72	17.28	29	13.34	15.66
9	CP	4	30	15	15	34	17	17	34	17	17
10	DS	2	12	9.12	2.88	12	9.12	2.88	12	9.12	2.88
11	EAS	3	27	10.26	16.74	29	11.02	17.98	18	6.84	11.6
12	CAB	4	46	14.26	31.74	22	6.82	15.18	33	10.23	22.77
13	FF	5	41	9.43	31.57	41	9.43	31.49	41	9.43	31.57
14	BHB	6	27	7.02	19.98	67	17.42	49.58	47	12.22	34.78
15	PFV	3	31	17.05	13.95	21	11.55	9.45	24	13.2	10.8
16	VFQ	4	30	6.3	23.7	30	6.3	23.7	30	6.3	23.7

CA - Chassis assembly, assembly of suspension legs; PE - Peripheral mounting, stabilizer bracket mounting, platform supporter mounting, bogey assembly; FS - Fitment of steering box, power steering pipe, brake valves, air tanks, and compressor pipe connecting; ROU - Routing and connection of air pipes; R&F - Rear and front spring mounting, tag axle and front axle mounting; ASS-Assembly of rear axle, fitment of rear axle and prop shaft ASL - Assembly of LSV rods and mounting into rear axle, tail light and wheel choke brackets, battery box, fuel tank bracket mounting, cab tilt mechanism mounting; CM - Chassis masking, loom connection, chassis rubbing, fitment of booster pipe and speed sensor, isolator board mounting; CP - Chassis painting; DS - Drying station; EAS - Engine subassembly, engine mounting, and preparation of cooling pack. Fitment of exhaust and gearbox; CAB - Cab preparation and drop, fitment of soundproof, drag link prep & mounting, air cleaner assembly, mirrors & mudguard mounting; FF - Fitment of fuel tank, tyres, and spare wheel; BHB - Bumper, head light, battery box, trailer loom and mirror, rear mudguard fitment, and brake test; PFV - Programming, filling with fuel, vehicle inspection brake roller, mechanical inspection] and start-up ; VFQ - Vehicle final quality inspection.

3.2. Methods

The link between research design, question and hypothesis was investigated, considering how the parameters were set up to establish the current state of VSM, and the current state of SVSM. These parameters define the data collection form, time study method and data analysis by VSM and SVSM schematic diagrams. The data was simulated using AnyLogic Discrete Event Simulation and manual VSM parameters. System design and process optimisation were done to improve productivity and eliminate hidden waste. The choice of discrete event simulation for this research basically to provide a logic system in discrete processes for autonomous and continuous times. The work measurement technique used in this study is determined by the time series involved in completing one unit in the production line and to compare different cycle times in the determination of the value flow and reliability of the process of the production process.

VSM application in truck manufacturing industry operation is an improvement strategy used to improve process cycle efficiency. An effective production process with a balanced cycle time to improve productivity and efficiency. Simulation process was used as an imitation of the processes in practise and considered as an applied mathematics technique to solve VSM techniques which have been integrated to optimise the production process and minimise errors made in lean manufacturing application projects. VSM was used to visualises what has been fed to the technique which is different to simulation because the results cannot be manipulated compared to VSM. VSM was used to identify all the types of waste involved and categories in which they belong in the value chain of the truck manufacturing industry. When combined, these two techniques bring more attention to detail by complementing errors that might occur as the result of the project, which is very costly in many cases.

Work measurement was used to compare different cycle times in the production process, determine the value flow and the reliability of the process. It assists management in decision-making and application of work rescheduling preparation based on the work content identified as the constraint in the production process. It is used to analyse the work activities identified when a time study was conducted. Identifying VA and NVA times helped the process to minimise or eliminate those tasks and times uses time and motion study to organise how the labour was aligned to the daily demand of the production, how actual cycle times perform against the production TAKT time as presented in the following equation:

$$T_C = Tr + \sum Tsi \tag{3.1}$$

In evaluating the work assignment

$$T_c = T_s + T_r \tag{3.2}$$

Production line efficiency is determined as

$$E = \frac{T_S + T_r}{\frac{60}{R_P}} \tag{3.3}$$

While production line efficiency balancing

$$E_b = \frac{T_{WC}}{wT_S} \tag{3.4}$$

Determination of daily rate of the production system

$$R_p = \frac{D_a}{S_d H_{sh}} \tag{3.5}$$

$$T_p = \frac{60}{R_P} \tag{3.6}$$

Production work content is determined as

$$W_C = \sum_{k=1}^{n} T_C \tag{3.7}$$

$$w = \text{Minimum integer} \geq \frac{T_{WC}}{T_S\, E_b} = \frac{T\, \frac{T_{WC}}{T_S\, E_b}}{T_S\, \frac{T_{WC}}{wT_S}} \tag{3.8}$$

3.3 Distribution Factor to the Assembly Line

Part arrivals are based on exponential distribution, which describes the process of occurrence in discrete events. This shows the number of parts and number of chassis coming through the assembly line. It is one of the findings identified in the model because it causes congestion in the system by supplying too many parts. This tends to overload other stations with less capacity in resources. Poisson distribution application was adopted to in equation is defined by the equation 3.9:

$$\text{f(x)} = \frac{u^x e^{-u}}{x!} \tag{3.9}$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

The secondary data was coded to create the value stream mapping current state and input data into AnyLogic discrete event simulation. As part of DES analysis, entities need to have sequential events that are timeous and behavioural. The time series in the case study populates discrete events occurrence in the production line and other departments contributing to make production a success. This paper focuses on VA and NVA times, achieved by looking at all the aspect that contributes the working states and co-ordinates of these times. Total cycle time is the result of VA and NVA combined and a representative of how the operation is running with respect to process control parameters. The process control parameter use in this paper is the TAKT time, as a pacesetter to all processes in the production line. These parameters used aligned the process with the schedule as the final output of the production line. It serves as guideline to the amount of resource required to complete one unit; thus, helps in the scheduling of the expected output. A tool that prevents spiking process fluctuations by ensuring each process is done under TAKT time. Work measurement technique identifies the time wasted in the process by not adding value to the customer demand (NVA). The observation done while measuring the cycle times are recorded and used during the analysis phase. This is major factor in identify how these wastes accumulates and gives an opportunity to classify the type of waste.
The flow in the production system is one of the important aspects of process improvement, which shows how VSM can be a valuable tool for analysis. TAKT time is one of the coordinates controlling how the production system should operate effectively (Equation 3.9) as a guideline to the determination of cycle times of each process to avoid abnormal fluctuation in production processes. Table 2 and Table 3 presents the initial state of the production system and initial productivity model input using VSM respectively from Table 1.

Table 2. Initial state of the production system.

Schedule Target	Available time (minutes)	TAKT time (minutes)
Daily	9	48.3
Weekly	45	48.3
Monthly	180	48.3

Table 3. Initial productivity model input using VSM.

Mixed Models	Total Cycle Time (minutes)	Total Throughput / day	Monthly Throughput	Monthly Target
FKI	486	8.05	161	180
PO2	471	8.3	166	180
JU3	472	8.29	165.8	180

3.4 Future State VSM - Effective Production Process to Improve Productivity

Process modelling using DES show the importance of keeping track in series rather than segregating the workstation. Isolating the workstation has a negative impact on production flow. The changes made to improve a problematic workstation or a workstation that can be improved for better flow affect the performance of the next workstation. This causes fluctuation in the production process and delays resulting in poor quality and customer service. When looking at the results of VSM compared to SVSM, it shows the importance of the value chain. In SVSM, there are no costly delays when testing the improvement of a change made in one variable; the impact can be seen immediately without spending more time and money in the production lines. Failures are seen, observed and rectified before the actual piloting of the improvement project. In production processes, workload distribution is essential to minimise bottlenecks, fatigue and job complexity. A well-distributed production process flow improves efficiency and productivity. This helps identify and eliminate non-value-added operations in the process where flow and value chain are key performance indicators. It is determined by the cycle times, which shows the adherence of the process sequence relative to the TAKT time of each model.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

Production processes are dependent on the logistics supply/delivery factor. When there is poor logistics delivery leading to low productivity and if production processes are not aligned to supply chain processes, production will encounter problems relating to parts and materials lying around the production plant congesting the operator's movement, which will lead to large non-value adding times. South African automotive industries mostly find themselves in this situation due to a lack of knowledge how to conduct their business leanly about lean manufacturing. The practitioners tend to focus on production improvement projects that lack track and mostly fail in execution, resulting in value chain issues. Simulation enhances accuracy when properly applied to minimise errors that may occur during the execution plan. As illustrated in Figures 1, the application of the two paradigms shows that the VSM is ideal for non-complex systems, and simulation simplifies complex production systems. In manufacturing processes, it is common that companies want to maintain a flow of processes based on easy management when all processes are in series. It is good practice that subassemblies and offline processes are used to minimise delay in the production line, which brings more relief and reduces the complexity of the system. In the system used in this research project, Figure 1 shows that processes such as spray painting, drying, programming and vehicle quality testing can be taken offline. This will allow free flow in the production process and minimise time spent waiting for these processes because they cannot be interrupted.

3.5 Effective Application of Lean Manufacturing in the Automotive Industry

Companies, mainly SMEs, always try to improve their economic impact in the automotive industry by assuring their support to the industry by on-time delivery, high quality, and better service provision. These processes are driven by an efficient company's process supported at all levels of the organisation. Lean manufacturing has played a significant role ever since it was outlined as a way of eliminating waste and providing stability, efficiency and an overview of where to improve for better production of products for customers. The effectiveness of lean manufacturing does not rely on results generated; it depends on how the process has improved, and the key elements that are needed to ensure non-re-occurrence of similar constraints and waste. The application of lean manufacturing principles has shown that all the stations in the process must be aligned to add value in the process chain of the manufacturing system in the automotive industry. Failure to adhere to these principles leads to major time loss due to breakdowns and other factors contributing to production processes. Stations 8, 9 and 10 (chassis painting and drying) can be optimised by completely removing them from the assembly line. The processes conducted in these workstations can cause significant constraints when they have breakdowns that affect the whole production line. One hour lost repairing and maintaining these workstations can result in approximately 14 hours of production downtime because each workstation loses the same amount of production time or more as the repaired workstation. Figure 2 shows an improved VSM called the future state, which is improved from the current state of the production system.

Value stream mapping is constructed using the cycle time, change over time, operators, and process description. This process visualises the production system and the behaviour of each workstation. This populate the waste recorded while collecting data during observation of the current state of VSM. All elements are exhibited to point out which areas have problem and potential solution are developed based on what is visible. To validate the populated and visualised concerns, the cycle times are categorised as VA and NVA to show how much the populated concern affect the process. The study of the NVA contributed to the cycle time envisage as the situation and reckoning with the presence of one of the seven waste lean. The contribution of the VA and NVA is shown in the Yamazumi diagram in Figure 1, depict how the processes are responding to the TAKT time. This is based on empirical data from the observation during time measurement. The Yamazumi confirms the issues observed and the NVA recorded by showing how close the process cycle times are to the TAKT time.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

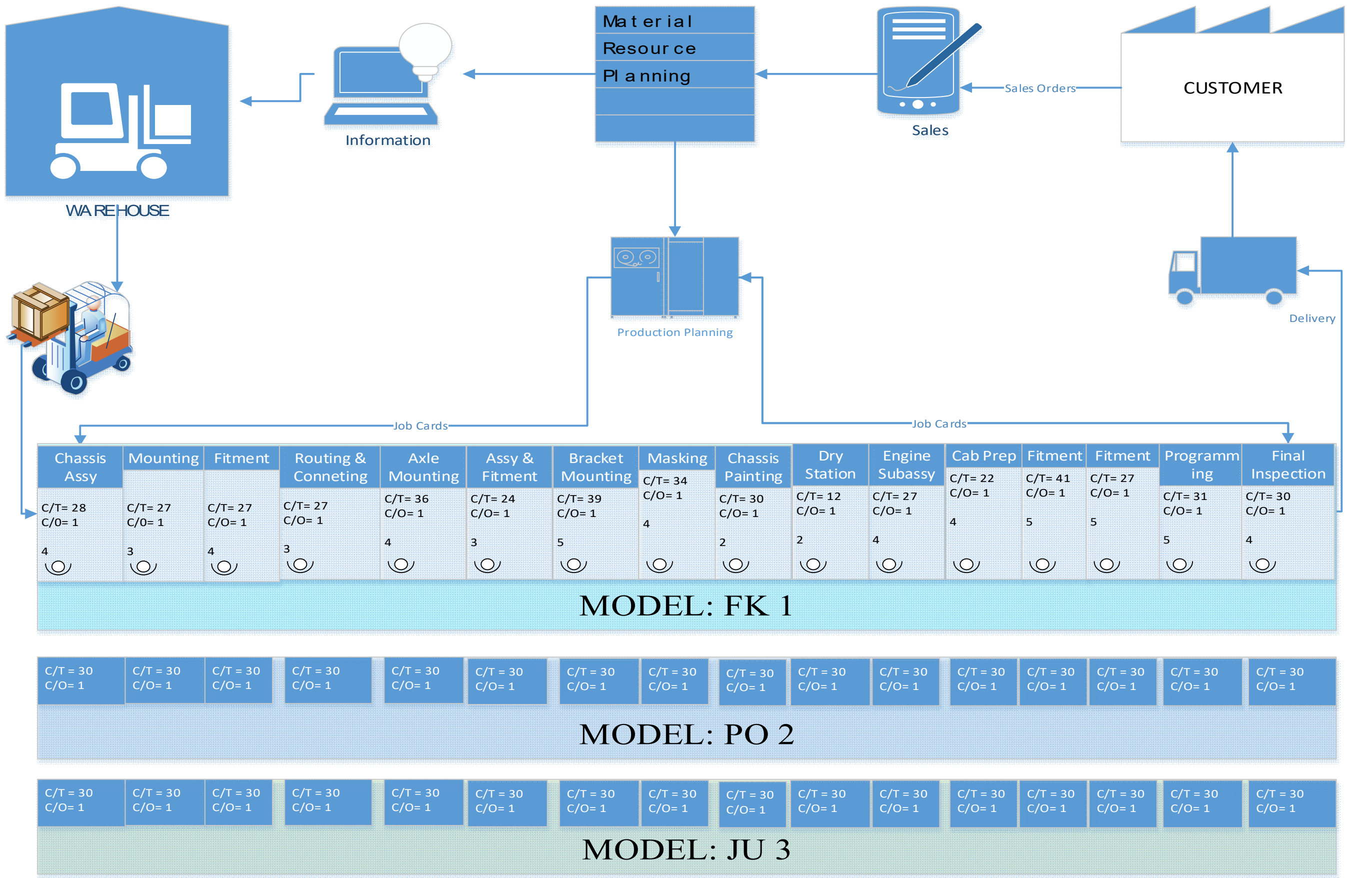

Figure 1: VSM modelling of Current State of the truck manufacturing industry

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

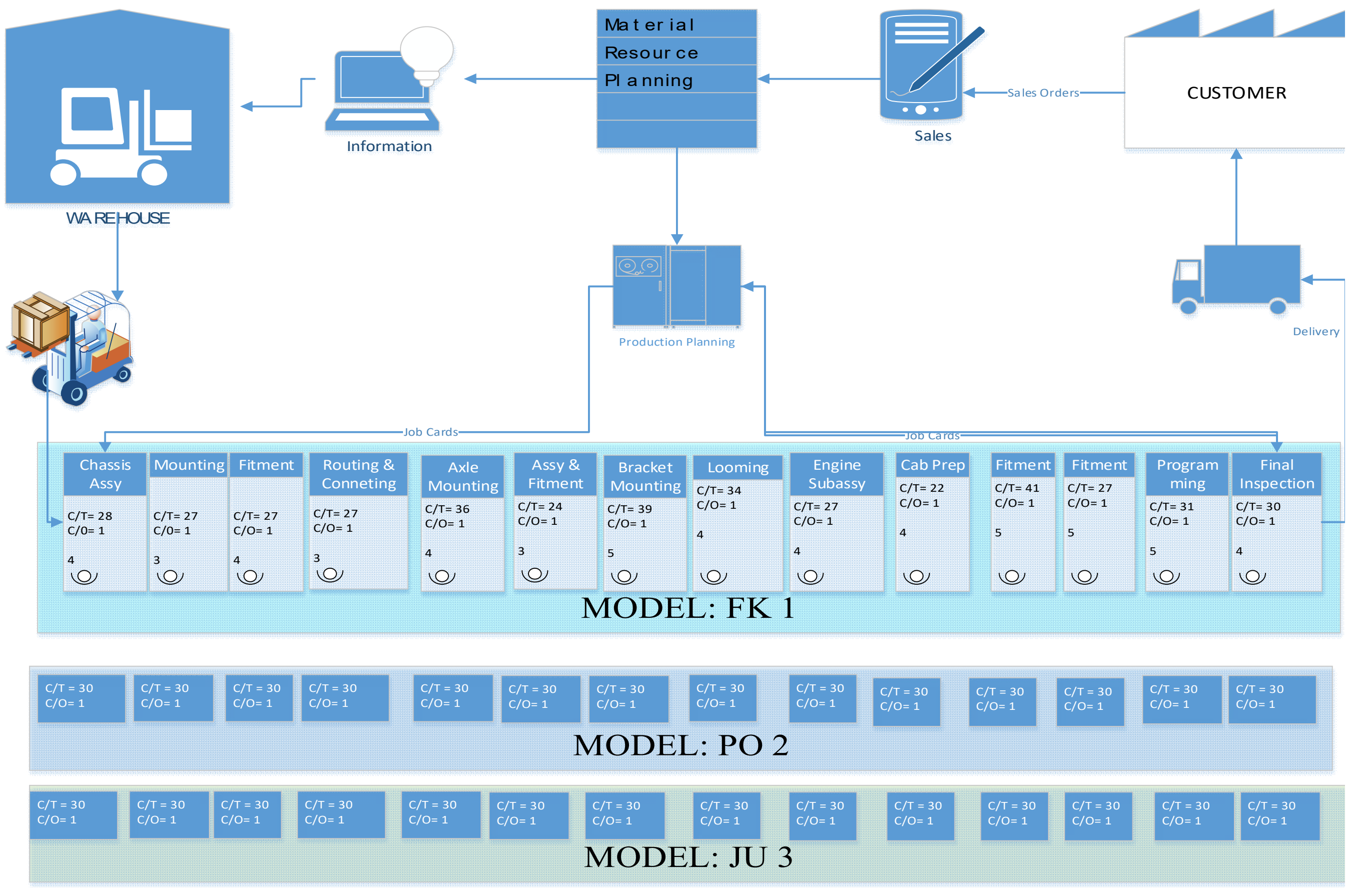

Figure 2: VSM modelling of future state.

Value stream mapping is constructed using the cycle time, change over time, operators, and process description. This process visualises the production system and the behaviour of each workstation. This populate the waste recorded while collecting data during observation of the current state of VSM. All elements are exhibited to point out which areas have problem and potential solution are developed based on what is visible. To validate the populated and visualised concerns, the cycle times are categorised as VA and NVA to show how much the populated concern affect the process. The study of the NVA contributed to the cycle time envisage as the situation and reckoning with the presence of one of the seven waste lean. The contribution of the VA and NVA is shown in the Yamazumi diagram in Figure 3, depict how the processes are responding to the TAKT time. This is based on empirical data from the observation during time measurement. The Yamazumi confirms the issues observed and the NVA recorded by showing how close the process cycle times are to the TAKT time.

3.6 Systematic Analysis of the Production System

The persuasion of manufacturing excellence in production environment is challenging based on understanding of the correct tools to be used. Lean manufacturing is the key influence in ensuring that the production system operates at its optimal performance. This is applicable when the correct tools are adopted to carry out process optimisation projects that will improve operational excellence. In the future state of this by reducing NVA, split operation where possible, have subassemblies instead of fit on the line improves productivity as shown as:

Current State
Productivity = Total time available/Total Cycle time
Productivity = 435/487.94

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

= 0.892 ≈ 89.2%
= 0.892*15
= 13.3 Units produced

The current state of the production system derived above where the total production time available for day. This time is measured against the total cycle time used in all the workstation to produce the first unit. This shows that the production system is not performing at its optimal. As a result, only 13.3 units produced a day instead of 15. This shows the is an efficiency in the system. Which is envisage by the total cycle time drawn from the process execution.

Future State

Productivity = Total time available/Total Cycle time

Productivity = 435/457.05

= 0.952*15

= 14.28 Units produced

The future state of the production shows that when the system shows such behaviour, there is something that is not being performed correctly. The study of the key aspect that contribute to the production system shows that unnecessary non-value adding times are the ones contributing to the efficient production system. Once the non-value adding times where identified, using VSM and simulation they were eliminated. As result the productivity has been improved by 6% and that result to an additional unit being produced which bring the operation closer to the target of 15 units a day.

The simulated value stream mapping (SVM) is the tool used to visualise the production system as a model. This method uses value stream mapping (VSM) parameters. The parameters are drawn from company XYZ where the case study was conducted. Work measurement techniques is used in this paper as the method of data collection played. Where time study is the tools used to show how the process is doing in support of production and productivity through the monitoring of the efficiency. Compilation of data source reflects the production system of company XYZ which used as a reference point for productivity improvement. In this paper time series is one of the elements being studied. This is envisaged production station and process cycle times shown in Figure 3.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

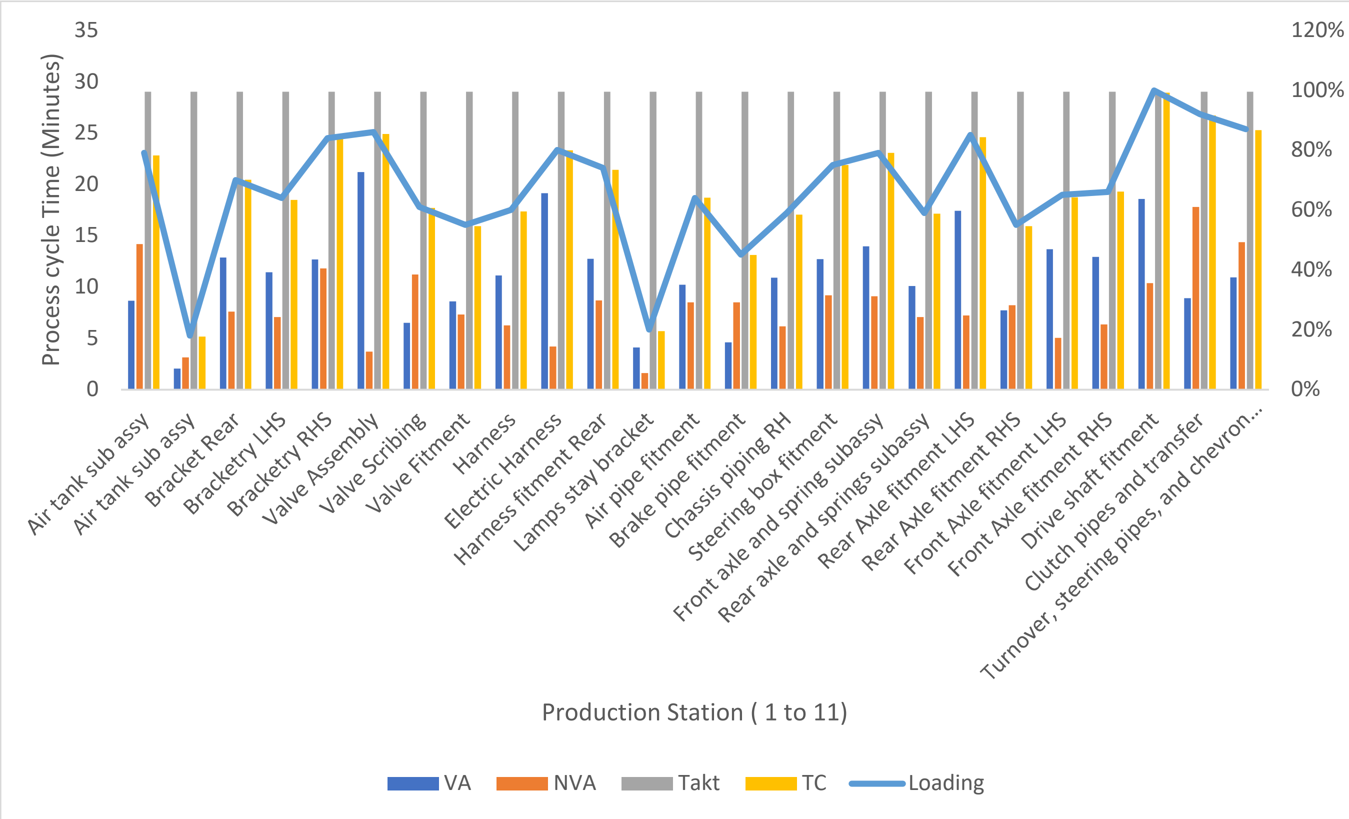

Figure 3: Production Station against Production Cycle Time

Figure 3 presents the setup that allows flexibility in the process by enabling all the models with a smaller capacity than the ones studied to be manufactured as a good technique in support of mass customisation. TAKT time is not used in simulation because it increases the delay time in process execution. The production system simulated and studied demonstrated that process balancing was not practised well because some workstations are more overloaded than others are a common practice in the automotive industry because of product improvement. Stations 1, 2, 3, 7, 8, 10, and 11 are good examples of this practice as shown in Figure 5. The application of lean manufacturing principles has shown that all the stations in the process must be aligned to add value in the process chain of the manufacturing system in the automotive industry. Failure to adhere to these principles leads to major time loss due to breakdowns and other factors contributing to production processes. Some of the workstations can be optimised by completely removing them from the assembly line and have subassemblies that increase availability. The processes conducted in these workstations can cause significant constraints when they have breakdowns that affect the whole production line. One hour lost repairing and maintaining for these workstations can result in approximately 14 hours of production downtime because each workstation loses the same amount of production time or more as the repaired workstation.

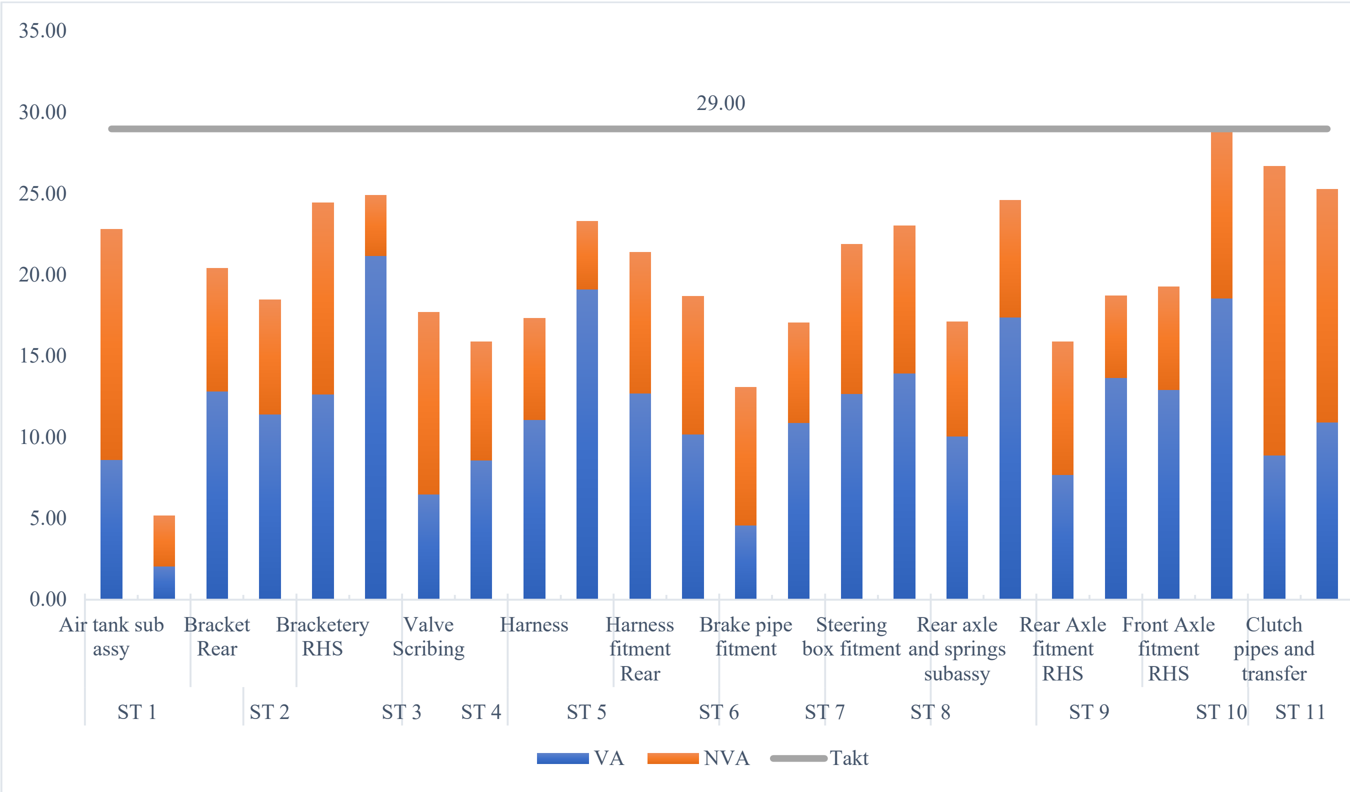

Figure 4: Initial State of the production line balancing

All parameters of this production system are then transferred and be used as simulation input variables for Discrete Event Simulation (DES). DES is an ideal simulation modeling technique because of the nature of the study. This allow the stochastic nature of the system to be presented well yet attaining the desired results, which in argument VSM doesn't give the edge which DES emulate. The use DES in this paper is to show the dynamics of the process that are being left out in VSM and validate the results being visualise in VSM. This shows how the process is being loaded and how long processes affect the productivity. Process capabilities and resource utilisation are being visualise for better decision making.

3.7 Results of Productivity Improvement through SVSM

Productivity improvement is a key strategy to maintain and gain competitive edge in automotive industry. The current process results clearly show that the overall production system is not compatible to yield the desire results. As shown in Figure 5, the targets are normal and can be achieved through well-established production system where the processes are operating at their optimal.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

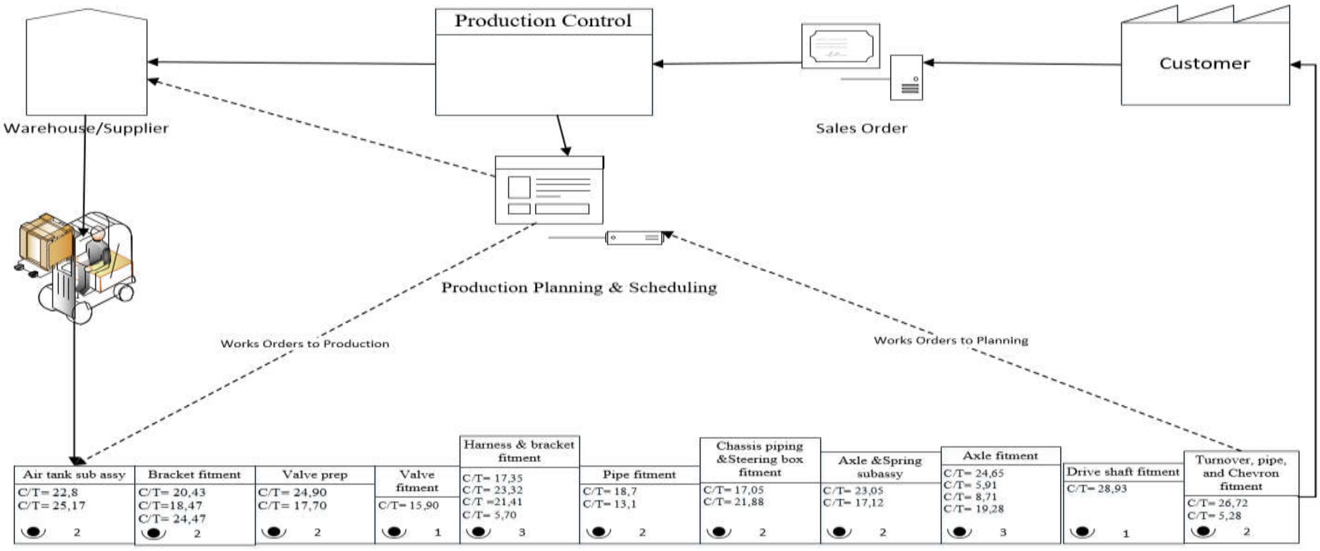

Figure 5: Initial VSM of the Production System

The value stream mapping shows an overview of the production system, using the information gathered during data collection to understand the production system behaviour. This proves the non-value adding time are the cause to inefficiency. This show how the workstations are loaded and the number of process done in one workstation. That show the effectiveness due to congestion because of these processes. This shows how tools, warehouse distribution and manpower utilisation and how the facility is arranged to allow optimal performance of production processes. Production system are seen in different perspective when it come to the utilisation of resources, which provides aspect of most companies practicing the replenishment of stock. Productivity and efficiency are affected negatively by this practised where quality is being compromised because the targets are not met. Figure 5 shows that the processes are not operating at the level best based on the results shown below. The are several factors affecting production system not to achieve its desired productivity. The potential factors that might affect this production system are highlighted by just looking at the NVA though it is understandable that some of the NVA are necessary. Proper execution of the processes defined by the cycle time determine the productivity and raise flag on how the resources are utilised. In most company these flags are ignore if the production runs without any disruptions shown, yet this contradict the theory of constraints, which state how small disruptions can contribution to the loss in productivity. The TAKT time in each workstation is the same and this is keeping production flow under control. Allowing fluctuating cycle time because the nature of the operation involves humankind that work at a different rate. However, the time lost in each workstation is equivalent throughout the system.

The case study shows that some of the process are overloaded because they operate closer to the TAKT time. When the processes are operating too close to the TAKT time are putting the system to a pressured operation. Evenly distribution of process operation balances the system and improve productivity. This is caused by high variation in processes and the production rate is determined by the capacity of the resources. After simulating the production system using DES, it shows the system is balanced see Figure 6, yet it does not meet the target. This is where we revert to issues that were highlighted during the study, to know the gaps and what are the potential solutions.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

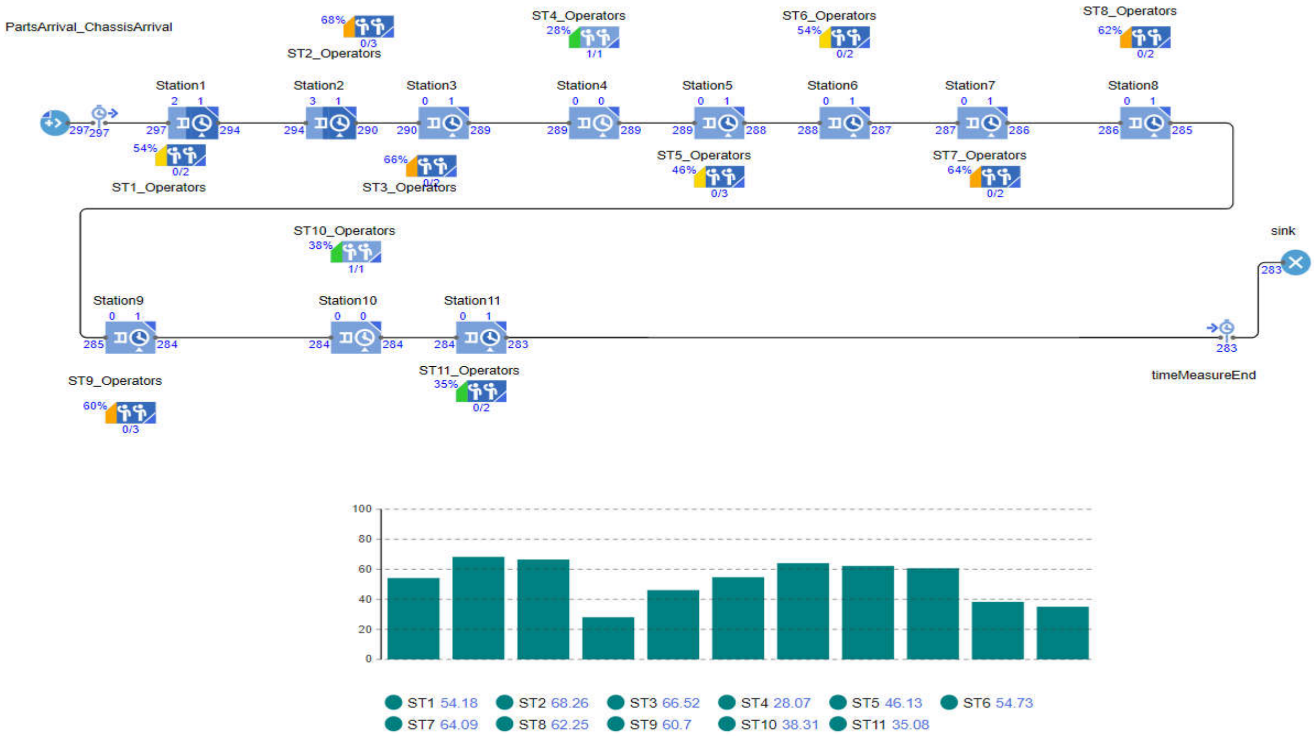

Figure 6: Balanced Production System using DES

Lean assessment tool intends to improve the performance of the overall production system where value chain is the key element. The flow determines how processes are capable of meeting customer demand with more emphasis on material supplier and space available. This support continuous flow of the process with less or no constraints that cause uncertainty in process execution. Use of technology in production system brings more stability and show how and where improvements are needed. Simulation is good complimentary tool that need to be used as an assessment and a validation tool for lean manufacturing projects.

3.8 Material Handling Support to Improve Productivity.

The effective application of lean manufacturing improves material handling and safety in the workplace. This happens by the improvement of material and parts movement, packaging and storage. Material handling and safety are crucial elements of any process because of their vital contribution to productivity and quality. These are determined by improving the distance covered to collect the part, safety of the surroundings and how the material is placed to support a safe working environment. Figure 7 shows how the movement, material handling, and parts storage around the workstation is visualised and improved using lean manufacturing. The effective application of this technique minimise unnecessary movement and gives an overview of the distance covered for each process. It identifies the longest paths, double handling of the process and shows the non-value adding times. Constraints are identified and dealt with to minimise the process and improve productivity. This tool balances the cycle time, manpower, and TAKT time [29]. It helps to design an improved facility layout that optimise the process by minimising cycle and lead times and improves overall production activities. A pull system must be applied in complex manufacturing systems to minimise congestion in the production line. The current manufacturing system in the automotive industry relies on a push system to feed the assembly and production lines because of the schedules and expected cycle times. This approach results in having too much buffer stock and unnecessary utilisation of resources. The pull system promotes lean manufacturing principles because all the required resources are pulled when necessary and required for use. This results in easily identifying waste and unsafe practices in the complex process. Material handling and safety are critical aspects in production free flow and advance the value chain at an optimal cycle time [30]. The constraint of material is a result of unlevelled production schedules causes too many changeovers in material handling.

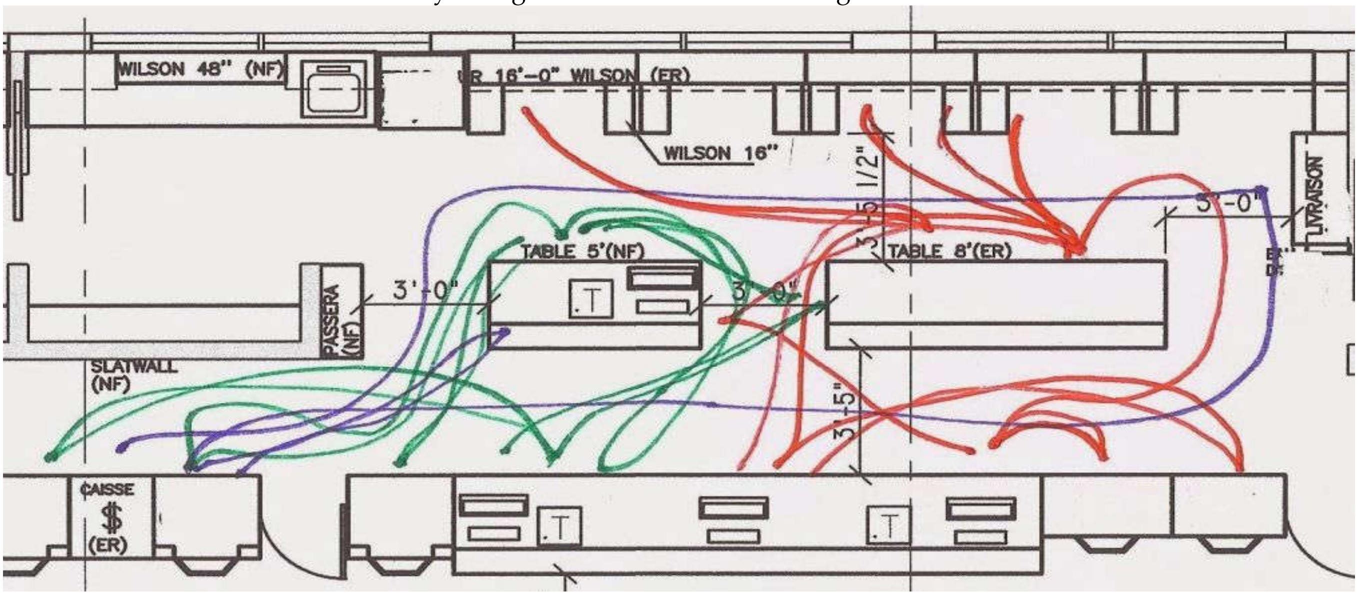

Figure 7: The Spaghetti diagram for visualised workstation movement, material handling, and parts storage.

4. Conclusions

Simulated value stream mapping proved that traditional VSM could not identify all process non-value adding by highlighting workstation that are affected by the dynamic of the production processes. These dynamics showed that in traditional VSM (a drifting operation is not identified due to static construction of VSM. It is one of the finding identified that some of the process in the value chain are automatic constraints and cannot be identified using traditional VSM. This shows that SVSM provides more production process visualisation, which is important in every project before implementation. This gives necessary information to make decision on the feasibility of the improvements and their impact to the entire production system.

This study identified stations with short cycle times that cause bottlenecks in the station that follows and disturbs the free flow. Hence, in other production systems, there are subassembly stations to avoid these unnecessary bottlenecks. This is one of the concerns that South African SMEs in the automotive industry face. Processes were established and aligned to serve the demand at the time; changes in the global market do not change how things are done. This is one of the findings shown by the painting and drying station; removing these two stations provides production free flow and improves productivity. These findings emphasised that Kaizen projects undertaken by SMEs must align to customer KPIs where optimised processes are crucial to productivity improvement. It is essential for SMEs to have a thorough approach to optimise the use of space to avoid excessive movement that will make the process take more time than expected. Optimised processes support quality and can support any change in the production system. Cycle and lead time are the key performance indicators of any production system; they determine how well each part of the system is doing. This research study shows a need for continuous process improvement to reduce the cycle time to be productive and competitive. As seen on what VSM displayed relative to the process cycle time and what was identified as NVA, failure to identify these process constraints will result in failure of the implementation phase of the project. Hence, this research project introduced SVSM, where an immediate trial is undertaken using the same parameters as VSM. The unforeseen NVA during the study automatically appears or is triggered by identifying delays in the processes.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

These are usually caused by parts presentation, unboxing and other waste mentioned earlier in the study.

Author Contributions: Conceptualization, F.P., and O.T.A.; methodology, F.P., software, O.T.A.; validation, F.P., O.T.A., and K.M.; formal analysis, F.P., and O.T.A.; investigation, O.T.A.; resources, F.P., and O.T.A.; data O.T.A.; editing, K.M.; visualization, O.T.A.; supervision, O.T.A. and K.M.; project administration, F.P., funding acquisition, K.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Research Foundation (NRF), grant number 123575, and the APC was funded by the Research Chair in Future Transport Manufacturing Technologies.

Data Availability Statement: In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Please refer to the suggested Data Availability Statements in the section "MDPI Research Data Policies" at https://www.mdpi.com/ethics. You might choose to exclude this statement if the study did not report any data.

Acknowledgments: The researchers acknowledge the support and assistance of the Industrial Engineering Department of Tshwane University of Technology, Gibela Rail, and the National Research Foundation (123575) of South Africa for their financial and material assistance in executing this research project. The opinions presented in this paper are those of the authors and not the funders.

Conflicts of Interest: None.

References

1. Sharma, D. Application of Value Stream Mapping in Papad Manufacturing," Int. J. Res. Appl. Sci. Eng. Technol., 2018, vol. 6, no. 4, pp. 874–878, doi: 10.22214/ijraset.2018.4148.
2. Azemi, F.; Luji, R.; Šimunovi, G.; Tokody, D. Selection the Basic Lean Manufacturing Techniques in Developing the Model for Industry 4.0 in Kosovo Manufacturing Industry 2020, doi: 10.3390/proceedings2020063062.
3. Al-Akel , K.; Marian, L.O. proceedings The Lean Six Sigma Algorithm-A Pathway for Decreasing the Continuous Improvement Projects Failure Rate, 2020, doi: 10.3390/proceedings2020063047.
4. Colim, A.R.; Morgado, P.; Carneiro, N.; Costa, C.; Faria, N.; Sousa, L.; Rocha, A.; Arezes, P. Lean Manufacturing and Ergonomics Integration: Defining Productivity and Wellbeing Indicators in a Human–Robot Workstation. Sustainability 2021, 13, 1931. https://doi.org/10.3390/su13041931.
5. Parv, L.; Deaky, B. Nasulea, M. D.; Oancea, G. Agent-Based Simulation of Value Flow in an Industrial Production Process, 2019, doi: 10.3390/pr7020082.
6. Venugopal, P. V.; Sigma, L. S.; Micro, T. Ranking of the seven wastes (Muda) for Lean Six Sigma Implementation in Indian SMEs, vol. 14, no. 6, pp. 1269–1274, 2019.
7. Shou, W.; Wang, J.; Wu, P.; Wang, X.; Chong, H. Y. A cross-sector review on the use of value stream mapping, Int. J. Prod. Res., vol. 55, no. 13, pp. 3906–3928, 2017, doi: 10.1080/00207543.2017.1311031.
8. Seth, D.; Seth, N.; Dhariwal, P. Application of value stream mapping (VSM) for lean and cycle time reduction in complex production environments: a case study Prod. Plan. Control, vol. 28, no. 5, 2017, doi: 10.1080/09537287.2017.1300352.
9. Sobuj K. M. M. R.; Rahman, C. M. L. (Vsm) Technique Application in a Selected Garments Factory of Bangladesh, Int. J. Eng. Res. Gen. Sci., vol. 3, no. 2, pp. 998–1007, 2015.
10. Lugert, A.; Völker, K.; Winkler, H. Dynamization of Value Stream Management by technical and managerial approach, Procedia CIRP, vol. 72, pp. 701–706, 2018, doi: 10.1016/j.procir.2018.03.284.
11. Bhatwadekar, S. Ghodawat, S. Value Stream Mapping : Simulation Approach, Ijeta-Ets Issn, no. July, pp. 38–43, 2015.
12. De Souza, L. B.; Tortorella, G. L.; Cauchick-miguel, P. A.; Nascimento, D. Application of Value Stream Mapping and Monte Carlo Simulation in a University Hospital, no. 2017, pp. 596–606, 2018.
13. Kotturu, C. M. V. V.; Mahanty, B. Determinants of SME integration into global value chains: Evidence from Indian automotive component manufacturing industry, J. Adv. Manag. Res., vol. 14, no. 3, pp. 313–331, 2017, doi: 10.1108/JAMR-02-2017-0013.
14. Antosz, K.; Stadnicka, D. Lean Philosophy Implementation in SMEs - Study Results, Procedia Eng., vol. 182, pp. 25–32, 2017, doi: 10.1016/j.proeng.2017.03.107.
15. Matthews, R. L.; MacCarthy, B. Braziotis, L.; C. Organisational learning in SMEs: A process improvement perspective, Int. J. Oper. Prod. Manag., vol. 37, no. 7, pp. 970–1006, 2017, doi: 10.1108/IJOPM-09-2015-0580.
16. Zeng, W.; Baafi, E.; Walker, D. "'/," Int. J. Mining, Reclam. Environ., vol. 33, no. 2, pp. 102–117, 2019, doi: 10.1080/17480930.2017.1348284.
17. Antonelli, D.; Litwin, P.; Stadnicka, D. Multiple System Dynamics and Discrete Event Simulation for manufacturing system performance evaluation, Procedia CIRP, vol. 78, pp. 178–183, 2018, doi: 10.1016/j.procir.2018.08.312.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 August 2022 doi:10.20944/preprints202208.0306.v1

18. Frazzon, E. M.; Albrecht, A.; Pires, M.; Israel, E.; Kück, M.; Freitag, M. Hybrid approach for the integrated scheduling of production and transport processes along supply chains, Int. J. Prod. Res., vol. 56, no. 5, pp. 2019–2035, 2018, doi: 10.1080/00207543.2017.1355118.
19. Li, H.; Yang, H.; Yang, B.; Zhu, C.; Yin, S. Modelling and simulation of energy consumption of ceramic production chains with mixed flows using hybrid petri nets, Int. J. Prod. Res., vol. 56, no. 8, pp. 3007–3024, 2018, doi: 10.1080/00207543.2017.1391415.
20. Nikolakis, N.; Alexopoulos K.; Xanthakis, E.; Chryssolouris, G. The digital twin implementation for linking the virtual representation of human-based production tasks to their physical counterpart in the factory-floor, Int. J. Comput. Integr. Manuf., vol. 32, no. 1, pp. 1–12, 2019, doi: 10.1080/0951192X.2018.1529430.
21. Liu, Q.; Yang, H.; Xin, Y. Applying value stream mapping in an unbalanced production line: A case study of a Chinese food processing enterprise, Qual. Eng., vol. 0, no. 0, pp. 1–13, 2019, doi: 10.1080/08982112.2019.1637526.
22. Sayid mia, M. A. Implementation of Lean Manufacturing Tools in Footwear Industry of Bangladesh. Aspects in Mining & Mineral Science, 20181, (1), 1–9. https://doi.org/10.31031/amms.2017.01.000503.
23. Kammer Christensen, M.; Janardhanan, M. N.; Nielsen, P. Heuristics for solving a multi-model robotic assembly line balancing problem. Production and Manufacturing Research, 2017. 5(1), 410–424. https://doi.org/10.1080/21693277.2017.1403977.
24. Agarwal, D.; Katiyar, A. Value Stream Mapping: Literature Review and Implementation for An Assembly Line. 2018. 7(1), 60–66.
25. Kovács, G.; Kot, S. Facility layout redesign for efficiency improvement and cost reduction. Journal of Applied Mathematics and Computational Mechanics, 2017. 16(1), 63–74. https://doi.org/10.17512/jamcm.2017.1.06.
26. Quan, Y.; Alfnes, E.; Brekken, H. G.; Eide, M. M. A Simulation Enhanced VSM Approach for high-Mix Manufacturing Environment. Iwama, 2016. 103–106. https://doi.org/10.2991/iwama-16.2016.19.
27. Chen, Z.; He, Y.; Zhao, Y.; Han, X.; He, Z.; Xu, Y.; Zhang, A. Mission reliability evaluation based on operational quality data for multistate manufacturing systems. International Journal of Production Research, 2019. 57(6), 1840–1856. https://doi.org/10.1080/00207543.2018.1508906.
28. Gu, C.; He, Y.; Han, X. A Novel Approach for Mission Reliability Modeling of Manufacturing System Based on the State Change of Machines and Materials. Procedia CIRP, 2016. 57, 286–291. https://doi.org/10.1016/j.procir.2016.11.050.
29. Sabadka, D.; Molnar, V.; Fedorko, G.; Jachowicz, T. Optimization of Production Processes Using the Yamazumi Method. Advances in Science and Technology Research Journal, 2017. 11(4), 175–182. https://doi.org/10.12913/22998624/80921.
30. Adeodu, A.; Kanakana-Katumba, M.G.; & Rendani, M. Implementation of lean six sigma for production process optimization in a paper production company. Journal of Industrial Engineering and Management, 2021. 14(3), 661-680. https://doi.org/10.3926/jiem.3479