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Research Article

Optimizing Vehicle Assembly Line Achievement via Lean Manufacturing: An Evaluation of the Bishoftu Automotive Manufacturing Industry

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Abstract

Vehicle manufacturers nowadays must contend with rising consumer demand and fierce competition for timely delivery of high-quality goods at affordable costs. But the assembly line was not productive at the required rate and capacity due to assembly line delay constraints. However, some workstations in the production line would be delayed. In the assembly line process, from the first to the last workstation, it became starving and blocking at some workstations in the assembly line due to unbalanced assembly workstation. The study aims to Optimizing Vehicle Assembly Line Achievement via Lean Manufacturing: An Evaluation of The Bishoftu Automotive Manufacturing Industry. The study was employed both qualitative and quantitative research approaches. By using those data, the current assembly line was developed with the help of lean manufacturing principles and technique among them methods, value stream map was the most important and the researcher used VSM. The most important wastes were found when the current assembly process then output was examined. Finally, optimized workstation and splitting suggested to the example company after a variety of alternative scenarios, including the current one, were performed to increase the company's production. The findings demonstrated that the first and second scenario increased the case company's bus assembly line output rate. There has been increased line efficiency by 44.65% from 19.25% to 63.9% and also production rate also increased by 0.125 unites.

Keywords

Automotive Manufacturing, Assembly Line Balancing, Lean Manufacturing, Lean Thinking, Line Production Process, Cycle Time, Value Added Manufacturing

1. Introduction

The fundamental duty for the survival of manufacturing firms is to improve their productivity. It plays a vital role in increasing the number of customers, changing technology, and more competitors emerging in the market. Enhancing the productivity of the company is the most important factor for today's manufacturing sector. The manufacturing sector significantly shows the production success of a country. In addition, the manufacturing industry must consider lead time, international competition and meeting the needs of customers in terms of quality and quantity [1].

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BAMI is a governmental company that assembles various vehicles and operates major tasks in automotive industry such as overhaul, assemble, upgrade, and localize different vehicles like bus, pick-up, SUVs, truck and military equipment's. Mainly Ethiopian military and AU peacekeeping use military vehicles, civil vehicles are also provided to government and private transportation providers [2].

Reducing these deadly wastes of production is the commonly used perception for the improvement of productivity in manufacturing firms. These wastes are waiting, excessive motion, unnecessary transportation, defect, over production, over processing and inventory [3].

Even though companies recognized these wastages, they couldn't avoid or reduce them, and the bus assembly manufacturing firms also face challenges like other automotive industries to be productive, Thus, it will be necessary to use the appropriate productivity improvement tools to enable the companies involved in the sector to be competitive and continue their work in a sustainable manner [4].

Lean manufacturing approach system for the Bishoftu Automotive Manufacturing Industry to increase assembly productivity efficiency. It uses different scenario analysis to minimize non-value-added activity and remove bottlenecks to enhance assembly production flow and assess the outcome. lean by eliminating wastes and improve productivity based on the issues observed in BAMI [5].

1.1. Problem Statement

There were stations hungry for work and others waiting for the next station to be ready, leading to idle stations and workers. This condition causes an idle assembly workstation to exist. And also, there is an unbalanced line assembly station. There was less productivity per operator and more waiting items on workstations as a result.

1.2. Objective

In order to achieve the main objective

1) To identify the existing production performance in the current assembly line for Bishoftu Automotive Manufacturing Industry
2) To evaluate the major bottlenecks or inefficiencies in the current bus assembly process
3) To assess potential improvement areas in the assembly line
4) To develop improvement model for future optimal production method

2. Methodology

The research design refers to the application of research, including strategies and techniques. Everything is covered, including how to use different methodologies and how to gather and evaluate primary and secondary data. Furthermore, the primary and secondary data are both qualitative and quantitative. The main data for this study was gathered about the company's assembly process, and secondary data was also gathered from numerous research projects and company papers. Next, in order to illustrate the current system of preceding and succeeding stations, distinguish the bottleneck station, and identify wastes, the actual manufacturing system sequence of the assembly line is studied using process mapping, value stream mapping, and flow control analysis.

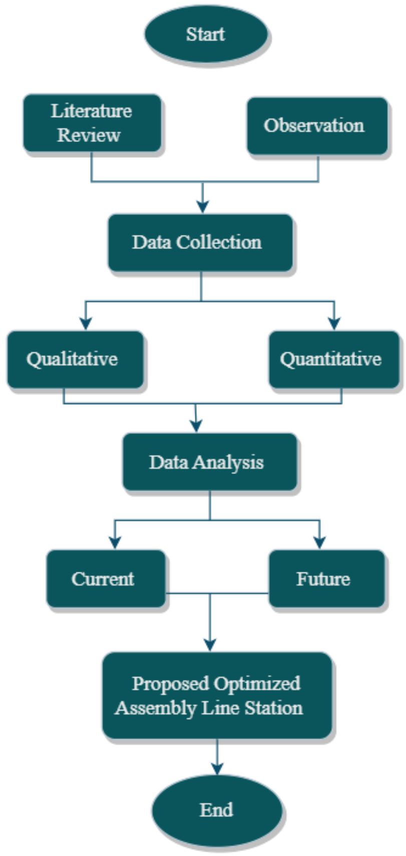

Figure 1. *Methodological diagram of the research procedure.*

After data was obtained through direct observation, interviews, and firm papers were displayed using tables, charts, and graphs as necessary. In addition to being able to distinguish between value added and non-value-added activities with clarity based on the deigned capacity drop, the value stream mapping was also able to identify bottlenecks that lower corporate productivity. Primary and secondary sources of information were consulted in the analysis of the data. The line balancing and standard time formulas were used to examine the gathered data [6].

Value Stream Mapping

The information flow and current production system of the bus assembly line were shown by the value stream model (VSM). The interview is then utilized to learn more about what the manufacturing industry customers want. The bottleneck station and the entire assembly line are depicted on the state map that was created as the first step in the data analysis process. in addition, VSM can identify bottlenecks that reduce productivity of the company according to the deigned capacity decline. It includes the duration of the bus assembly line method for each workstation. Each workstation has a specific task allocated to it, depicted as a process, to simplify the map. For example, in addition to loading, aligning, and welding, there are processes needed for body assembly, frame alignment, and chassis. The value stream map shows each stage of the procedure as well as each task that members of the product family finish. Process steps include things like chassis preparation, engine and body assembly, partition welding, and final assembly. Numerous properties are measured at each stage of the procedure. Generally, the various parameters include cycle time, VA and NVA timings, available work load capacity hours, and personnel count [7].

Flow Control Analysis

Value stream map identified bottleneck stations, VA and NVA operations, and improvement opportunities using the state map that was already in place. The differences between the stations' cycle times and the takt times for the flow control analysis results are also compared and using Excel. Especially programming, flow control analysis is a method used to comprehend and assess a program's execution routes. It focusses on the flow of control via the many components of a program, including conditionals and loops. Developers and tools can optimize programs' performance, make sure they behave as intended, and spot possible problems like infinite loops, unreachable code, or unhandled errors by examining the control flow [8].

Types of Flow Control Analysis:

1) Static Analysis: Examines the code without executing it. This is commonly used in compilers and static analysis tools to detect errors, optimize code, or ensure conformance to coding standards.
2) Dynamic Analysis: Involves analyzing the program's behavior during execution. This can help identify issues that depend on specific runtime conditions.

Cycle Time and Workload

The assembly line must be designed to achieve a production rate, Rp, sufficient to satisfy demand for the product. Product demand is often expressed as an annual quantity, which can be reduced to an hourly rate. Management must decide on the number of shifts per week that the line will operate and the number of hours per shift [9]. Assuming the plant operates 50 weeks per year, the required hourly production rate is given by

$$\mathrm{Rp} = \frac{\mathrm{Da}}{50 * \mathrm{Sw} * \mathrm{Hsh}}$$

Where: -

Rp = average hourly production rate, units/hr.;

Da = annual demand for the single product to be made on the line, units/yr;

Sw = number of shifts/wk; and

Hsh = hr/shift.

If the line operates 52 weeks rather than 50, then

$$\mathrm{Rp} = \frac{\mathrm{Da}}{52 * \mathrm{Sw} * \mathrm{Hsh}}$$

If a time period other than a year is used for product demand, then the equation can be adjusted by using consistent time units in the numerator and denominator.

This production rate must be converted to a cycle time Tc, which is the time interval at which the line will be operated. The cycle time must take into account the reality that some production time will be lost due to occasional equipment failures, power outages, lack of a certain component needed in assembly, quality problems, labor problems, and other reasons. As a consequence of these losses, the line will be up and operating only a certain proportion of time out of the total shift time available; this uptime proportion is referred to as the line efficiency. The cycle time can be determined as

$$\mathrm{Tc} = \frac{60\mathrm{E}}{\mathrm{Rp}}$$

Where: -

Tc = cycle time of the line, min/cycle;

Rp = required production rate, units per hour;

The constant 60 converts the hourly production rate to a cycle time in minutes; and E = line efficiency. Typical values of E for a manual assembly line are in the range 0.90–0.98. The cycle time Tc establishes the ideal cycle rate for the line

$$\mathrm{Rc} = \frac{60}{\mathrm{Tc}}$$

Where: -

Rc = cycle rate for the line, cycles/hr.; and

Tc is min/cycle

This rate Rc must be greater than the required production rate Rp because the line efficiency E is less than 100%. Line efficiency E is therefore defined as

$$\mathrm{E} = \frac{\mathrm{Rp}}{\mathrm{Rc}} = \frac{\mathrm{Tc}}{\mathrm{Tp}}$$

Where: -

Tp = average production cycle time Tp = 60/Rp.

An assembled product requires a certain total amount of time to build. This is the work content time (Twc), which is the total time of all work elements that must be performed on the line to make one unit of product. It represents the total amount of work that is to be accomplished on the product by the assembly line. It is useful to compute a theoretical minimum number of workers that will be required on the assembly line to produce a product with known Twc and specified production rate Rp. To determine the number of workers on a production line:

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

Where: -

w = number of workers on the line;

WL = workload to be accomplished in a given time period, min/hr.; and

AT = available time per worker during the period, min/hr./ worker.

The time period of interest will be 60 min. The workload in that period is the hourly production rate multiplied by the work content time of the product, that is: -

$$WL = Rp * Twc$$

Where: -

Rp = production rate, pc/hr.; and

Twc = work content time, min/pc.

Tc = 60E/ Rp can be rearranged to the form Rp = 60E/Tc. Substituting this into WL = Rp*Twc

$$WL = \frac{60ETwc}{Tc}$$

Available time AT = one hour (60 min) multiplied by the proportion uptime on the line; that is, AT = 60E.

Substituting these terms for WL and AT into w = WL/ AT the equation reduces to the ratio Twc/Tc. Because the number of workers must be an integer,

$$w^* = \text{Minimum Integer} \geq Twc/\ Tc$$

Where: -

w* = theoretical minimum number of workers.

If each workstation has one worker, then this ratio also gives the theoretical minimum number of stations on the line. Achieving this minimum theoretical value in practice is very unlikely.

w* = Minimum Integer ≥ Twc/ Tc ignores two critical factors that exist in real assembly lines and tend to increase the number of workers above the theoretical minimum:

In this manufacturing company BAMI, there were 102 employees which were in bus assembling production system. In this study both qualitative and quantitative type research, in order to do so questionnaire and interview was conducted. Based on the response of the respondent and personal and expert opinion were also incorporated.

The collection and analysis of data in various methods were important to enhance the current VSM. Data was gathered from various operations carried out at each station, including the quantity of units produced and the assembly procedures. The veracity of the information will determine how these actions turn out. The extent of each person's actions and workstations can be ascertained if the routines of every station are understood. A station is an area with a defined function and limited work output. This will be the basis for choosing the quantity of stations, features, and personnel. Every task's duration is expressed in hours and is documented in the data document. To determine how to increase the productivity of the organization, a focus group was held to collect qualitative data.

The researcher discussed with the company's deputy heads and department leaders, including the supervisors of the correction station, the head of the design department, the head of production and deputy production, and the heads of the rear and front compartment assembly. The assembly line and the possibility of employees moving to different stations if their responsibilities are comparable and must be completed in the same way at each location were the key topics of discussion. After combining and analyzing data, proposed optimized assembly line station was developed to help the organization increase productivity sustainably.

The precedence Bus assembly line in BAMI is

The bus whole assembly consist 10 workstation the assembly line was: -

Due to description daily assembled 2 car per day therefore this provide the cycle time which is as the following: -

Cycle time = production time/output rate = (8h*60)/2= 240 minute

Table 1. *Precedence assembly line cycle time.*

No of work-station	Cycle time	Time taken workstation	Idle time (minute)
1	240	17	223
2	240	24	216
3	240	29	211
4	240	29	211
5	240	32	208
6	240	83	157
7	240	54	186
8	240	42	198
9	240	83	157
10	240	69	171
Total	2400	462	1938

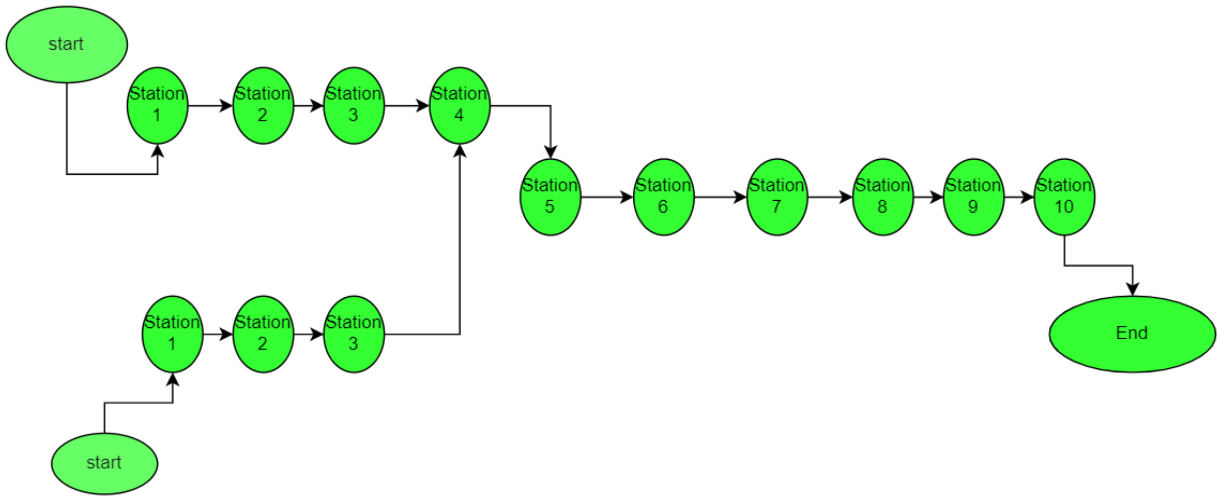

Figure 2. *Precedence network diagram of current bus assembly line workstation.*

The current assembly line performance measured

Total idle time = 1938

Cycle time = 240

Line Efficiency =100% - balance delay

Line efficiency = 100% - (Total Idle time/total of work-stations time) *100%

Line efficiency = 100% - (1938/10*240) *100%

= 100% - (1938/2400) *100%

=100% - 0.8075*100

= 100% - 80.75%

= 19.25%

Therefore, Delay balance = 80.75

And also, average hourly production rate

$$Rp = \frac{Da}{52*Sw*Hsh}$$

2 bus/day

2*5 = 10 bus /week

240 proper working day in year/5 working day in week =48 week in yearly

Therefore 48*10= 480 bus assembled in yearly

Rp = 480 bus /52*1*8h

$Rp = \frac{480\ bus}{48*5*8h}$ = 0.25 units

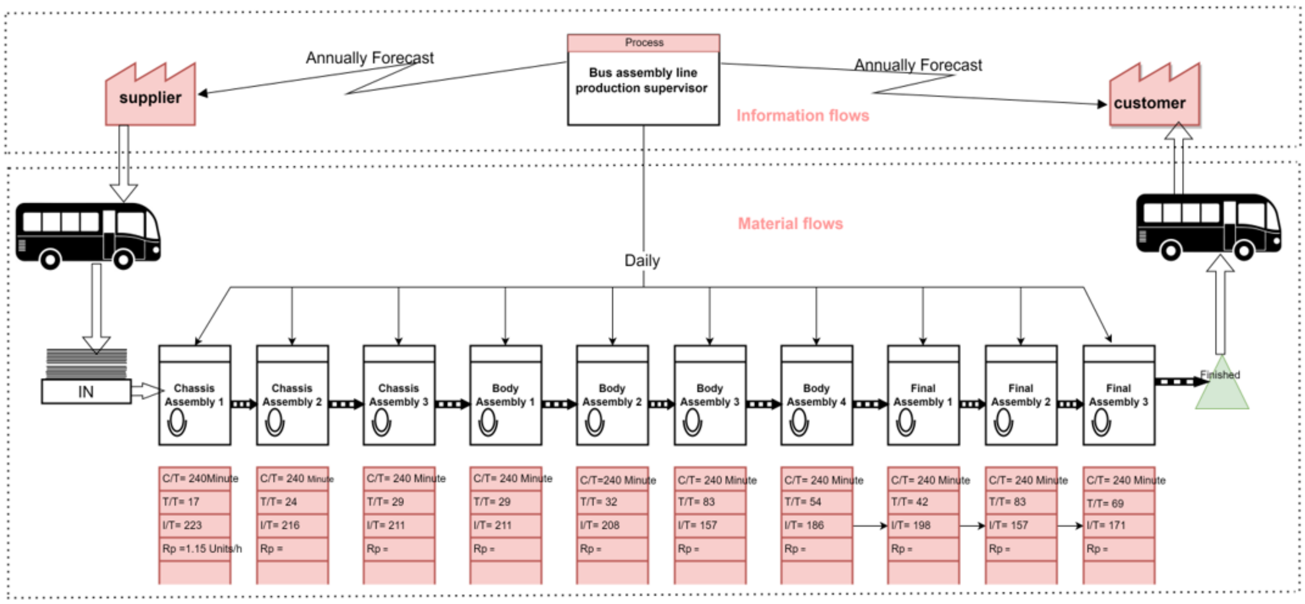

Figure 3. *Current Value Stream Map.*

Two fundamental methodological approaches for optimizing line efficiency in the context of assembly line balancing problems [10]. (ALBP): -

Type I: Fixed Cycle-Time, Minimize Number of Workstations

Type II: Fixed Number of Workstations, Minimize Cycle-Time

***Table 2**. Comparison of methodological approaches for optimizing line efficiency.*

Aspect	Type I	Type II
Input constraint	Fixed cycle-time	Fixed number of workstations
Optimal Goal	Minimize the number of workstations	Minimize the maximum cycle-time
Focus	Resource efficiency	Production speed and throughput
Typical Application	High-demand environments	Small-scale or resource constrained setups

Comparison of Type I and Type II:

Type I is optimal when sustaining a consistent production rate is essential.

Type II is more appropriate when operational or financial limitations restrict the number of workstations.

Both approaches aim to optimize line efficiency by addressing different aspects of the assembly line balancing problem.

For optimization the efficiency of the bus assembly line first is to minimize the cycle time by increasing the output rate and then arranging the workstations. If the company has enough equipment to assemble, the available human resources, and also has enough space to assemble the bus. So, optimizing the efficiency of the line first is to minimize the cycle time by increasing the output rate and then re-arranging the workstations. Previously the output rate was assembling 2 cars per day, but now it is assembling 3 cars per day. Hence, this will decrease the cycle time and make the station to be fully engaged at work somewhat larger in the above-mentioned condition [11].

Cycle time = production time/output rate

CT = (8h*60)/3=160

Next would be the rearrangement of workstations keeping precedence diagram.

Cycle time decrease 240 to 160.

***Table 3**. Modified rearranging assembly cycle time.*

Workstation	Cycle time allocated	Time taken assigned	Idle time
1	160	46	114
2	160	50	110
3	160	63	97
4	160	63	97
5	160	62	98
6	160	63	97
7	160	63	97
8	160	52	108
Total	2400 previous	462 previous	818

The optimized assembly line performance measured

Idle time = 114+110+97+97+98+97+97+108 = 818

Line efficiency = 100% - (Total Idle time/total of workstations time) *100%

= 100% - (818/8*160) *100%

= 100% - 818/1280*100%

= 0.6390*100%

= 63.9%

Delay balance = 36.1%

In the assigning future optimized implementation model framework for average production rate

$$Rp = \frac{Da}{52*Sw*Hsh}$$

3 bus/day

3*5 = 15 bus /week

240 proper working day in year/5 working day in week = 48 week in yearly. Therefore 48*15= 720 bus assembled in yearly.

Rp = 720 bus /52*1*8h

$Rp = \frac{720\ bus}{48*5*8h}$ = 0.375 units

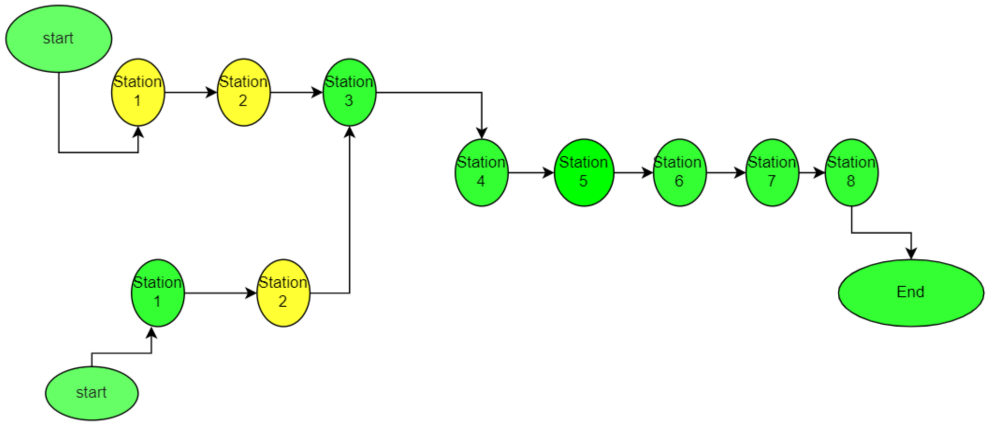

Figure 4. *Optimized network diagram of Future Bus Assembly Line Workstation.*

In the first scenario, as we have seen from the existing state, the processing time of body assembly section and chassis assembly section are longer and affect the output. Hence for the reduction of NVA activity of the other stations and WIP of the bottleneck station, splitting the workstation and perform the assembling process in parallel was applied. The existing of parallel stations enable. It allows to do the work that was done outside the assembly line. The workstations replaced the existing station, to increase the number of products of the station and to provide a smooth flow of a product from one process to another which is effective and saves time to reduce the total cycle time of the assembly product. The part of the bus assembly body section assembly section, such that body assembly 1 and body assembly 2 are operated at the same time without waiting the ladder and some equipment's. By dividing the station into two and allowing them to work in parallel, the assembly line increased the production rate and enables to work both parallel bus parts cooperatively and to reduce unnecessary movement of workers. Moreover, the two parallel stations can receive parts of the bus equipment simultaneously and provide two parts of buses for down streams.

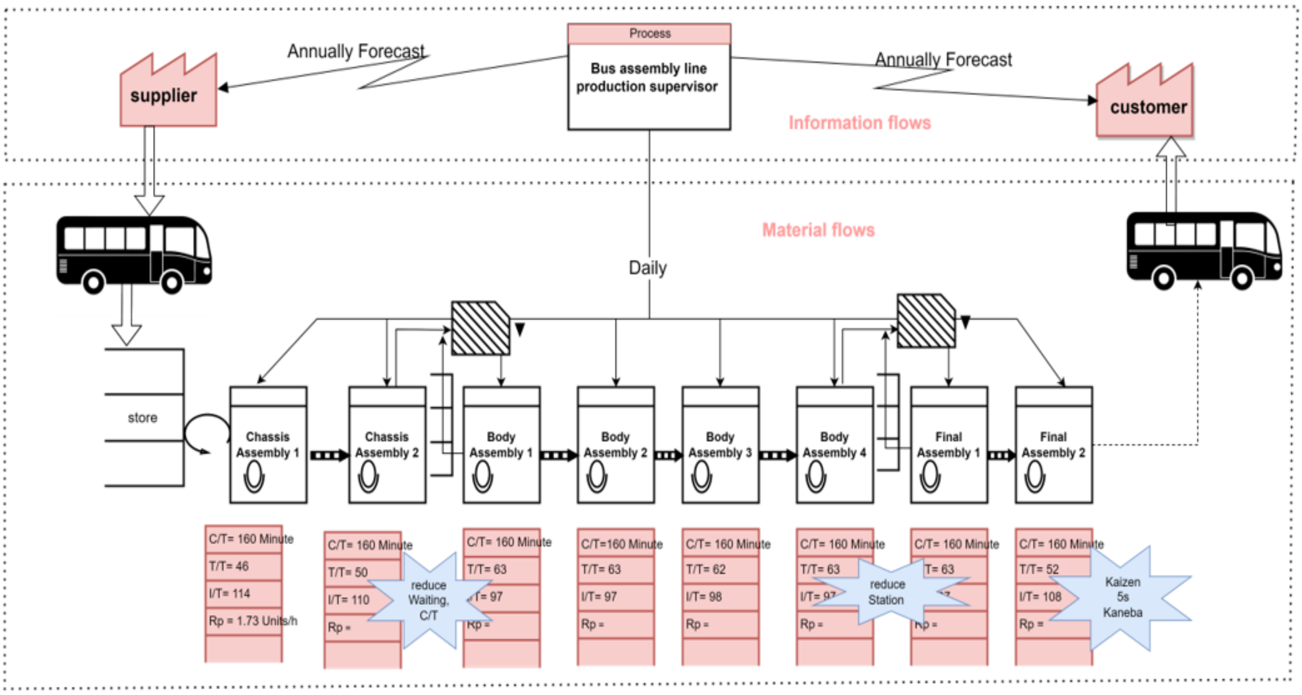

Figure 5. *Future Value Stream Map to Process Optimization for Continuous Improvement.*

The researcher discussed with focal groups about applying room for additional station, equipment's and transfer of employees from each station to the additional parallel station, those are idle by different cases. The determination of transferring of employees makes the company more productive and performs at full resource capacity.

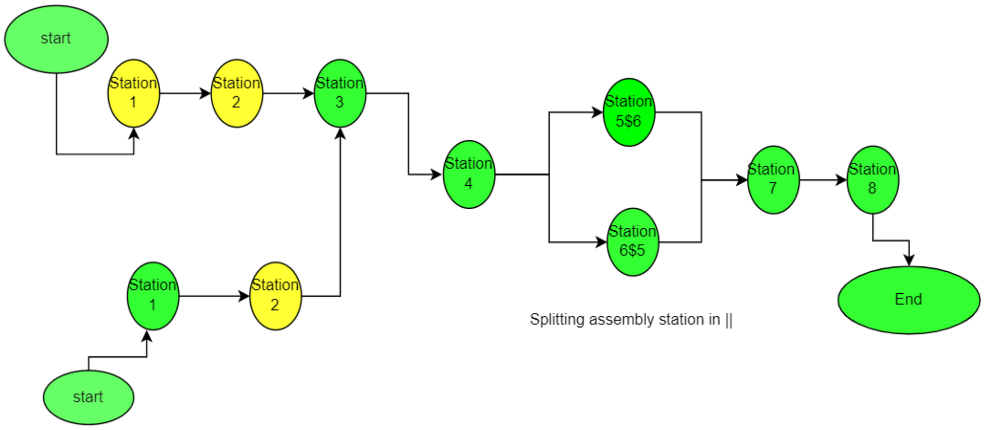

Figure 6. Proposed Bus Assembly line workstation.

Finally, Changes in the existing model permit the assembling line more productive and while implementing a technique that was avoiding the effect of the bottleneck station in the bus assembling line by splitting the workstation in parallel. After implementing there is an improvement output of the product from the existing 2 buses per day to 3 buses per day and there is a reduction of total idle time from 1938 minute to 818 minute. And also delay balance also reduced from 80.75% to 36.1%.

3. Results and Discussion

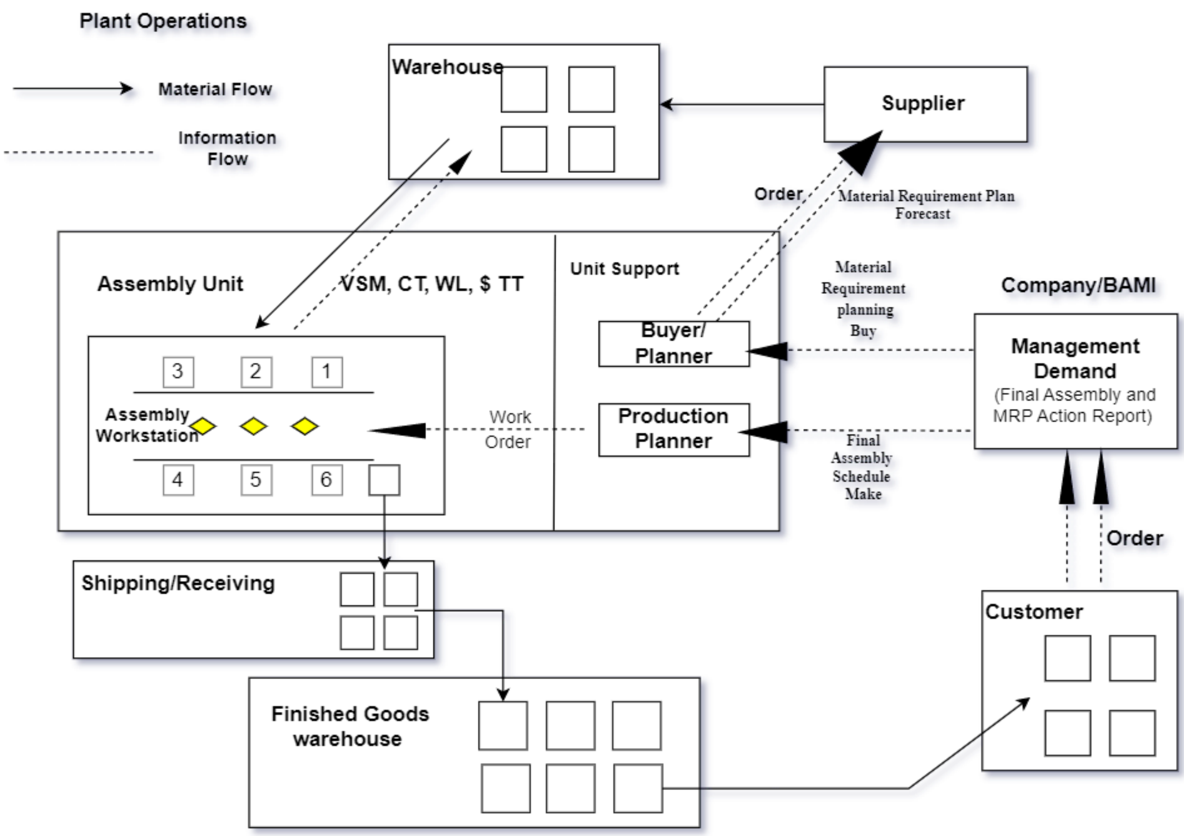

Figure 7. Proposed supply chain management framework for optimized assembly line.

Data was obtained from the company's papers and different assembly lines. Vehicle assembly structure production systems, which consist of multiple workstations with interconnected processes, typically face productivity issues that make it difficult to produce more with the same amount of labor, materials, and energy. The intended results were not achieved when these factors are concentrated on at the same time. If awareness is restricted to areas where there are bottlenecks and non-value-added jobs, production flow improvements can be made with little extra effort. The identification of non-value-added activities and bottleneck areas was aided by VSM. The purpose of creating future VSM is to avoid bottlenecks, reduce non-value-added time, to make the assembly line more productive and where each station performance needs to be dynamic according to factory demand by connecting to its factory either by continuous flow. Furthermore, the bottleneck region was examined in relation to takt time utilizing flow control analysis, and ultimately, the bottleneck's removal strategy may result in an enhanced VSM [12].

In addition, it takes an average of 8 hours per day to assemble the bus production, which results in long wait times and idle time for the other stations. The body section and chassis section assembly process have cycle times that are longer than takt timings, according to a comparison of station cycle times and takt periods. Therefore, in order to meet demand within the allotted period and enhance production flow, process capabilities must be upgraded.

A station would enable the product to be manufactured in close proximity to the intended client demand. The complete bus assembly process, including cycle time, VA, NVA time, and the number of operators at each station, was also displayed by VSM. The current state map depicted the entire assembly line, from the preparation of the chassis and body section assembly as well as the areas that require improvement based on the cycle time and NVA time of individual stations.

The bus assembly line can be optimized using a number of different techniques, but the most efficient approach to reduce idle or waiting periods at other stations is to reduce a work station and split it from the bottleneck station. This would enable the efficient use of human resources by allowing the idle workers at each station to be qualified for the position.

Finally, optimized workstation and splitting suggested to the example company after a variety of alternative scenarios, including the current one, were performed to increase the company's production. The findings demonstrated that the first and second scenario increased the case company's bus assembly line output rate. There has been increased line efficiency by 44.65% from 19.25% to 63.9% and also production rate also increased by 0.125 unites.

Because of this, the vast majority of station staff members are occupied with NVA tasks like needless travel or assignment waiting. The bottleneck station was the reason people had to wait for other stations. When one assembly station finishes the task fast while the other does not, there is a waiting period. The research also proposed reassigning employees from other stations to the bottleneck station so that the responsibilities are split equally across the stations and the idle workers on the assembly line are taken into consideration. ultimately came to the conclusion that companies who manufacture the manufacturing capabilities might see a large gain in efficiency from the use of VSM [13].

In general, the design of the assembly line should be the main focus when planning production. Next, the shed should be designed with this consideration. to ensure it can be as productive as needed or planned. However, the researcher noticed that the organization where am conducting my research paper is prone to this issue. One reason for this was that the original purpose of the shed was not for car assembly. To implement what is shown in the picture above, the workflow should run consistently from supplier to customer and streamline the bus assembly process appropriately. It was important to plan and implement a Material Requirements Plan (MRP) as necessary in the assembly process to reduce challenges at the assembly workstation and maintain continuous productivity. The assembly unit receives orders from suppliers, places them in storage, and then begins the assembly work.

The researcher was able to use value stream mapping, the line balancing optimization method, and bottleneck analysis for a single-model assembly line to address challenges in the manufacturing process, particularly at the assembly workstation. As a result, we were able to increase the production rate by reducing the cycle time and the number of workstations.

4. Conclusions

To be competitive in the sector, the vehicle assembly industry is straggle to increase productivity and reduce cycle times. Improving efficiency through the elimination of idle time and non-value-adding operations and reduction of bottlenecks is critical to the competitiveness of vehicle products and their market demand share. A vehicle assembly line relies heavily on manpower as well as tools and machinery that execute intricate and progressive tasks.

The automotive sector is striving to lower cycle times and boost productivity in order to remain competitive in the sector. The competitiveness of vehicle products and their market share depend heavily on increasing efficiency through the removal of non-value-adding processes and the reduction of bottlenecks. Manpower and equipment that performs complex and progressive operations, like compressors, grinders, rivet guns, welding machines, and drilling machines, are essential components of a vehicle assembly line.

This study provided a method for integrating VSM to increase production flow in the BAMI bus assembly manufacturing plant by reducing NVA activities and removing the assembly line bottleneck. A bus assembly line has several stations that are connected to one another. Increasing productivity and producing more with fewer machines, laborers, and energy resources is a challenge. Trying to solve while concentrating on all those elements would be challenging. Rather than that, concentrating on the primary issues and avoiding the assembly line bottleneck greatly enhances the manufacturing system.

The cycle time used and the precedence diagrams used were based on the result of this study. It would be now easy to realize that, it would be more profitable to choose the balanced, future production line, because it can minimizes/saves the labor cost of the production line.

The idle time and work stations were minimized to improve productivity. A modified, new production line of 8 workstations was introduced instead of the previous 10 workstations. The idle time or delay balance reduced from 80.75% to 36.1% the balance efficiency increased from 19.2% to 63.9%. the idle time reduced from 1938 to 818. And the production rates increased from 0.25 units to 0.375 units.

The main goal of this research is to enhance the bus assembly line's production flow by decreasing wastes and removing bottlenecks in order to produce more. The primary goals of the project were to employ VSM to reduce waste and prevent bottlenecks.

Abbreviations

BAMI	Bishoftu Automotive Manufacturing Industry
CT	Cycle Time
FC	Flow Control
GDP	Growth Domestic Product
LM	Lean Manufacturing
MTEI	Manufacturing Technology & Engineering Industry Research
NVA	Non-Value Added
Rp	Production Rate
TT	Takt Time
VA	Value Added
VSM	Value Stream Mapping
WL	Work Load
WS	Workstation

Author Contributions

Semere Ayele Mengistu is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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