



SIMULATION-BASED MANAGEMENT OF AN AUTOMOTIVE ASSEMBLY LINE: A CASE STUDY USING ARENA SOFTWARE

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ABSTRACT

Today, most automotive assembly lines are equipped with advanced technologies that play a crucial role in improving productivity. Bottlenecks, processing times, and resource utilization are the most significant challenges in automotive assembly line management. The research aims to evaluate the performance of the assembly line system and analyze the bottlenecks of the workstations and their resource utilization. A discrete event simulation-based assembly line model has been developed using Arena software. In this work, the BAIC assembly line in the automotive and equipment company was selected as a case study. Data collection from a real system for model simulation, utilizing standard data and recorded observations obtained from company management. The analysis of the results from the assembly line model, conducted after running the simulation process, reveals that there are workstation bottlenecks and underutilization. The final results of the alternative solutions indicate that the proposed model can improve the assembly line productivity by 15%, and the average waiting time is reduced by 25% on the assembly line compared with the initial model. This study demonstrates that the simulation approach is an effective tool for an automotive company to improve the performance of assembly lines by enhancing efficiency and productivity

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KEYWORDS: Simulation & Modeling, Arena Software, Assembly Line, Utilization, Bottleneck, Productivity.

إدارة خط تجميع السيارات القائمة على المحاكاة: دراسة حالة باستخدام برنامج أرينة

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الملخص

تجهز اليوم معظم خطوط تجميع السيارات بتقنيات متقدمة تلعب دورًا حاسمًا في تحسين الإنتاجية. تعد الاختناقات وأوقات المعالجة واستغلال الموارد من أهم المشكلات التي تواجه إدارة خطوط تجميع السيارات. يهدف البحث إلى تقييم أداء خط تجميع من خلال تحليل اختناقات محطات العمل ومدى استغلال الموارد. تم تطوير نموذج خط تجميع يعتمد على طريقة محاكاة الأحداث المنفصلة باستخدام برنامج Arena. في هذا العمل، تم اختيار خط تجميع سيارة BAIC في شركة السيارات والمعدات كحالة دراسية. تم جمع البيانات من نظام حقيقي لمحاكاة النموذج بناءً على البيانات القياسية والقراءات المسجلة، والتي تم الحصول عليها من إدارة الشركة. يوضح تحليل نتائج نموذج خط التجميع بعد تشغيل عملية المحاكاة وجود اختناقات في بعض المحطات ونقص

في استغلال الموارد. تشير النتائج النهائية للحلول البديلة إلى أن النموذج المقترح يمكن أن يحسن إنتاجية خط التجميع بنسبة ١٥٪، ويقلل متوسط وقت الانتظار بنسبة ٢٥٪ على محطات خط التجميع مقارنة بالنموذج الأولي. توضح هذه الدراسة أن نهج المحاكاة يعد أداة فعالة لشركة السيارات لتحسين أداء خطوط التجميع من خلال تعزيز الكفاءة والإنتاجية.

الكلمات المفتاحية: المحاكاة والنمذجة، برمجيات أرينة، خط التجميع، الاستخدام، الاختناقات، الإنتاجية.

1. INTRODUCTION

Currently, the manufacturing industry exhibits significantly increasing returns to scale, offering distinct advantages across many sectors. In this context, competitiveness is an essential prerequisite for success in markets that warrant significant consideration, especially within the automobile sector. An automotive assembly line is a systematic procedure in automotive manufacturing where car components are assembled, and the car body progresses sequentially from one workstation to another until the final vehicle is completed [1]. An assembly line is a manufacturing process involving the sequential assembling of several components into a product at various workstations to create the final item. Mass production extensively utilizes it for the fabrication of diverse products, including automobiles and technological devices. Employees sequentially organize the workstations and perform their tasks concurrently. Assembly line systems represent a significant use of simulation. Utilization is a critical performance measure in assembly line systems. Utilization indicates the amount of output produced by a facility in relation to its maximum capacity. Utilization is a significant metric for evaluating a manufacturing plant's performance, especially regarding the effective utilization of production facilities [2].

Computer simulation is an effective method for assessing various industrial implementation scenarios to enhance performance and productivity. Simulation methods are particularly advantageous for manufacturing system design and the prototyping of new production processes, as they facilitate the identification of component combinations (resources, operation and setup times, intermediate buffers, etc.) that ensure an adequate level of throughput in the system [4]. Furthermore, employing computer simulation in the automotive sector offers numerous benefits, including cost savings, improved resource efficiency, reduced process cycle time, and increased throughput. A simulation tool enables rapid and efficient change implementation, while real-life experimentation can be exceedingly time-consuming and costly. This simulation program allows the efficient assessment and enhancement of line throughput, machine usage, and cycle time. The simulation of industrial systems facilitates the evaluation of diverse scenarios within the confines of a restricted budget. It mitigates prevalent issues in the industrial sector, including utilization inefficiencies and bottlenecks [4].

The success elements of the automotive industry depend on performance efficiency, encompassing the maintenance of high productivity on the assembly line. The optimal quantity of resources, in terms of humans and workstations, must be meticulously evaluated. A contentious topic in car assembly lines is the congestion at workstations. The management system is seeking to develop strategies to eradicate bottlenecks and reduce waiting times in the assembly lines. Consequently, the majority of automobile firms are endeavoring to maintain their competitiveness by enhancing resource usage and mitigating workstation bottlenecks. This research aims to perform a simulated analysis of an automotive assembly line to evaluate the system's performance using simulation methods and identify any existing issues. A simulation model utilizing Arena software has been designed to simulate and evaluate resource use and workstation bottlenecks. A novel enhancement scenario is proposed to augment the system's performance and productivity [5].

The subsequent sections of the paper are structured as follows: The literature review section consists of an analysis of related works in the relevant field. The methodology section presents the main steps of the procedure followed in the research. This work addresses the automotive assembly line components, as detailed in the case study section. The development section presents all the details of the simulation process for assembly line modeling. The results analysis section presents the main findings from various scenarios, along with alternative solutions. The final section includes the main conclusion highlighted according to the findings, along with a few suggestions for future efforts.

2. LITERATURE REVIEW

Currently, simulation models are employed to evaluate several facets of manufacturing systems. A large number of researchers have extensively examined the matter of enhancing competitiveness and the productivity of current simulation software. Arena software is a popular simulation tool that offers comprehensive capabilities for creating simulated models, encompassing input data analysis, model construction, model validation, and output analysis, among others. This literature review indicates a deficiency in the integration of contemporary temporal analyses with novel simulation methodologies in existing literature, which motivated the current study.

A simulation method to reorganize and balance workloads in a car assembly line to improve performance and productivity has been used. It uses discrete system simulation to identify problems and provide solutions that reduce material handling time, resource utilization, and production time. The study highlights the cost-effectiveness, flexibility, and reduced risk of computer-aided simulation over real experimentation, improving automotive sector work processes and efficiency [6]. A discrete-event simulation to mimic an automotive assembly facility's production floor, warehouse, and material handling system has been presented. This method accurately determines the ideal batch size for complicated manufacturing processes, addressing client demand fluctuations and product complexity. The study uses "what-if" studies to improve automotive assembly performance and productivity [7]. The existing working circumstances and juxtaposed them with many proposed alternative solutions has been examined. The authors demonstrated that the suggested enhancements significantly boost productivity in the motorcycle headlight production line, with a 25.51% reduction in production cycle time and a 28.36% increase in production capacity relative to the current state, alongside a 13.33% improvement in labor efficiency compared to the existing conditions [8]. Assembly line productivity and diminished expenses with his discrete simulation model by reducing underutilized assembly line resources has been enhanced. The executed simulations enhanced the efficiency of all production line processes and overall market competitiveness [9]. Siemens software for process simulation to evaluate a prototype assembly line consisting of automated logistics systems, robots, and job guidance systems has been employed, thereby establishing a methodology for assessing simulation software within the context of Industry 4.0 assembly lines [10]. Improving assembly line productivity through simulation and lean techniques, identifying crucial areas for enhancement has been focused. It demonstrates a discrete event simulation model, resulting in reduced WIP, cycle times, and a 7.14% increase in throughput [11]. Agent-based simulation modeling for a flexible GPU card assembly line, not specifically on the automotive industry has been focused. It emphasizes flexibility, reconfigurability, and performance analysis through sequencing and scheduling, particularly addressing part tardiness and throughput conflicts [12]. Assembly line optimization using MTM time standards and simulation modeling, specifically in a medium-sized company has been focused, to improve performance and reduce costs, but do not specifically address the automotive industry or a case study within it [13]. A comprehensive scenario analysis using discrete-event simulation to evaluate lineless assembly systems in the automotive industry has been conducted, focusing on flexibility, throughput, and utilization, ultimately comparing hybrid and classical line assembly systems based on real industry data [14]. A case study on the SAIPA saloon car assembly line has been presented, utilizing Arena simulation software to identify bottlenecks and inefficiencies, ultimately aiming to enhance performance and productivity through data analysis and discrete-event simulation modeling [15]. A systematic methodology for work measurement and process design in mixed-model assembly lines has been presented, utilizing analytical models and discrete event simulation to enhance performance and productivity, particularly focusing on cycle time analysis and efficiency in manufacturing systems [16].

Different literature has demonstrated that the automotive industry's ability to remain competitive in the global market is largely dependent on production improvement. To investigate this concept, we selected a real case study of an automotive assembly line facing specific problems. Arena software and discrete event simulation were used for modeling and simulation before implementation in the actual system.

3. METHODOLOGY

As mentioned earlier, the modeling and simulation of assembly line management in the automotive industry are crucial because of their ability to enhance performance and productivity. In this work, the discrete event simulation method has been employed to identify the problem of workstations and resources. The proposed methodology, as illustrated in **Fig. 1**, uses Arena software for modeling and simulation based on the discrete event method. The work implements a case study based on an actual automotive assembly line. Simulation of an assembly line model aims to increase the utilization of resources and determine the bottlenecks of workstations.

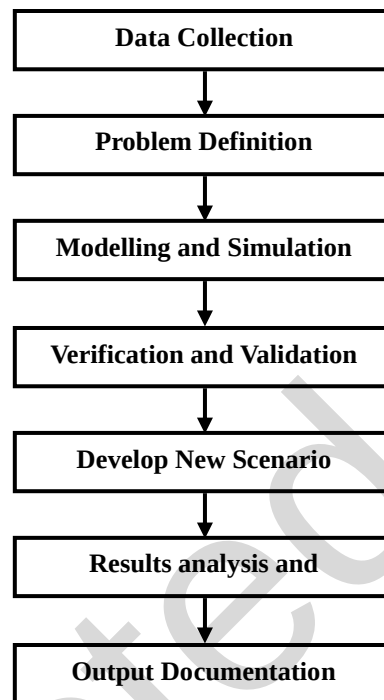


Fig. 1: Block Diagram of Methodology

A real case study provides necessary data for the simulation, which includes standard data and direct observations from the assembly line workstations. Data collection regarding assembly line configuration comprises elements such as processing durations and workstation resources. Problem identification entails an analysis of data from the assembly line workstations. The primary concern confronting assembly line management is the enhancement of performance and productivity. Consequently, the assembly line management analyzes the bottlenecks at different workstations and assesses the utilization of resources. Queues indicate that prolonged processing times have resulted in workstation congestion. Moreover, the inefficient use of resources, including labor and machinery, results in observable declines in productivity as noted by the industrial management of the assembly line.

The proposed methodology entails modeling and simulating different phases through a discrete event simulation approach that integrates case study models. In discrete event simulation, a system's operation is represented as a sequence of events, each occurring at a specific time and indicating a change in the system's state. Discrete event simulation is an experimental method commonly used for intricate modeling, as it allows for the representation of assumptions related to buffer capacity, processing time distributions, and priority dispatching. Arena software is a discrete simulation and automation application developed by Systems Modeling and owned by Rockwell Automation, utilizing the SIMAN simulation language. In Arena software, the user creates an experimental model using modules that represent real-world processes or enhance the model's logic. Users employ connecting lines to link modules or define a particular process flow. Arena offers animations for the entities used to improve the visualization of the process flow. Various statistical data can be collected and displayed in real-time during the simulation, as well as presented in a report upon its completion. After the model's construction and the simulation of the automobile company's assembly lines, verification and validation were performed to evaluate the model's

accuracy. The verification and validation process involves assessing whether the simulation model accurately and reasonably reflects the actual system being studied.

4. CASE STUDY

Selecting an automotive company as a case study is a vital component of this research. The Ministry of Industry and Minerals oversees the State Company for Automotive and Equipment, located in the Babylon Governorate of Iraq. The assembly plant for saloon cars exemplifies the company's operations. The factory comprises four primary assembly lines dedicated to the production and assembly of saloon cars, organized in a configuration that aligns with the factory's layout. **Fig. 2** presents the overall configuration of the factory's plant layout. The production system's process flow initiates with the trim conveyor, proceeds to the mechanical conveyor, and concludes with the finish conveyor. All the sequential processes of the BAIC assembly line are illustrated in **Fig. 3**, wherein the workstations encompass the principal assembly operations. According to the assembly line workstations, this study presents the following actual data concerning the production system, which includes the following parameters: daily working shift = 1, working hours per shift = 8, available time per shift = 480, lunch break per shift = 60, and total daily demand = 14. A comprehensive analysis of the production assembly line for BAIC vehicles, encompassing initial and final evaluations, is conducted based on the collected data and observations. This study sampled each operational task over a month, and **Table 1** displays the data required from each workstation. The table additionally delineates the processing duration and workforce quantity at each workstation of the assembly line. This study selected the assembly line that generates queuing due to its unbalanced nature. Therefore, we simulate and enhance the production system's assembly line to increase productivity.

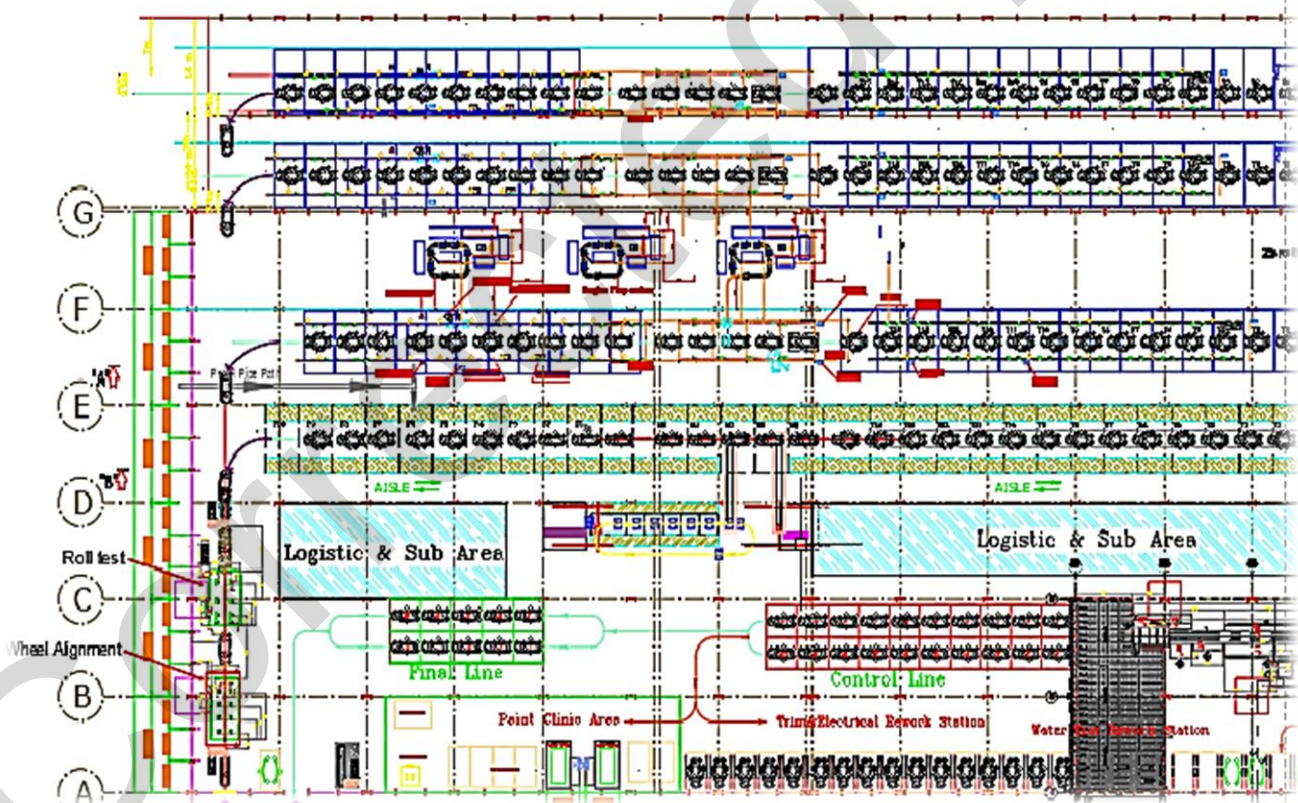


Fig. 2: Plant Layout of BAIC Vehicle Factory.

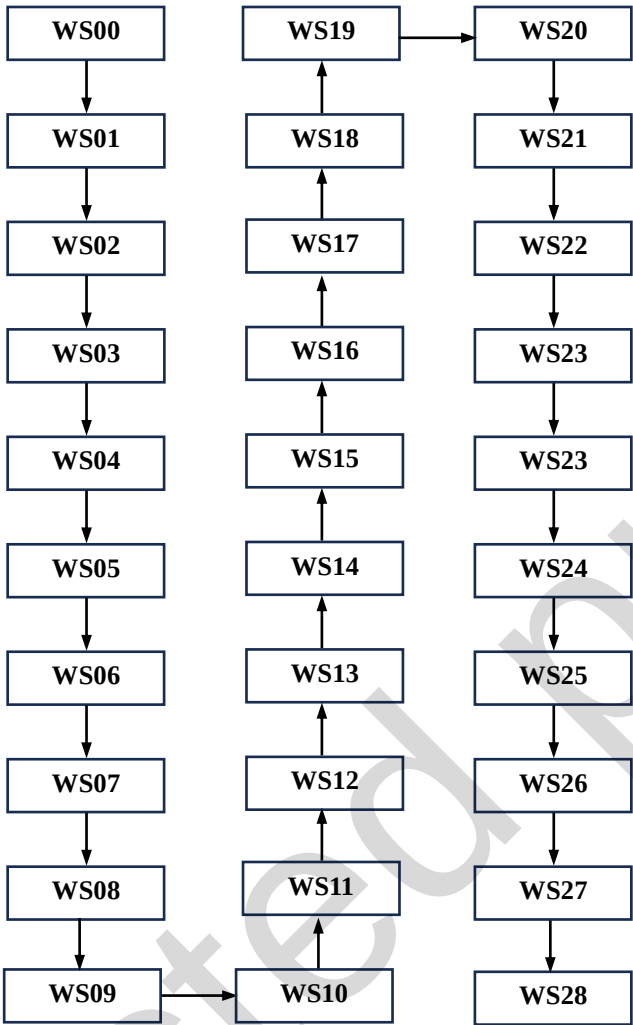


Fig. 3: The Sequence Workstations of Automobile Assembly line.

After analyzing the data collected to assess the assembly line situation, several problems have been identified: lower labor productivity, increased waiting times, and a significant amount of work in progress. To solve these challenges, the discrete event method utilized by Arena software was employed to construct a simulated model able to identify the crucial locations and assess the bottlenecks of assembly line workstations.

Table 1: Data Collected from the Assembly Line

Workstations No.	Assembly Workstation Tasks	Mean of Processing Time (min)	Number of Workers
WS00	Washing the body and preparing to assemble	19	3
WS01	Connecting the fuel tank Connecting the insulation under the dashboard	23	5
WS02	Connecting the door lock Prepare the main/sub wires that link the hand brake	22	4
WS03	Connecting the brake separator to the pipes Connecting (wiper motor) with the arms	17	5
WS04	Connecting the steering column Connecting pedals (accelerator path)	25	3
WS05	Connecting the cooling radiator Buckle the rear seat belt	18	4
WS06	Connecting the front doors Front door glass installation	21	6
WS07	Connect the rear doors Rear door glass installation	22	3
WS08	Bonding of ground insulation and floor covering Connecting the four door locks	17	6
WS09	Connecting the rear bumper and taillights Connecting the box lock	20	4
WS10	Connecting the cooling system with the fan	17	6
WS11	Dashboard placement and instrument panel	23	5
WS12	Connecting the cooling tubes Attaching the front strut	21	6
WS13	Front and rear linkage Connecting parts of the structure	22	4
WS14	Attaching side mirrors Connecting the steering wheel	22	5
WS15	Vehicle inspection point by quality control.	20	3
WS16	Connecting the side brake to the brick tubes Installing the double in (Shift Drive)	24	5
WS17	Installing the engine Connecting the fuel hose	18	6
WS18	Attaching the exhaust insulator Installing the four wheels	21	6
WS19	Connecting the front brakes Connecting air ducts and air filters, and power tubes	22	4
WS20	Connecting the radiator Connecting headlights	19	6
WS21	Connecting the fuse box Installing water sprinklers for the windshield	23	3
WS22	Connecting the front and back seats	18	5
WS23	Preparing the battery Installing the front and back windows	19	6
WS24	Filling the radiator with water Filling the car engine with oil	22	4
WS25	Filling the refrigerant gas into the cooling system	23	5
WS26	Filling the tank with fuel Filling the steering wheel oil	21	3
WS27	Definition and programming of the control panel	24	6
WS28	Vehicle inspection point by quality control	19	3

5. DEVELOPMENT OF THE ASSEMBLY LINE MODEL

The conceptual model of the BAIC assembly line workstations includes both a manual assembly process and a semi-automated assembly process. These two types of assembly processes each consist of a variety of separate methods. The flow of the product begins at the first workstation (WS00), continues through each succeeding workstation, and finally reaches its conclusion at the last station (WS28). We used Arena software to simulate the assembly line as part of this study. When the program integrates the real production factors, it is possible to determine the entire amount of time that is allotted between workstations in the production line. That allows the software to examine the effect of equipment and labor on the assembly line of the production system. The first part of the modeling process involves using the build function in Arena software to create a representation of the existing assembly line model. The model, which simulates various timeframes, involved processing a single vehicle through the assembly line while simultaneously modifying several characteristics. We have investigated 27 workstations on the assembly line, each with its operational variables. After each stage of the assembly line, update the simulated model with real data as shown in **Fig. 4**. The exponential distribution is a continuous probability distribution used to model the time elapsed before a given event occurs. Because of the operational nature of production parameters, the proposed simulated model is adapted to this type of distribution. To obtain accurate results from the assembly line model, the simulation was conducted for several replications, reaching 25 replications using the Arena simulation software. **Fig. 5** displays the final step of the modeling process as a diagrammatic model of the assembly line in the Arena software environment. The simulation model is running, but it needs to be reliable, which can be verified by comparing the results obtained from the model with the real situation, which has been explained in the discussion.

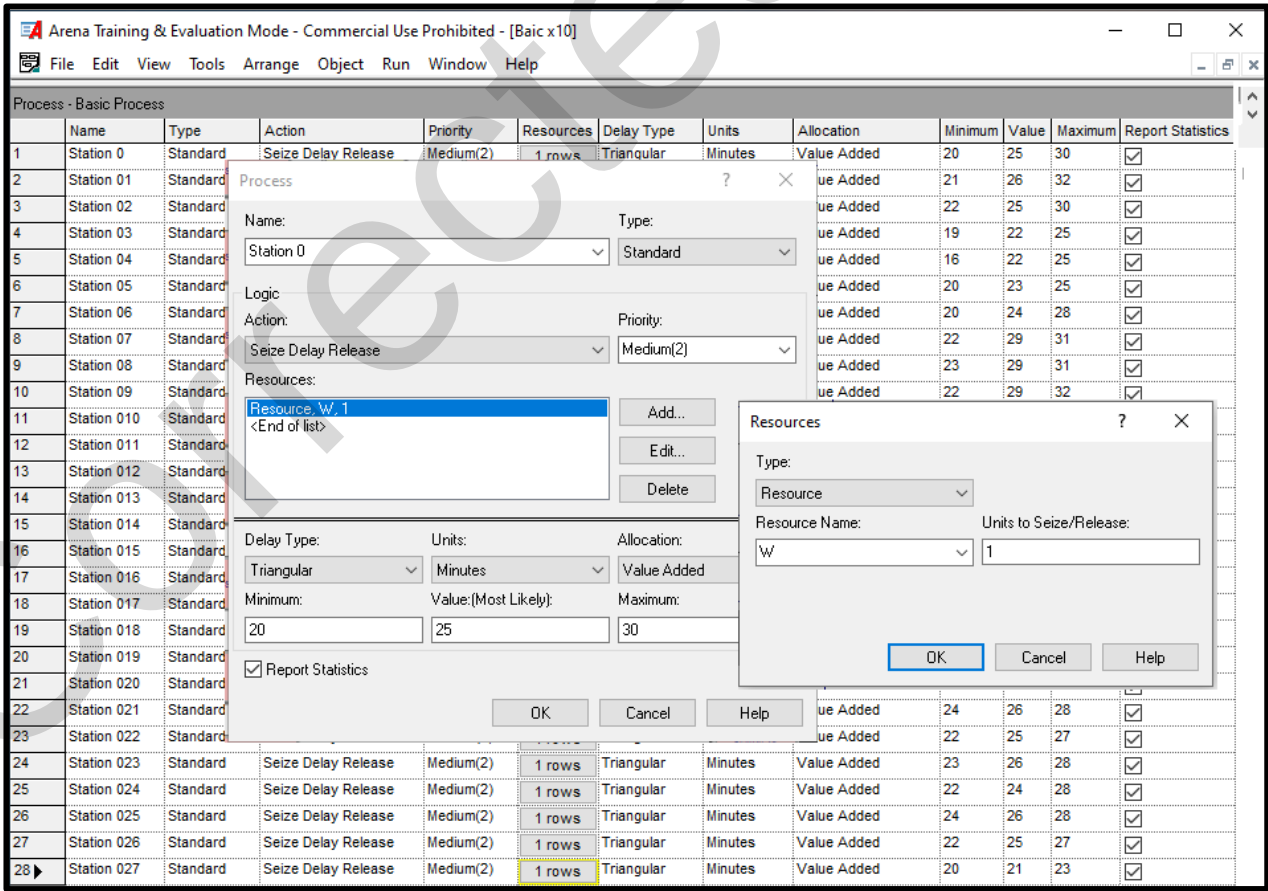


Fig. 4: Data input of Assembly line Model Using Arena Software

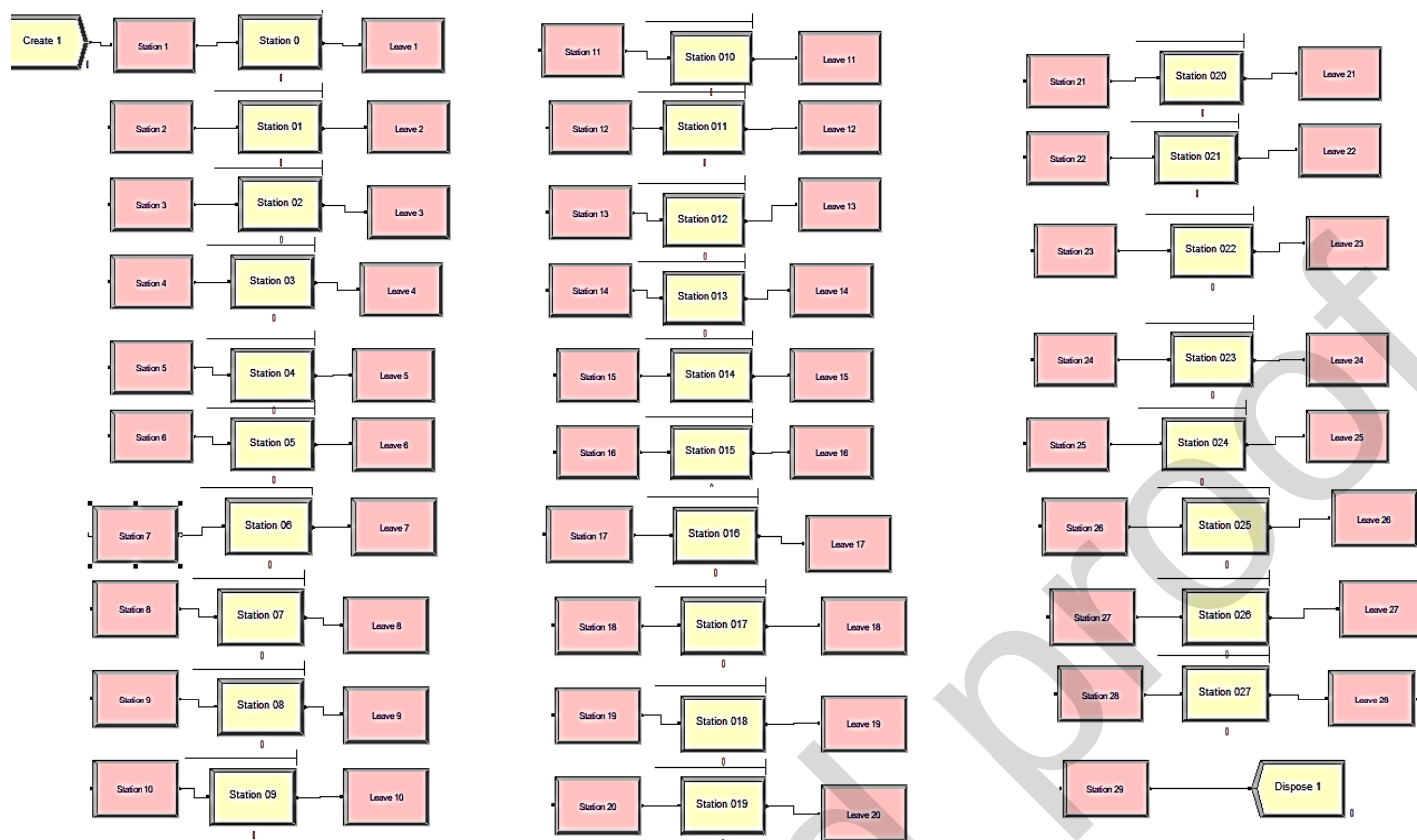


Fig. 5: The Simulation Model of Assembly Line Using Arena Software.

6. RESULTS ANALYSIS OF SIMULATION MODEL

In this work, a simulation of the initial assembly line model was constructed and executed using Arena software. **Table 2** presents the output results of the simulation model, which include the waiting time at workstations and utilization of resources. The results shown in the table demonstrate that both utilization and waiting time associated with the workstations are categorized into high, medium, and low percentages, respectively. According to the initial results of these categories, **Fig. 6** illustrates graphically the amount of variance among workstations. The analysis of variance indicates that both waiting time and utilization rate are the primary causes of the workstation bottleneck problems occurring in the assembly line. The graphical representation clearly shows that the workstations experiencing problems are WS3, WS8, WS12, WS15, WS19, and WS25. Meanwhile, other workstations, such as those in the assembly line, are not facing any queue issues. Regarding the waiting time results, the highest bar shows that the workstation queue has the longest waiting duration throughout the entire process. Furthermore, the utilization rate of workers at those workstations is concerning, as some bars appear to have the lowest values compared to other resources. Meanwhile, other workstations are not facing a reduction in the utilization rate of the resource. Increasing the utilization of resources at the bottleneck workstations has improved the performance of the assembly line model by addressing these challenges. Therefore, different scenarios of the simulation model for the development of the assembly line have been considered. Bottleneck analysis involves simulating different combinations of assembly line models. The best scenario has been selected based on the value of maximum utilization and minimal waiting time at the workstations. The final results, as shown in **Fig. 7**, indicate that the justifications on the modified model have solved the bottleneck problem on the assembly line and achieved the main aim of the research.

Table 2: Results Analysis of Assembly Line

Workstations No.	Workstation Waiting Time (S)	utilization Rate %
WS00	10	95
WS01	87	89
WS02	92	82
WS03	386	35
WS04	33	74
WS05	69	86
WS06	97	76
WS07	81	88
WS08	457	42
WS09	40	93
WS10	97	71
WS11	39	84
WS12	379	44
WS13	74	87
WS14	59	79
WS15	458	32
WS16	72	84
WS17	35	97
WS18	91	93
WS19	248	47
WS20	38	92
WS21	53	89
WS22	84	78
WS23	57	86
WS24	48	91
WS25	347	54
WS26	85	80
WS27	66	93
WS28	10	95

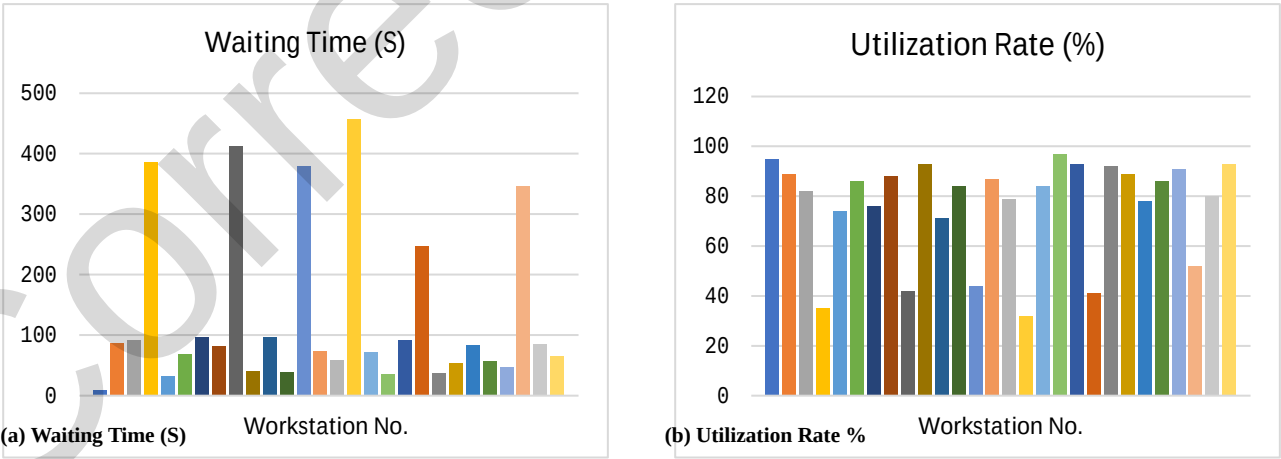


Fig. 6: The Results of the Simulated Model for the Current Assembly Line

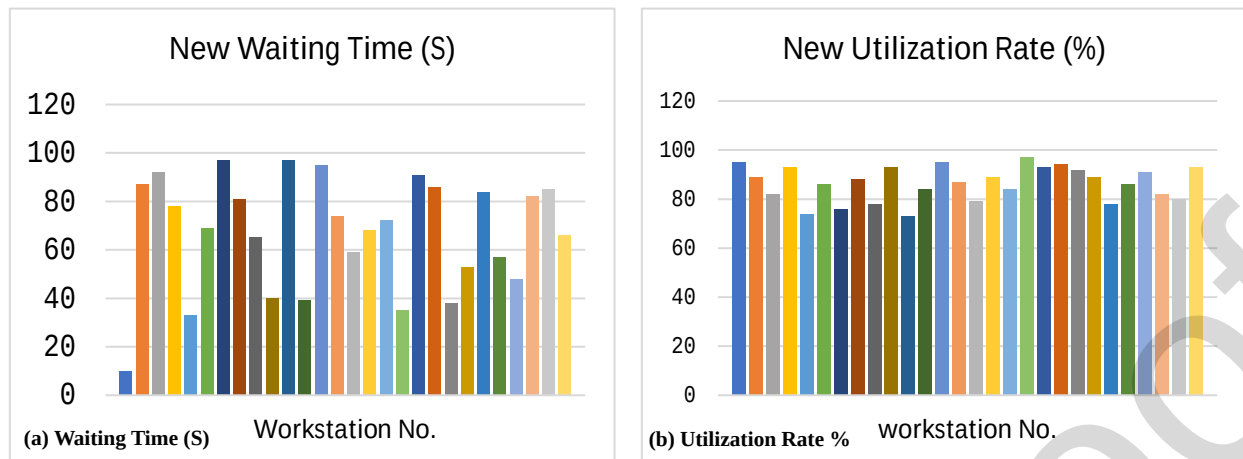


Fig. 7: The Results of the Simulated Model for the Proposed Assembly Line

7. IMPROVEMENT AND DISCUSSION

In this work, after analyzing problems and improvement opportunities, the initial results obtained from the simulation process of the assembly line indicate a lack of proper balance in the assembly line. The case study results have been evaluated based on the performance analysis of the assembly line through computer simulation. The final results show a significant improvement in efficiency as well as productivity. Furthermore, to see if assembly line performance improved, a before-and-after comparison was done. The main findings after running the model are that the total waiting time recorded in the production system queue is 61 minutes, with a maximum waiting time of 11 minutes and 45 seconds. So, A queue at a workstation indicates that the previous procedure is impeding the current one. After justifying the production parameters using the developed simulation model, the total waiting time per product has been reduced from 6 minutes to 4.5 minutes. Moreover, the bottleneck of the assembly line workstations became more adaptable and exerted a diminished impact on production flow. Other workstations do not experience waiting time and have not encountered any bottleneck issues. This study has investigated the worker utilization issue at each workstation, identifying that some workers have low utilization, which affects assembly line performance. Therefore, the developed model improved the utilization rate of workers at workstations that were facing problems by increasing the average resource utilization from 76% to 86%. The model achieved balance in the assembly line by redistributing workers between workstations, especially those facing bottlenecks. The final findings indicate that the optimal scenario results in enhanced productivity due to a reduction in waiting time. To improve the assembly line model, some suggestions are presented as alternative solutions for the current assembly line. Using Arena software to model and simulate the assembly line enhances efficiency and productivity by increasing throughput from 10 to 12 automobiles, reflecting a 15% increase in productivity compared to the initial model. The company can implement alternative solution #2 of the simulation model to obtain these findings without increasing the number of workers or workstations in the production system. To verify the accuracy of the simulation model, examination and testing were carried out using relevant actual data for the production system under study.

Furthermore, the simulation model was validated by the quantitative comparison between the outcomes and recorded historical data about the assembly line workstations. Thus, the simulation results of the simulation model and the actual system show that the output is higher than the actual output by 0.5%. Therefore, the simulation model is considered validated and reliable for further analysis.

CONCLUSIONS

In conclusion, this research was conducted utilizing a real case study focused on an assembly line within the automobile industry. We acquired the simulation model outcomes by analyzing the assembly line utilizing Arena software. Here are the main conclusions and recommendations for the future works:

- 1) The study advances current research on diverse enhancement strategies utilized in the automotive sector to bolster its market competitiveness.
- 2) The study identified a positive correlation between utilization and waiting time based on the bottlenecks and processing duration at each workstation.
- 3) The research study demonstrates that Arena software is an efficacious simulation tool for modeling and improving productivity.
- 4) The results indicate an enhancement in assembly line performance, characterized by decreased waiting times and increased utilization that contributes to improved efficiency and productivity.
- 5) The results of the investigation indicate that the assembly line has become more efficient, as evidenced by increased utilization and decreased waiting time.
- 6) A simulation study was performed under the assumption of disregarding worker fatigue and machine malfunctions, with no practical implementation of the proposed model.
- 7) Applying the proposed model in a real-world system and in a practical manner is not difficult to accomplish and can further justify future research in this field.
- 8) It is recommended that future research investigate how variations in throughput rate impact the utilization parameter while maintaining a constant production size.

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CONFLICT OF INTEREST

The author has no financial interest to declare concerning the content of this article.

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