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# SIMULATION BASED PERFORMANCE IMPROVEMENT: A CASE STUDY ON AUTOMOTIVE INDUSTRIES

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**Abstract**

In automotive industries, variable customer needs' increase the competition amongst enterprises. However, manufacturers are struggling to complete the customer demand on time. This paper presents a case study taken region in the automotive industry in Michigan, USA. It aims to reduce the production delay by stabilizing manufacturing processes that improve production throughput. Many tools are used including project charter, process flow diagram, Arena simulation, design of experiment (DOE), and layered process audit sheet. The project charter is used to represent the problem, objectives, scope, and methodology. The investigation of the system and the possible improvements are performed using Arena simulation along with DOE. Shop-floor data were collected and statistically analysed to model the different processes. Besides, the Ishikawa diagram was used to identify the root causes of the problems. Results show significant improvements. The number of finished products increased from 726 to 14161 units. The average WIP number increased from 4.9543 to 6.3615 units. The variation amongst the workstations' utilization is reduced. The cycle time decreased from 203.96 to 130.20 sec.

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**Key Words:** Automotive Industry, Performance Improvement, Project Charter, Discrete Event Simulation, Arena Simulation, Design of Experiment, Root Cause Analysis, Layered Process Audit Sheet

## 1. INTRODUCTION

Industry performance enhancement springing up from expanded manufacturing integration and cost reduction can be considered one of the main interests for firms in the current era. Driven by continuously increasing factors including globalization, increased competition, and multiplied customer needs, firms are following strategies for enhancing their performance and controlling costs. To acquire sustainable competitive advantages, enterprises should define their goals and translate them into shop floor levels then measure the gained performance [1]. Discrete-event simulation (DES) is a methodology that is widely used to imitate production processes and investigate the consequences of modifications suggested after method engineering. Amongst the high-quality tools, simulation software can be used to point out the overall performance of any production enterprise [2]. Simulation applications can be classified into simulation languages and simulators. The simulation language is generic by nature and can accommodate numerous applications. However, the required effort increases with increasing problem complexity. The simulator is pre-developed for specific system type(s) using certain ready modelling constructs with no or little programming [3]. These types of software are flexible enough that allows considering customer desires and complex modelling situations [3]. Generally, simulation is a problem-solving methodology that resembles a real-world device over a duration of time [4]. Literature has significant spectra of real-world issues analysed and solved using simulation models [5]. These models furnish beneficial statistics for choice making and additionally amplify the hassle solver's understanding of the system through

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experimentation. Simulation fashions can be continuous or discrete events. The discrete-event simulation includes modelling a gadget whose state adjustments instantly whereas in continuous simulation, state adjustments continuously with recognition of time [6]. The Arena simulation tool is used for simulation purposes. Simulation software is the creation of a digital twin the usage of historic statistics and vetted in opposition to your system's true results. Arena simulation software makes use of the discrete-event approach for most simulation efforts; it can be adapted to what is needed to be imitated [2]. Arena simulation was adopted in many applications. For example, it was applied in: landmine and improvised explosive device detection [7], performance improvement of assembly lines [8-12], manufacturing processes [13], optimization of production mix [14], manufacturing cell layout [15], solar panel production processes [16], analysis of system failures [17, 18], food industry [19], retail stores [20], health care [21] and many other applications.

Other tools can be used successfully for the different phases of any performance improvement project. For example, in order to understand the manufacturing process, the graphical illustration of the Process Flow Diagram is used. It is a structural diagram that represents the flow of material or information for a specified process. Process Flow Diagram is used in analysis, design, documentation, or management techniques or applications in a range of fields [22]. By analysing the process, many constraints can be discovered. The reasons behind these constraints should be investigated [23, 24]. The manufacturing constraints are any problem that prevents the manufacturing system from achieving higher levels of performance. Many tools are available to perform this process, e.g. Ishikawa diagram, and fault tree analysis [25]. The Ishikawa diagram is also known as the cause and effect diagram or fishbone diagram; it is used as a tool for root cause analysis [22]. It helps to track down the explanations for imperfection, variation, defects, or failures. It suggests the relationship of all causes that lead to the given state of effect. It identifies the essential motives and breakdown into sub-causes. During the problem-solving process, the Ishikawa is used to find out the alternate conclusion about the root reason for a problem [22]. Recently, Ayachi et al. [26] combined this diagram with Arena simulation to investigate the customer-supplier in the engineer to order applications.

For collecting the necessary information, the Design of experiments (DOE) is often used [27, 28]. DOE is described as the methodology of utilizing data that offers after planning and implementation, then using analysis tools for inferring assessments to consider the elements that manipulate the cost of the independent parameter(s). It permits multiple input elements to be investigated simultaneously, identifying their interaction impact on the specified output. All the possible combinations amongst the independent variables can be considered (full factorial design). In addition, a portion of the complete possible combinations can be considered according to a specified experiment design (fractional factorial) to make reasoning at an acceptable cost. A strategically deliberate and performed test may additionally grant a remarkable deal of statistics about the impact on response variables due to one or extra factors [29]. Many experiments contain preserving sure elements steady and altering the stages of some other variable. This "one factor at a time" method to system understanding is inefficient when compared with changing element ranges simultaneously. Recently, the DOE is used with Arena simulation to investigate flexible manufacturing systems [9, 27, 28]. Another tool is the Layered Process Audit (LPA) Sheet. It is an exceptional audit sheet, which is no longer restricted to the safety, or quality department, but to the personnel assigned to conduct the audit checks. It is simply used for the standardization of processes [30]. It is used to assure that procedure that personnel is auditing is following all the proper methods as referred to in the strategies barring deviation or adjustments from the genuine process [31]. The failure of LPA can result in an interior quality alert or assigning a worker to rectify the process.

In the competitive world of manufacturing where time is more valuable than any other factor, the manufacturing industry is struggling to compete with the remaining competition in the manufacturing market and stabilize their production process to gain and maintain customer confidence. This paper introduces a simulation-based approach for improving the performance of a case study on the automotive industry. The manufacturing industry under consideration is concerned about the stability of the manufacturing process of a new contract from their customer. However, the manufacturing company is having trouble satisfying the customer demand for a number of products that are about 1400 finished parts but the manufacturing company is able to produce only about 700 parts. In the manufacturing industry, the production process starts with the arrival of raw material, which is the coil for the stamping process and a weld nut for the welding process from the supplier. These raw materials are stored in the storage area until it is demanded by the respective production team. As the demand arises, the coil from the supplier is moved to the stamping press. Whereas the coil is made into work-in-progress (WIP) parts and from which the stamped WIP parts are moved to the weld nut welding area and the robot assembly area. Consequently, the finished product is moved to the inspection process, from which the certified good parts are moved to the storage area and shipped to the customer as the customer demands the product. The main target is to solve the highlighted manufacturing problem (Low production throughput). The proposed methodology to solve the problem relies on a set of different techniques. These techniques include project charter, flow process chart, data collection, discrete event simulation, Arena data Input analyzer, Design of experiment, Arena Output analyzer, root cause analysis, lean concept, and Layered process audit sheet. The integration of all of such tools to solve the problem produces a novel methodology that can be adopted by practitioners/professional engineers to solve their manufacturing constraints.

The rest of the paper is organized in the following manner. The next section introduces the research problem along with the solution methodology. In section 3, the case study is introduced accompanied by the simulation, analysis, and suggested improvement. Section 4 presents the research results and outcomes. Finally, conclusions and perspectives are discussed.

## 2. PROBLEM DESCRIPTION

The production delay is one of the major wastes in the production system. The identification and elimination of the production delay enhance the system performance significantly. As illustrated in Table I, the project charter of the case study is developed to present the problem, objectives, business case, scope of the case study, the adopted methodology, and the team members. The main problem of the manufacturing system is the production delay that forms a bottleneck process. Consequently, the objective is to recognize these bottlenecks, then improve the production process, and thereby increase the production throughput. The business case states that the customer will save production time, people's loyalty, and customer satisfaction, conserve resources, reduce costs and hence increase profit. The scope is focusing on the use of simulation models e.g. Input analyzer, Arena software, and Output analyzer for development and analysis. The scope out states that no products will be purchased to alter results. However, the results will be driven by changes in manufacturing and usage while existing conditions stay constant. The methodology relies on a set of tools and software for the development and analysis of the simulation model as listed in Table I. An audit tool layered process audit sheet is proposed to standardize the process and to make sure the improvement is sustained continuously during the manufacturing process.

For solving the highlighted industrial problem, the research methodology relies on some steps and tools that are listed in Table II. The process starts with the understanding of the manufacturing system using the process flow chat. The shop floor data were collected using Notepad and recording. After that, the Input analyzer is used to determine the best-fit distribution for each process. The process is then modelled using Arena simulation to imitate the real process. Based on this simulation model, the bottleneck process and the number of manufacturing process output as finished products are determined. Consequently, a root cause analysis is performed using the Ishikawa diagram to determine the main causes of the production delay. Consequently, DOE is developed to investigate the effect of the different factors. Based on the root causes, an improved flow diagram and an improved simulation model are created. As an audit tool, the "layered process audit sheet" is used to standardize the process and assure that the improvement is sustained continuously during the manufacturing process.

Table I: The Project Charter for improvement of the production process.

| **Project Charter** | |
|---|---|
| **Problem statement** | **Scope** |
| The customer is concerned about the current production process, delay in the manufacturing process, and the bottleneck process. | **IN**: Software like Input analyzer, Arena software, and Output analyzer are used to simulate the production system and analyse the suggested improvements. |
| | **OUT**: No products will be purchased to alter results. The results will be driven by changes in manufacturing and usage while existing conditions stay constant. |
| **Objective statement** | **Methodology** |
| The objective of the project is to recognize the bottleneck station in the production process, improve the production process, and thereby increase the production throughput. | Process Flow Diagram |
| | Data collection |
| | Discrete-event simulation |
| | Root cause Analysis |
| | DOE |
| | Improved Data collection & Flow Diagram |
| | Improved Simulation model |
| | Output analyzer |
| | Layered Process Audit Sheet |
| **Business case** | **Author** |
| The customer will save time, peoples loyalty, customer satisfaction, conserve resources and increase profit etc, | Authors' names |

Table II: The proposed methodology.

| Step | Suggested tool/Software/Device |
|---|---|
| 1. Process flow diagram | MS Office |
| 2. Data collection | Notepad |
| 3. Data analysis for Arena model to get distributions | Arena Input analyzer |
| 4. Building the simulation model | Arena Simulation Software |
| 5. Bottleneck analysis | Arena Report |
| 6. Root cause analysis | Ishikawa diagram |
| 7. DOE | Statistical software "Minitab" |
| 8. Building the system improved model | Arena simulation software |
| 9. Investigate results | Output analyzer |
| 10. Standardization of the process | Layered process audit sheet |

## 3. CASE STUDY

For understanding the problem at hand, the process flow chart is developed as shown in Fig. 1. The manufacturing processes start with receiving the raw materials from the suppliers: pre-stamped parts for the stamping process and the weld nut for the welding process. The raw materials from suppliers are received and stored in the storage area upon their need. The pre-stamped parts are moved to the stamping process where the parts are stamped again and the stamped "WIP" parts are moved to the weld-nut welding process where the weld nuts are welded into the "WIP" parts and these parts are moved to the robot assembly process where the stamped parts are assembled. Followed by which the parts from the robot assembly process are moved to the inspection area where these parts are inspected for any defects such as dents, splits, scratches, etc., and reworked at the metal surfacing area if they are rejected. Finally, the certified good parts are moved to the loading area waiting for the customer’s demand and shipped to the customer.

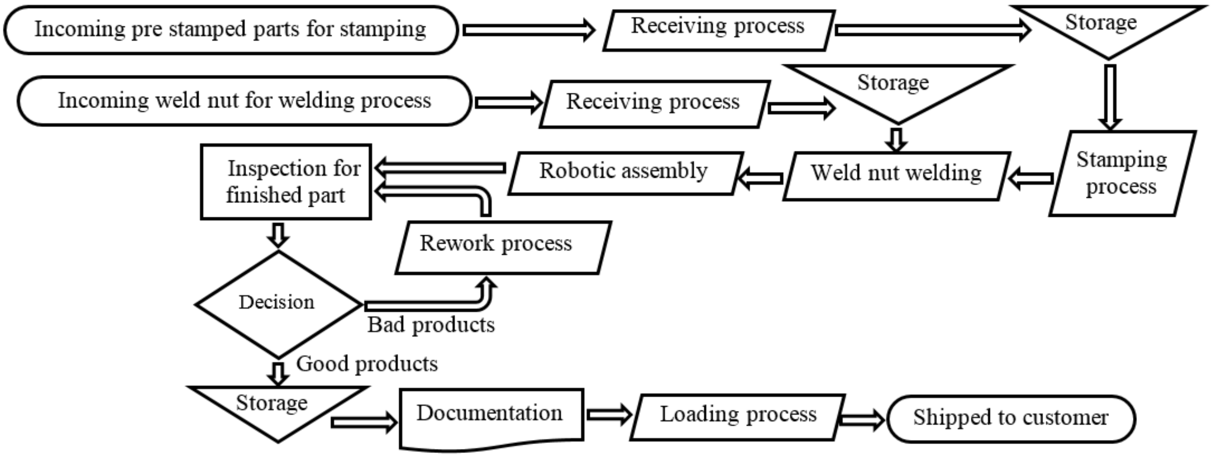


Figure 1: Initial process flow diagram.

### 3.1 Data collection and analysis

After careful observation of the production process, the data for each process is collected from the shop floor and tabulated as illustrated in Table III. As listed, the data were collected for each process (truck arrival, receiving process, stamping process, weld-nut welding process, robotic assembly process, the inspection process, rework process, and finally loading process of finished parts). The notepad is used as a data collection apparatus, and then the Input analyzer software is used to determine the best distribution that significantly fits the collected data for each process poses. The results of the Input analyzer were investigated and the most significant distribution for each process was identified as listed in Table IV. Where the best-fit distribution and its respective square root error are collected and tabulated.

Table III: Shop floor data of the manufacturing processes.

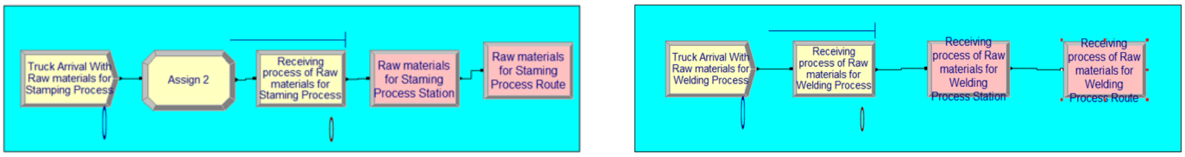
| Truck arrival | Receiving process | Stamping process | Weld nut process | Robotic assembly | Inspection process | Rework process | Loading process |
|---|---|---|---|---|---|---|---|
| 89 | 9 | 20 | 40 | 40 | 15 | 60 | 9 |
| 85 | 6 | 25 | 35 | 39 | 14 | 65 | 6 |
| 67 | 7 | 22 | 30 | 35 | 10 | 67 | 7 |
| 95 | 5 | 20 | 33 | 33 | 12 | 65 | 5 |
| 87 | 8 | 25 | 37 | 37 | 13 | 67 | 8 |
| 69 | 9 | 27 | 39 | 39 | 14 | 69 | 9 |
| 80 | 7 | 26 | 35 | 38 | 15 | 60 | 7 |
| 64 | 10 | 22 | 37 | 39 | 12 | 64 | 10 |
| 82 | 7 | 20 | 35 | 33 | 14 | 62 | 7 |
| 96 | 9 | 28 | 30 | 34 | 15 | 66 | 9 |
| 77 | 6 | 20 | 33 | 30 | 16 | 67 | 6 |
| 95 | 8 | 29 | 37 | 39 | 12 | 68 | 8 |
| 93 | 9 | 23 | 36 | 36 | 14 | 63 | 9 |
| 71 | 7 | 22 | 35 | 30 | 17 | 61 | 7 |
| 89 | 6 | 28 | 38 | 35 | 15 | 69 | 6 |

### 3.2 Simulation model

Relying on the process flow chart and the results of the Input analyzer the simulation model was developed using Arena as shown in Fig. 2. Besides, the animation of resources and its path are created. The simulation model was developed using the station and “route tool”. As shown in Fig. 2 b, the arrival station for the coil was modelled using the arrival distribution. Then it is connected to the process of “receiving process of raw material for stamping process”. After that, it is connected to the station in the advanced transfer known as “Raw materials for stamping process station”. Finally, it is connected to a route tool named “Raw materials for stamping process route”. With the same concept, the next station was modelled that represent the “Arrival Station for Weld-nut” as illustrated in Fig. 2 c. It contains mainly four tools, which are created (truck arrival with raw material); process (receiving process of raw material, transfer to the welding, and the routing tool). The stamping process station is created with the process and then it is routed as shown in Fig. 2 d. The station of weld-nut is created with process distribution then it is routed as shown in Fig. 2 e. As shown in Fig. 2 f, the robotic assembly process station is created using its distribution. After that, the entities are routed to the upstream station. As illustrated in Fig. 2 g, the inspection process is modelled. The decision tool is then used to separate the proportion of good parts from the proportion of failed parts. After that, each type is routed respectively to the loading or rework stations. The rework station is created. Consequently, the reworked parts are routed to the inspection station as shown in Fig. 2 h. As shown in Fig. 2 i, the good parts are loaded in the loading station.

Table IV: Initial Arena model data distribution.

| Steps | Distribution from Input analyzer | Square root error |
|---|---|---|
| Truck arrival with Raw materials | 63.5 + 33 × BETA(0.874, 0.679) | 0.048834 |
| Receiving process of Raw materials | 4.5 + 6 × BETA(1.64, 1.6) | 0.018582 |
| Stamping process | POIS(23.8) | 0.037092 |
| Weld nut Welding process | NORM(35.3, 2.82) | 0.065023 |
| Robotic Assembly process | 29.5 + 11 × BETA(1.15, 0.944) | 0.052889 |
| Inspection process | TRIA(9.5, 14.6, 17.5) | 0.033475 |
| Rework process | 59.5 + 10 × BETA(0.86, 0.743) | 0.018317 |
| Loading process of Finished product | 4.5 + 6 × BETA(1.64, 1.6) | 0.018582 |

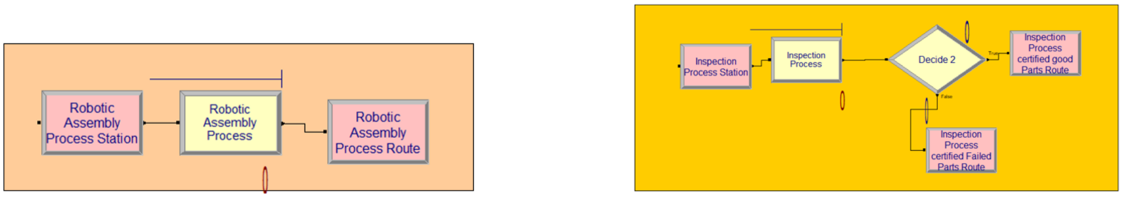


a) Modelling of coil arrival station

b) Weld-nut arrival station

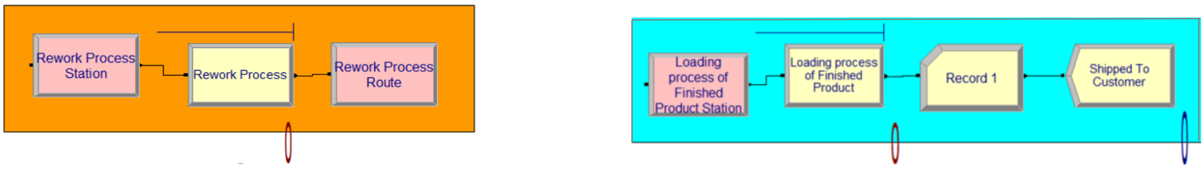
c) Stamping process

d) Weld-nut welding process



e) Robotic assembly process

f) Inspection process



g) Rework process

h) Loading of finished products

Figure 2: Simulation model using Arena.

### 3.3 Design of Experiment (DOE)

The DOE is a statistical tool that is used to analyse data to determine the main and interaction effect of a set of factors on a specified response variable(s). In this analysis, the factors taken into consideration are inspection process capacity, weld-nut welding capacity, and robotic assembly capacity. The response is taken as the production throughput as illustrated in Table V. Minitab software is used for this analysis using the full factorial design. The regression analysis is also performed and the regressed equation is represented in Eq. (1). As illustrated in the Pareto chart in Fig. 3, the major factors that affect the production throughput are respectively *AC*, *B*, *BC*, *C*, and *AB*. The highest effect is the linear interaction between the inspection process and robotic assembly capacities. The second effect level is given to the weld-nut welding capacity. The third parameter is the linear interaction between the capacities of weld-nut welding and robotic assembly. The effect of the robotic assembly capacity shows an equal effect as the interaction effect of the capacities of the inspection process and weld-nut welding. These effects are shown using Fig. 4 which shows the main effect plot and the interaction effect plot.

Table V: Design of Experiment.

| Std. order | Run order | Centre point | Blocks | Inspection process capacity (*A*) | Weld-nut welding capacity (*B*) | Robotic assembly capacity (*C*) | Throughput (*TP*) |
|---|---|---|---|---|---|---|---|
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 726 |
| 2 | 2 | 1 | 1 | 4 | 1 | 1 | 730 |
| 8 | 3 | 1 | 1 | 1 | 3 | 1 | 729 |
| 4 | 4 | 1 | 1 | 4 | 3 | 1 | 732 |
| 7 | 5 | 1 | 1 | 1 | 1 | 2 | 730 |
| 5 | 6 | 1 | 1 | 4 | 1 | 2 | 727 |
| 6 | 7 | 1 | 1 | 1 | 3 | 2 | 731 |
| 1 | 8 | 1 | 1 | 4 | 3 | 2 | 727 |

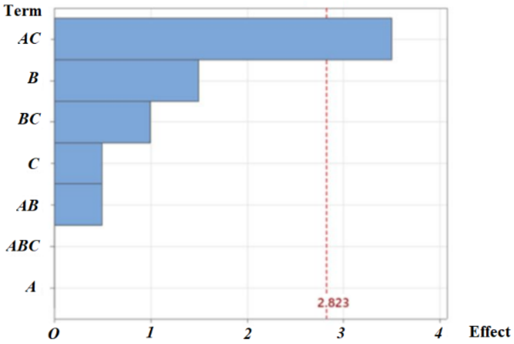
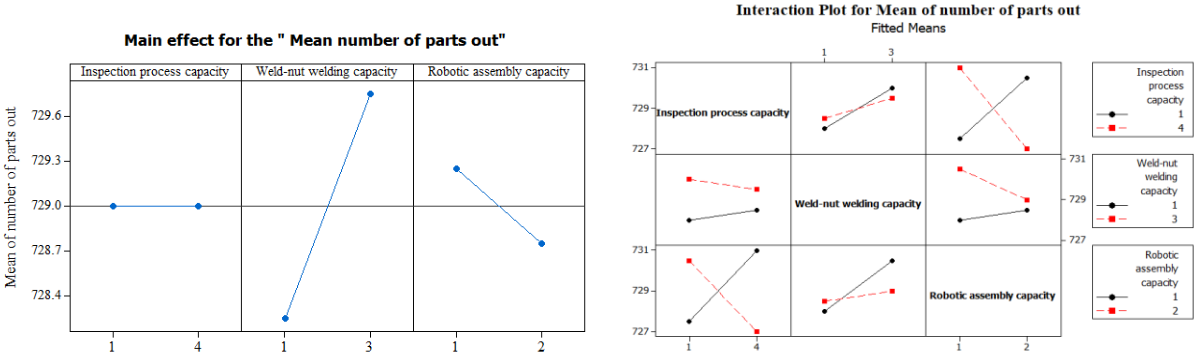


Figure 3: Pareto chart of the factors that affect the production throughput.



a) Main effect plot b) Interaction plot amongst *A*, *B*, and *C*

Figure 4: The effect of factors *A*, *B*, and *C* on the production throughput.

$$TP = 715.7 + 3.833A + 2.667\,B + 7.333\,C - 0.1667\,AB - 2.333\,AC - 1.0\,BC \qquad (1)$$

### 3.4 Root cause analysis

In order to identify the main root causes of the production delay, the fishbone diagram is adopted. For the current case study, many factors were identified as shown in Fig. 5. The main discovered root causes are management or engineering, machinery, schedule, people, transportation, and materials. For each one of these main categories, the sub-causes are also identified.

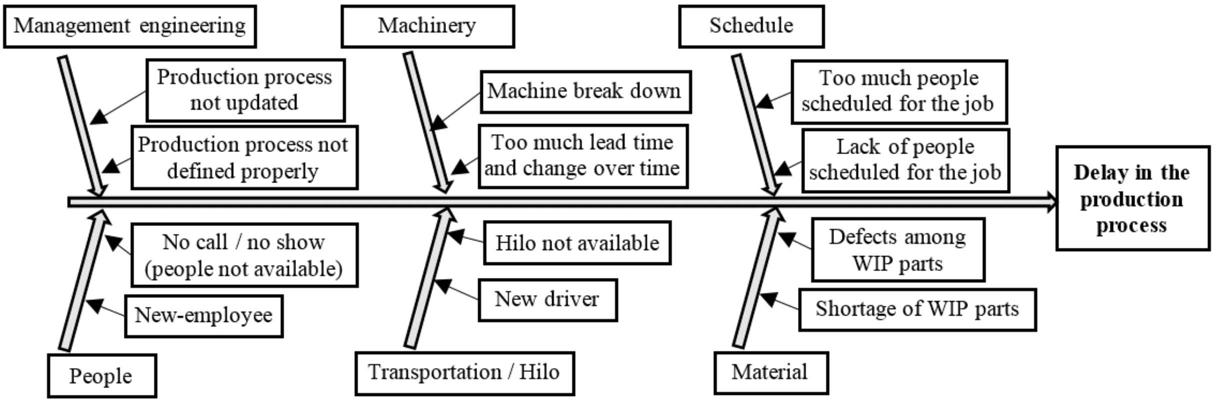


Figure 5: Ishikawa diagram for the problem of production delay.

### 3.5 Improved model

After the detailed study of the production process using simulation, DOE, and root cause analysis, the next step is the identification of process improvements. Relying on the results of the DOE, the welding process and the robotic assembly form the bottleneck process in the system. As a solution to improve the manufacturing process few proposals were proposed. One of them is to add more capacity to the weld-nut welding process, inspection process capacity, and robotic assembly capacity. To evaluate the impact that may result from the capacity increase, a design of experiment-based investigation was done using the main model. Considering that, the response is the number of parts out from the system and the independent input parameters are the above factors. Results show that changing the capacity of the investigated factors improved the number of parts out (response) but it was not enough to satisfy the customer demand. Hence, the above proposal was rejected, the second proposal was to replace the robot assembly with one more robust and advanced robot, in which the weld nut welding and robot assembly are done in the same process, which saves time and reduces human interaction that improves the quality of the product and increases the speed of the process. Moreover, according to the root cause analysis, many reasons are discovered that include: management, machines, maintenance, lack of efficient scheduling, inefficient quality system, or unavailability of the workforce. Accordingly, the following improvements were suggested and implemented:

- Both the welding weld-nut process and robotic assembly process are combined as a single process by the installation of a new robot assembly station.
- Management commitment.
- Implementation of effective maintenance planning (autonomous maintenance).
- Implementation of planning and scheduling techniques.
- Quality control and assurance.
- Providing workforce training programs.

After the implementation of the suggested improvements, the manufacturing process of the enterprise starts its production process by receiving the raw materials from the supplier, in this case, the receiving raw materials are the incoming pre-stamped parts for the stamping process and the weld nut for the weld-nut welding process. The raw materials from the suppliers are received and stored in the storage area until the need of the production department. The pre-stamped parts are moved to the stamping process where the parts are stamped and the stamped WIP parts are moved to the robot assembly area where the weld nuts are welded and the stamped parts are assembled. Followed by which the parts from the robot assembly process are moved to the inspection area where these parts are inspected for any defects such as dents, splits, scratches, etc., and reworked at the metal surfacing area if they are rejected. Finally, the certified good parts are moved to the loading area waiting for shipment to the customer. After that, the data were collected again. New distribution was noticed for the robotic assembly and welding, as "NORM (21.1, 3.1)" at a square root error of 0.112780. Also, a new distribution was noticed for the inspection process as "2.5 + 7 × BETA(1.84, 1.69)" at 0.014064. Using the newfound distributions and the new construction of the production line the simulation model for improvement was reconstructed.

## 4. RESULTS AND DISCUSSIONS

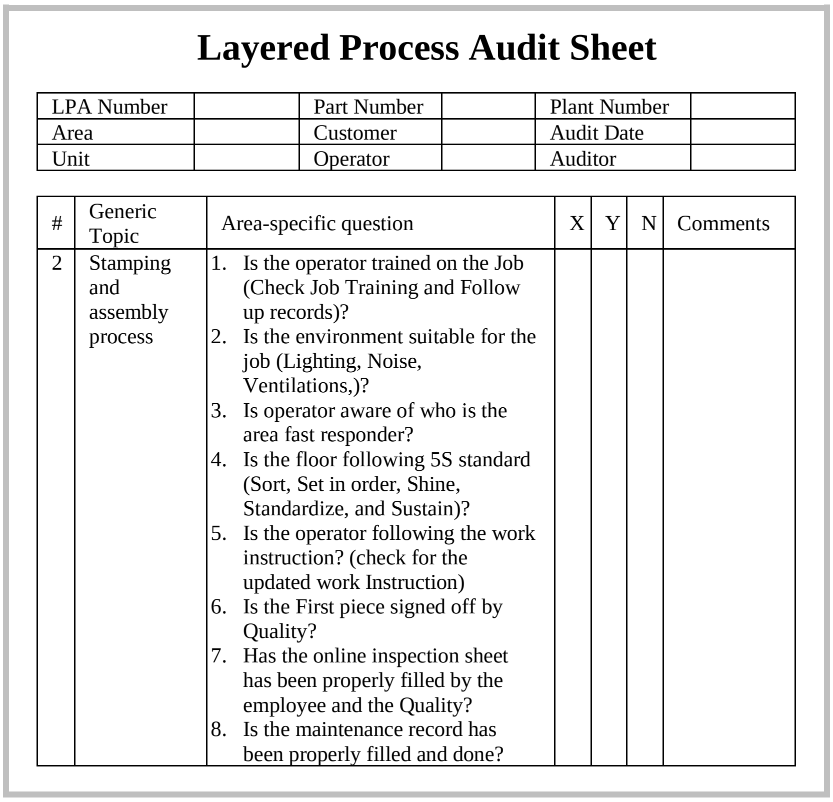
The results from the Arena simulation are run in the Output Analyzer and the data are recorded. The classical confidence interval on the mean of the initial process and the improved process were identified. the analysis includes the average WIP, initial process current utilization, initial process cycle time, initial process number-in, initial process number-out, and initial process average value-added time with a 95 % confidence interval. Then the comparison is performed amongst these values for both processes (before improvement and after improvement, as listed in Table VI.

Table VI: Result comparison.

| Outputs | Initial process | Improved process |
|---|---|---|
| Number In | 730.80 | 1466.80 |
| Number Out | 726 | 1461 |
| Value-added time average (s) | 141.95 | 75.7811 |
| Average WIP | 4.9543 | 6.3615 |
| Utilization stamping process | 0.2897 | 0.5823 |
| Utilization of robotic assembly process | 0.8616 | 0.5344 |
| Utilization inspection process | 0.3917 | 0.7953 |
| Cycle time (s) | 203.96 | 130.20 |

As listed in Table V, the number of units feed into the system got increased from 731 units to 1467 units, similarly, the number of finished products increased from 726 units to 14161 units, whereas the average value-added time decreased from 141.95 to 75.7811 sec. The Average WIP number increased from 4.9543 to 6.3615 and the utilization of the stamping process increased from 0.2897 to 0.5823, whereas the utilization of the robotic assembly process decreased from 0.8616 to 0.5344, and the utilization of the inspection process increased from 0.3917 to 0.7953 while the cycle time decreased from 203.96 to 130.20 sec.

In order to maintain this achievement, the standardization process is proposed. The standardization process assures that the changes or the improvements in the production process are maintained and are being followed throughout the production process. For the standardization process, the case study uses the tool of audit sheet or layered process audit sheet (LPA). If the process is violated the LPA can result in the issuing of an internal quality alert and hence the update in the production process can be enforced to be followed/maintained. The case study uses the LPA as illustrated in Fig. 6 for the standardization process of the manufacturing process.



**Layered Process Audit Sheet**

| | | | | | |
|---|---|---|---|---|---|
| LPA Number | | Part Number | | Plant Number | |
| Area | | Customer | | Audit Date | |
| Unit | | Operator | | Auditor | |

| # | Generic Topic | Area-specific question | X | Y | N | Comments |
|---|---|---|---|---|---|---|
| 2 | Stamping and assembly process | 1. Is the operator trained on the Job (Check Job Training and Follow up records)?<br>2. Is the environment suitable for the job (Lighting, Noise, Ventilations,)?<br>3. Is operator aware of who is the area fast responder?<br>4. Is the floor following 5S standard (Sort, Set in order, Shine, Standardize, and Sustain)?<br>5. Is the operator following the work instruction? (check for the updated work Instruction)<br>6. Is the First piece signed off by Quality?<br>7. Has the online inspection sheet has been properly filled by the employee and the Quality?<br>8. Is the maintenance record has been properly filled and done? | | | | |

Figure 6: Layered Process Audit Sheet (LPA).

## 5. CONCLUSION

This paper presents a case study of performance improvement in one production line of an automotive company. A new integrated methodology has been adopted and presented. The methodology relies on many tools for identification, analysis, improvement, and control. Whereas the Project Charter was used for the identification of the objective and project scope. Many analysis tools were used e.g. time study, Arena Input analyzer, Arena simulation, Design of Experiment (DOE), regression analysis, main effect analysis, and root cause analysis. Using root cause analysis, the main system bottleneck was identified and different improvements were suggested that including investment, and production improvement. For the control, the Layered process audit sheet is developed and implemented to assure performance sustainability. As a result, the production process is improved as intended by the customer. The results show that the number into the system increased from 731 to 1467 units, similarly, the number of the finished products increased from 726 to 14161 units. Whereas the average value-added time decreased from 141.95 to 75.7811 sec. The Average WIP number increased from 4.9543 to 6.3615 units and the utilization of the stamping process increased from 0.2897 to 0.5823. Whereas the utilization of the robotic assembly process decreased from 0.8616 to 0.5344, the utilization of the inspection process increased from 0.3917 to 0.7953 and the cycle time decreased from 203.96 to 130.20 sec. These results indicate the capability of the proposed methodology to investigate the manufacturing system and identify the system constraints. Moreover, it is capable to investigate the feasibility of the proposed performance improvement initiatives. Engineers from different manufacturing sectors can adopt the followed methodology to study and improve their production systems. For perspectives on this work, one can consider the fuzzy nature of the different parameters and performance responses, especially in the DOE.

The second direction that can be adopted is the integration of optimization techniques and simulation for enhancing the performance of the manufacturing processes.

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## REFERENCES

[1] Alzameli, K.; Alwerfalli, D. R.; Ali, A.; Alsamarai, A. (2016). Optimization of assembly line of printed circuit board using simulation, *International Journal of Scientific & Technology Research*, Vol. 5, No. 7, 128-132

[2] Kelton, W. D. (2010). *Simulation with Arena*, 5th edition, McGraw-Hill, New York

[3] Martinez, F. E. (2002). *Application of SIMAN ARENA Discrete Event Simulation Tool in the Operational Planning of a Rail System*, Final Report, University of Puerto Rico, San Juan

[4] Banks, J. (1998). *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice*, John Wiley & Sons, New York, doi:10.1002/9780470172445

[5] Grznar, P.; Gregor, M.; Gaso, M.; Gabajova, G.; Schickerle, M.; Burganova, N. (2021). Dynamic simulation tool for planning and optimisation of supply process, *International Journal of Simulation Modelling*, Vol. 20, No. 4, 441-452, doi:10.2507/IJSIMM20-3-552

[6] Pidd, M. (2004). *Computer Simulation in Management Science*, 5th edition, John Wiley & Sons, New York

[7] Johnson, D.; Ali, A. (2015). Modeling and simulation of landmine and improvised explosive device detection with multiple loops, *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, Vol. 12, No. 3, 257-271, doi:10.1177/1548512912457886

[8] Pandian, A.; Ali, A. (2011). Automotive robotic body shop simulation for performance improvement using plant feedback, *International Journal of Industrial and Systems Engineering*, Vol. 7, No. 3, 269-291, doi:10.1504/IJISE.2011.03898

[9] Altayib, K.; Ali, A. (2011). Improvement for alignment process of automotive assembly plant using simulation and design of experiments, *International Journal of Experimental Design and Process Optimisation*, Vol. 2, No. 2, 145-160, doi:10.1504/IJEDPO.2011.040264

[10] Blake, J.; Ali, A. (2011). Simulation analysis and performance improvement of engine assembly line, *International Journal of Process Systems Engineering*, Vol. 1, No. 3-4, 288-301, doi:10.1504/IJPSE.2011.041563

[11] Krstovski, S.; Ali, A. (2012). Productivity improvement in subsystem of assembly process utilising simulation, *International Journal of Modelling in Operations Management*, Vol. 2, No. 3, 227-241, doi:10.1504/IJMOM.2012.047945

[12] Lorou, B.-F. T. E.; Muchiri, P. N.; Kuloba, P.; Kimotho, J. K. (2021). Performance improvement of truck assembly line through modeling and simulation using Arena software, *Open Journal of Optimization*, Vol. 10, No. 3, 88-100, doi:10.4236/ojop.2021.103007

[13] Polubinski, J.; Ali, A. (2011). Simulation analysis of commercial truck spiral bevel gear process, *International Journal of Modelling in Operations Management*, Vol. 1, No. 2, 197-208, doi:10.1504/IJMOM.2010.038149

[14] Zghair, H.; Ali, A.; Nedeltcheva, G. N. (2016). Analytical simulation for production mix optimization of flexible assembly systems, *Proceedings of the 2016 Western Decision Sciences Conference*, 90-102

[15] Pandian, A.; Ali, A. (2016). Manufacturing cell layout improvement using simulation modeling and group technology, *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management*, 103-114

[16] Kilic, R.; Erkayman, B. (2021). A simulation approach for transition to JIT production system, *International Journal of Simulation Modelling*, Vol. 20, No. 3, 489-500, doi:10.2507/IJSIMM20-3-566

[17] Pandian, A.; Ali, A. (2015). Investigation of maintenance assumptions for an automotive production line using simulation modeling, *2015 International Conference on Industrial Engineering and Operations Management*, 7 pages, doi:10.1109/IEOM.2015.7093773

[18] Pandian, A.; Ali, A. (2014). The effects of system failures in a robotic assembly line-simulation modeling and DOE analysis, *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management*, 513-522

[19] Abdul Rasib, A. H.; Abdullah, R.; Bazilah, N. F.; Mohamad Rafaai, Z. F.; Noor, R. M. (2021). Production smoothness improvement through ARENA application in the food manufacturing industry, *Turkish Journal of Computer and Mathematics Education*, Vol. 12, No. 3, 3516-3526, doi:10.17762/turcomat.v12i3.1627

[20] Sridhar, P.; Vishnu, C. R.; Sridharan, R. (2021). Simulation of inventory management systems in retail stores: a case study, *Materials Today: Proceedings*, Vol. 47, 5130-5134, doi:10.1016/j.matpr.2021.05.314

[21] Ahmad, A. N. A.; Ahmad, M. F.; Hamid, N. A.; Hamid, N. A. A.; Lee, T. C.; Nawanir, G.; Bakri, A.; Rahim, M. A. (2021). Implementation of lean technique towards reducing waiting time in a public healthcare using Arena simulation, *International Journal of Integrated Engineering*, Vol. 13, No. 7, 201-214, doi:10.30880/ijie.2021.13.07.024

[22] Rahman, M.; Brackett, D.; Milne, K.; Szymanski, A.; Okioga, A.; Huertas, L.; Jadhav, S. (2022). An integrated process and data framework for the purpose of knowledge management and closed-loop quality feedback in additive manufacturing, *Progress in Additive Manufacturing*, published online, 14 pages, doi:10.1007/s40964-021-00246-7

[23] Seleem, S. N.; Attia, E.-A.; el-Assal, A. (2016). Managing performance improvement initiatives using DEMATEL method with application case study, *Production Planning & Control*, Vol. 27, No. 7-8, 637-649, doi:10.1080/09537287.2016.1165301

[24] Seleem, S. N.; Attia, E.-A.; Karam, A.; el-Assal, A. (2020). A lean manufacturing road map using fuzzy-DEMATEL with case-based analysis, *International Journal of Lean Six Sigma*, Vol. 11, No. 5, 903-928, doi:10.1108/IJLSS-12-2017-0147

[25] Barnett, W. P.; Greve, H. R.; Park, D. Y. (1994). An evolutionary model of organizational performance, *Strategic Management Journal*, Vol. 15, No. S1, 11-28, doi:10.1002/smj.4250150903

[26] Ayachi, R.; Guillon, D.; Aldanondo, M.; Vareilles, E.; Coudert, T.; Beauregard, Y.; Geneste, L. (2022). Risk knowledge modeling for offer definition in customer-supplier relationships in Engineer-To-Order situations, *Computers in Industry*, Vol. 138, Paper 103608, 14 pages, doi:10.1016/j.compind.2022.103608

[27] Krstovski, S.; Ali, A. (2021). Design of experiment base scenario analysis in discrete event simulation of multi-path manufacturing system, *International Journal of Process Systems Engineering*, In press – Online First, doi:10.1504/IJPSE.2021.10038026

[28] Nabi, H. Z.; Aized, T.; Riaz, F. (2022). Modeling, analysis and optimization of carousel-based flexible manufacturing system, *Journal of Industrial and Production Engineering*, published online, 15 pages, doi:10.1080/21681015.2022.2031323

[29] Al-Refaie, A.; Lepkova, N.; Abbasi, G.; Bani Domi, G. (2020). Optimization of process performance by multiple pentagon fuzzy responses: case studies of wire-electrical discharge machining and sputtering process, *Advances in Production Engineering & Management*, Vol. 15, No. 3, 307-317, doi:10.14743/apem2020.3.367

[30] Bertagnolli, F. (2022). Standardization, Bertagnolli, F. (Ed.), *Lean Management: Introduction and In-Depth Study of Japanese Management Philosophy*, Springer, Wiesbaden, 129-147, doi:10.1007/978-3-658-36087-0_10

[31] Bertagnolli, F. (2022). Shop floor management, Bertagnolli, F. (Ed.), *Lean Management: Introduction and In-Depth Study of Japanese Management Philosophy*, Springer, Wiesbaden, 327-348, doi:10.1007/978-3-658-36087-0_25