

Throughput and Efficiency Improvement Using Discrete Event Simulation

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Abstract

The design of a balanced and resource-efficient assembly line is a critical concern that decides the profit and loss of an industry. This case study is based on an assessment of the assembly line in an automotive component vendor company through the study of discrete events in sequence along the line. Firstly, the intimation of the current system is established in software that allows experimentation in a virtual environment, which then enables the use of what-if scenarios to check whether the set of changes would perform better or not based on simulation results.

Simulation is a powerful and cost-efficient technique for the design and operation of manufacturing systems. Simulation through the software model allows one to check the feasibility of different improvements with ease rather than having to wait and gather data for weeks.

This model is set up by taking actual data using time study techniques from each workstation and process along the production line. All the processes, starting from the arrival of raw materials, forging, to the packing of final products are studied and their data is used to set up a model in software. Before the data is input in software, it is analyzed using statistical software to determine the statistical distribution for each process.

The simulation results obtained after the validation of the system that is currently running demonstrates the performance of all the processes involved in the production line. The bottleneck processes are indicated, and their possible solution is also suggested. The resources with less utilization are removed and the cost is reduced. All the suggested changes and their effects are discussed in this study.

Keywords: Production Line; Discrete Event Simulation; Modelling and simulation; Throughput Rate

Introduction

Industries are changing their production systems due to changes in their client's demands. Flexible and faster production systems are necessary that can help achieve a high variety of products simultaneously in small numbers. There is a need for line balancing to manage the high demand in variety with complex layouts and changing operations on different workstations. To avoid interruptions in the production flow, idle time must be minimized. Common issues in a production line that need to be addressed, include firstly, reducing the operation time given on different workstations. Secondly, minimizing the workload of the operator on each workstation when cycle time and workstation cannot be altered. And thirdly, to improve man and machine resource utilization by reducing the idle time.

Changing the layout of the production line can be a costly and tedious task. Likewise, deciding whether a new set of changes will perform better than the current scenario is hard to decide until the new system is established. If the new layout doesn't achieve the required improvements and results, a lot of time and capital is consequently wasted. So, it is desirable to test the ability of the new production system with a new set of changes before purchasing and installing new equipment. The assessment of different staff requirements and few distinct designs can be imitated with ease in the simulation model, which would otherwise have taken years for testing or gathering the data. The main focus of this study is to balance the assembly line of automobiles within the automotive components manufacturing industry using the simulation technique. Through this technique, the company can save a lot of capital and time, as well as improve the performance of the current production line as compared to the customary method of conducting experimentation on the actual production system.

The Process Simulator software proved to be a powerful tool in assessing the changes that should be made for a manufacturing line before incurring actual manufacturing improvements. The focus of this study is to evaluate different scenarios by applying various 'what-if' analysis to help eliminate bottleneck and idling time, hence increasing line efficiency and productivity. It will then aim to subsequently expand profitability through the implementation of simulation techniques using the Process Simulator Software.

Literature Review:

Following is the research that has been carried out in the past-

Omogbai, et al., (2016) [1] improved the existing system of manufacturing by using Lean techniques. Lean assessment manufacturing is a tool that is used to assess the current performance and after which the current system is optimized using discrete event simulation. Changes were suggested and implemented in simulation software to validate the future performance of the proposed design of manufacturing. The objectives included were setup time reduction, quality management, total quality management, reduction of waste, and just in time production (JIT). The improvements that were made caused the system to perform better by reducing setup time by 100%, and by increasing preventive maintenance frequency wherein the average time between downtime and uptime was increased to 10,000 minutes. To reduce motion waste, the travel time between workers and machines was reduced to zero. The lead time of the supplier was reduced to zero using all the resources as in the previous system. The changeover time of the machines was reduced by 100%. The system was run at the fastest theoretical time to complete the operation. Different scenarios were created to optimize the performance of the system. The best scenario was then chosen to be implemented, and it showed improvement from the previous system.

El-Khalil, et al., (2015) [2] proposed a solution for the inefficiencies that were identified in the assembly line of the car industry using discrete event simulation of the current assembly line which would help improve the throughput. One-year data was taken from the vehicle assembly line and used as input for the simulation model. The simulation model was imitated with the real system and the results of the simulation showed all the bottleneck points that were present within the system. Two improved scenarios were tested on the simulation that improved the cost by \$1.6 million/annually. The results that were obtained helped the management in making decisions about the size of the buffer and batch size, as well as to determine alternative solutions to solve the bottleneck points for making improvements in the current system. The downtime, maintenance time, labor efficiency, and uptime of robots was not considered in the simulation model.

Liu, et al., (2013) [3] used an object-oriented technique of simulation modeling technology to optimize issues such as non-value adding processes, high WIP load and large cycle resulting from the problems in the system. The objectives that were set to be achieved were to point out the bottleneck points and processes causing the large cycle time. The balancing of the line was done using eM-plant simulation software which helped discover the operation and process causing limited production and large cycle time. For this purpose, a

virtual simulation environment was developed using the simulation software after collecting the data from the assembly line to address the issues facing automobile manufacturing enterprises. The proposed solution for the assembly line developed using the simulation software caused an improvement in the overall efficiency of the assembly line that catered to the interior of the automobile, which resulted in smoother and more adept operations. The improvements made in the production line addressed the issues that were restricting the reduction of the cycle time and causing limitations in the production line.

Dewa, et al., (2013) [4] worked on batch modeling lines that were the best fit for moderate demand, although, they were categorized by high WIP inventories, which caused an increase in the product cost and led to a large cycle time of the designed line. Improvements were made to achieve the flexibility in the production of the final products when the demand of the clients changes for the different types of the product with different demand. A model of the mixed lines was proposed to reduce the high work in process and improve flexibility to handle the different products at a time with the reduced cycle time. The objectives of the study were achieved for a manual assembly line system for automobiles and the system was optimized by pointing out the bottlenecks and making sure that maximum utilization was achieved for machine and human resources. The cycle time was reduced by reducing the length of the queue before the arrival at the workstation. This also helped in reducing the downtime of the working station. The study was carried out by collecting extensive time study data from the floor of the assembly line. The data obtained from the time study was utilized using a simulation model development of the existing system. The developed model was validated with the current performance of the system. After validation of the simulation model, a detailed analysis of the bottleneck study was conducted, and an optimal solution was suggested for the batch mode of the manual assembly line. The devised methodology that was developed could also be used for a single model of the manual assembly line for the achievement of the objectives.

Marsh, et al., (2010) [5] worked on a dynamic model using discrete-event simulation provided holistic modeling of the manufacturing system, involving simulation of the all the processes and including all the operational details and cost of each particular resource being utilized. Using discrete event simulation, a complete model of the manufacturing system and its associated costs was developed using simulation software. The production cost was optimized by controlling the lead time, cycle time, and inventory. Many scenarios were developed to optimize the cost of production through the simulation model. Suggestions were

developed by analyzing the simulation results of the existing system. Upon running the system after implementing the suggested changes, it was found that the system improved and performed better in the context of the associated cost. The optimized design of the production system performed better by saving the assembly cost.

Savory, et al., (2010) [6] worked on the cost estimation of a cellular company that manufactured mobile cells at a small-scale using group technology rather than job technology, which works on job layout. A concept activity-based costing (ABC) was introduced in this particular case study using discrete-event simulation. The model was developed on a U-shaped layout wherein the final product was being produced by a part of the family along with its four members. The data for each activity was taken and specific information about the cost of every attribute was considered. The model was enhanced for analysis of cost estimation involving economic considerations. The final model that was developed showed a reduction in invested cost and an increase in profitability.

Holt, et al., (2010) [7] focused on an assembly line that was responsible for installation and assembly of the booms of the truck within the truck bed utility section of the plant. Multiple layout designs were tested to increase the line efficiency and throughput rate of the final products involved. Material handling was improved, the storage point was reconsidered, and the assembly line was balanced to achieve the set objectives. The current system model was simulated using Flexism simulation software for each of the layouts involved to validate the system with the current performance of the system. Scenarios with multiple staffing were developed to determine the optimum layout that would produce maximum productivity. A two-phase layout strategy was developed after analyzing the results obtained using different layouts. The first phase of the layout was implemented for short term production planning of the industry. The second phase was implemented to meet the demand for future long-term production goals.

Abed (2008) [8] discussed process optimization in the food processing industry where there is a problem associated with decision-making to meet the variable demand of the customers while keeping the quality at the highest level. This case study was conducted in a Rusk manufacturing company using Arena simulation software to validate the current performance of the industry. An analysis of the different processes involved in the production process was conducted along the production line. Data was collected for each process for inputting into the simulation model. The current performance of the system was validated, after which what-if scenarios were tested to optimize the existing manufacturing system. The simulation results revealed the bottleneck points and the under-utilized resources. The

suggested changes resolved all the problems and improved the utilization of man and machine resources. After the potential changes were implemented, there was a reduction in the cycle time by up to 11.4 percent and an increase in the throughput by 50 percent with an additional investment of capital. The invested capital was monetarily admissible because it was paid back within 35 days by the additional profit that was achieved as a result of the changes made and due to an increase in the productivity of the manufacturing line.

Masood, et al., (2006) [9] presented the line balancing of a cylinder block production line to increase the machine resource utilization and to reduce the total cycle time of the cylinder block in an automotive production plant. Line balancing of the production line was verified by simulation results obtained using the simulation software. The results that were obtained indicated that there was a significant increase in machine utilization and throughput rate. Critical problems were identified that caused the highest cycle time and were selected for optimizing the performance of the production system as part of the study. The improvements made in the simulation model resulted in a reduction of the cycle time from 293.9 to 200 seconds, which represented a reduction in cycle time by 32 percent. As a result of the reduction in cycle time, the throughput increased by 65 percent. At all the stations there was an improvement in utilization by up to 95 percent.

Scholl, et al., (2006) [10] solved the problem in balancing an assembly line and redesigned the line through optimization of configuration. The objectives that were to be achieved were workload management at every workstation along the assembly line, reduction in cycle time, re-arranging the layout of the assembly line, and improving the efficiency of the line. Different procedures were tested to optimize the current assembly line. The best method was implemented, and changes were made to achieve the objectives.

Yu, et al., (2006) [11] used simulation modeling using computer technology to predict the performance of the manufacturing assembly line even before the production process itself is initiated. The system was planned to keep in view ergonomic design, and human and machine utilization. The prime focus was the productivity improvement of the assembly line. The shortcomings in the system were identified after the validation of the current performance using simulation software. Data was collected from each workstation of the assembly floor regarding the devices which assisted in lifting, for being put into the simulation software. The productivity of the simulation model was validated with the current manufacturing system. Human resource and machine utilization results were obtained from the output of the pro-model software. The problems of the assembly line were optimized, and the improved model was developed.

Baesler, et al., (2004) [12] presented the model of a sawmill using discrete event simulation. Data was taken from all the workstations for building the simulation model. The simulation results of the current system validated the productivity results of the simulation model. Bottleneck analysis of the woodwork was done to identify the processes that negatively impacted the productivity of the production line. Different alternative solutions were tested to yield better production with improved process utilization. The results obtained by every design combination were compared and the best set of improvements was proposed for implementation to improve the productivity of the production line. The implementation of the changes to the improved model increased the throughput by up to 25 percent.

Samuel, et al., (2003) [13] considered traditional parameters of productivity metrics such as throughput and rate of resource utilization to be insufficient for evaluating the performance of the manufacturing system with the aim of bringing about improvements in the system. A systematic methodology was developed for the measurement of productivity and factory level analysis of the system. Equations for the productivity parameters of Overall Throughput Effectiveness (OTE) and Overall Equipment Effectiveness (OEE) were developed for the productivity measurement of the system and the quantitative measurement of its equipment. These parameters were calculated using simulation software and the productivity of the system was validated. After validation, improvements were made in the system. A simulation model was developed through data collection of all the processes at the factory level. The results obtained by the pro-model software showed that the improved system behaved better as compared to the previous system.

This study is done using Process Simulator Software that is an add-in in Microsoft Visio and allow to create any complex manufacturing operation, chemical processes, power stations and other similar technical processes. This technique is rarely used to validate the manufacturing industry, predict the productions, and improve the production system.

An industrial case study will be examined to validate the current performance and to predict the performance of the proposed system. The manufacturing process will be simulated and analyzed, to identify the bottleneck in the production line, which can be addressed to optimize the manufacturing line.

Applying Simulation to the Working Assembly Line

The behavior of a system can be easily imitated using simulation software to help researchers in decision-making and authorities in bringing about improvements in their

production system. This process is accomplished by primarily conducting a time study of that system. After fully duplicating the system, the software-based results can help predict the possible risks of failure of a decision related to the system. A lot of money and time wastage can be prevented if the system is properly studied. In this study, the bottleneck points in the production line are to be identified and possible solutions are suggested to assist decision-making at the managerial level. After the time study of each workstation, the data has been put into the statistical analysis software to find out the most suitable combination of best-fit distribution that can be put into the simulation software.

The structural outline of the simulation study has been illustrated in **Fig 1**. The objective that has been set for the system under discussion is to address the problems in the production system. For the purpose of the study, the production system was imitated in the simulation interface and first validated for current performance and output. The output of the system after validation indicates the problems in the assembly line. All the attributes of the production system have been simulated in the software including the warmup time of the system, the number of workstations, setup time, the arrival time of entities involved, resources attached to the workstations, and their availability time. A calendar was programmed with the shift timings of the industry and its holiday schedule. The simulation model was developed in such a way that it behaved like the real working system. Once all the time study data was submitted to their respective places, the model was then ready for simulation. The simulation was run after setting the simulation time of one month. The output viewer of the system showed the results, which were presented in the form of graphical bar charts and tables listing the attributes. Once the production system was validated, improvements were tested for the solution of the problems present in the current scenario of the production system. After the improvements were tested then, the results were compared, and the best result scenario was chosen for the purpose of decision implementation.

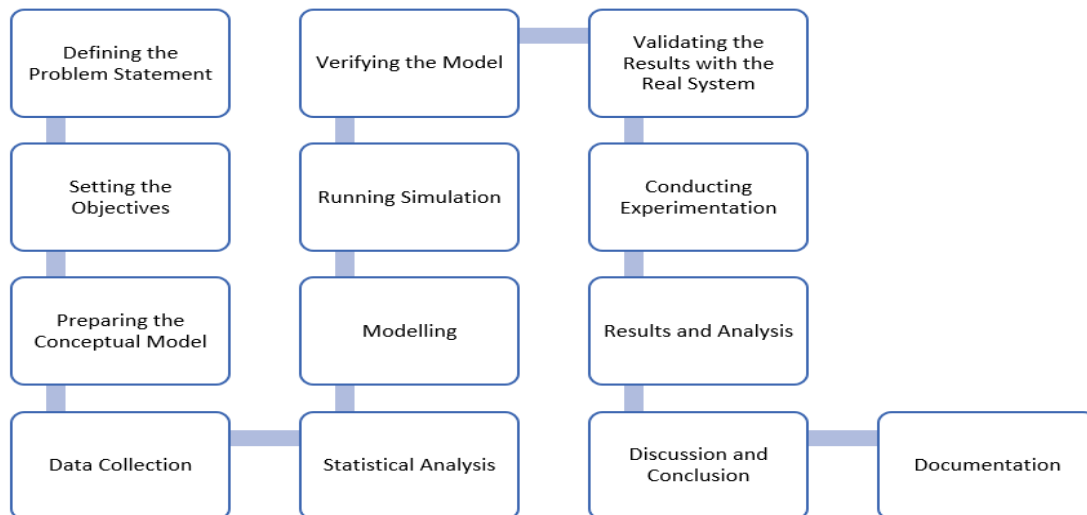


Figure 1: Methodology

Developing the Current Scenario and the Assumptions

An outline has been drawn before simulating using the software to save plenty of time while developing an imitation of the production system. In the outline, all the resources, workstations, buffers, inventories, and locations have been designed according to the flow of the product. All the entities are situated at their proper place and locations according to the real industrial layout. All the operation times and travel times used in the simulation are relevant and from reliable sources. Operation used in the outline are shown in **Table 1**.

This simulation setup uses assumptions similar to every simulation software due to the availability of insufficient data. The assumptions are made for short periods until the accurate readings are available. However, the output of the system is not affected if the assumptions are minor. Another approach for dealing with assumptions is to create virtual situations of worst and best scenarios to overview the impact of the assumptions on the system. In this study, the following are the assumptions that are to be considered in modeling of the production system.

- Activities designed are time-based in nature.
- The attendance of the working resources has not been considered in the calendar.
- The time required to set up the machine for each process is constant.
- Only one worker can work on each workstation.

Table 1: Operations Used in Simulation Model

1	Arrival	Arrival type is scheduled at 20,000 pieces per order. A sample for inspection is taken from the lot by the inspector and checked for the quality of forging upon arrival.
2	Inspection	The Inspector takes a sample of 20 pieces for visual inspection, dimensional inspection, and fixture (profile) inspection, and to compare the sample with the standard dimensions so as to make the decision with regard to whether the lot is acceptable or not.
3	Grinding	The pieces are dried and then ground with sandpaper from all the sides of the peddle.
4	Turning	The turning process is done to the workpiece and the tip to make the surface round using the lathe machine. The product is moved to the next operation through the same bucket as a batch of 100.
5	Drilling 1	A 12 mm through-hole is bored by the drill machine operator by controlling the machine manually. The rejects from the drilling process are dumped in the drum placed nearby. The drilled pieces are moved manually to the next operation in a bucket as a batch of 100.
6	Milling	A cut on the end of the tip is machined with a manual vertical milling machine. The operator accumulates the parts and then moves to the next machine since the chamfer in the drilled hole is operated by the same operator.
7	Facing	This process of removing metal from the end of a workpiece is done to produce a flat surface.
8	Chamfering 1	This operation is done to make a bevel on the workpiece.
9	Burnishing	A smooth hard tool is rubbed with significant pressure on the metal surface.
10	De-burring	This is done to remove the burrs over the surface and make the workpiece smoother.

11	Chamfering 2	Again, this operation is done to make a bevel on the workpiece.
12	Fastening Cut	The cut is made using a milling machine for fastening purpose.

The layout of the production system is illustrated in **Fig. 2**.

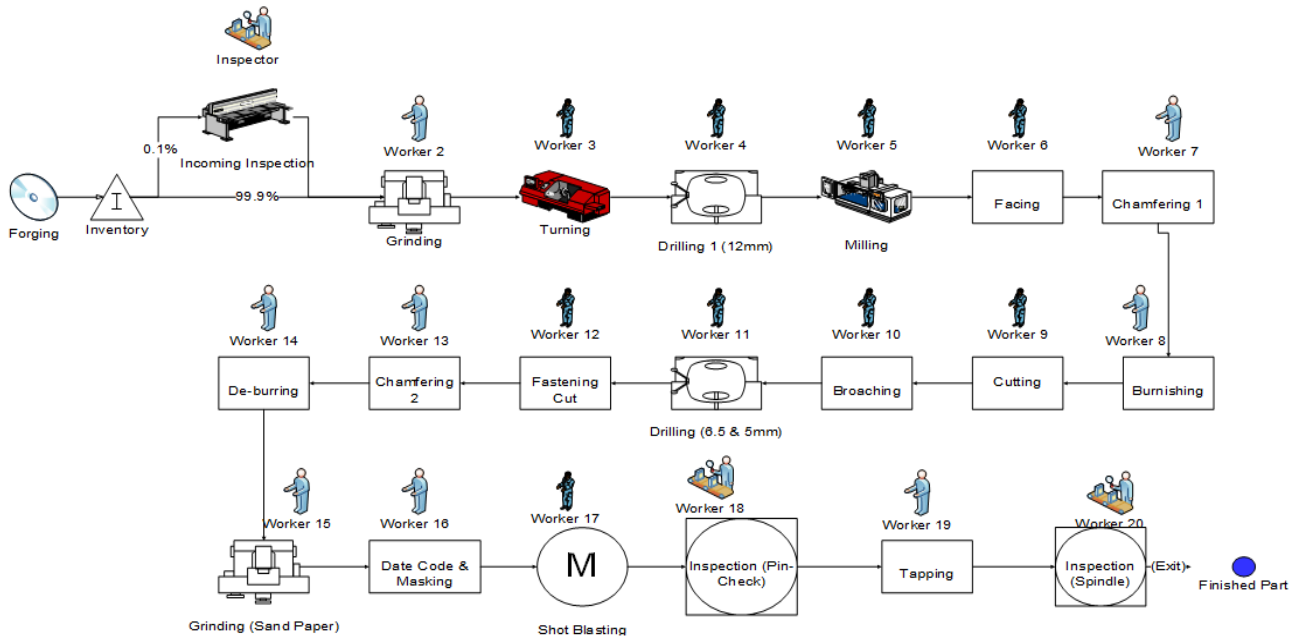


Figure 2: Production Layout

The schematic illustrates the layout of the industry and the processes involved in the production of automotive components. The 0.1 % of incoming forging is inspected by the inspector to testify the quality of the forging lot. In case of a successful inspection, the forging lot is accepted, and it flows towards the next workstation and so on to till it reaches the final product. The main focus of the study is to find the bottleneck point in the production line. The bottleneck is the point of congestion in the assembly line which limits or slows down the production system. It limits the capacity of the whole manufacturing system. Bottlenecks happen when the worker is slow down due to overload or as a result of the parts or material arriving too quickly to his/her workstation. As a consequence of the bottleneck point, the overall cost of production increases. A bottleneck refers to the characteristics of a bottle, whereby the neck of the bottle limits the flow of the liquid due to it being the narrowest point of the bottle. This causes congestion and slows down the liquid flow. Similarly, the bottleneck point slows down the production of forthcoming stations and increases the time and resources required for producing the final product. It is a critical issue for the manufacturing industries

because the bottleneck point is caused by a flaw in the production process due to which it must be corrected. When the demand increases, this issue becomes more prominent and it limits the capacity of the production system.

To simulate the current system of the production line, the data is collected from each process and imitated using the simulation software. After all the processes are simulated the warmup time is input to get more precise results. The calendar is included for every resource and machine that contains all the shift timings, working days and holidays.

Simulation Properties

Define Run Length By:

Time Only Weekly Time Calendar Date

Warmup Period

	Date	Time
Warmup Begin	10-Apr-20	12:00 AM
Sim Begin	22-Apr-20	8:00 AM
Sim End	22-May-20	5:00 PM

Number of Simulation Replications:

Options

Pause at Start

Adjust for Daylight Saving Time

Unit for Avg CT Display:

Clock Precision:

Animation

Initial Speed:

Logic

Initialization Logic... (None)

Termination Logic... (None)

Run Simulation OK Cancel

Figure 3: Simulation Properties

The warmup period is selected in such a way that all the processes are activated, and the workpiece reaches all the workstations. The number of replication or repetition is set to be 3, to get more precise results. The simulation is run for a month to get the monthly production as depicted in **Fig. 3**. Firstly, the current system is validated, and the bottleneck points are indicated. Secondly, the different scenarios are proposed to overcome the problem. All the required data is collected, and it is analyzed to develop statistical distributions that can be equipped in the activity time. The layout is designed such that it fills the required data boxes, whereas the complex activities that require logic are developed using a set of logic in the logic builders. A calendar with shift timings is added for every activity and arrival.

The output viewer comprehends the graphical analysis of all the attributes of an entity. The resource utilization and machine utilization graph are available in the form of horizontal bars and vertical bars. Time plots, histograms, and pie charts are generated automatically in the output viewer of the Process Simulator. The output viewer reveals that the total exit is 9,166 and the resource utilization of the respective workers is indicated in graphical form. It is evident that most of the human resources have idle time as a result of which production is affected as shown in **Table 2**. The resource utilization for the current system is shown in **Fig. 4**.

Table 2: Current Performance of Assembly

Scenarios	Total Exits	Average Operation Time/part (s)	Line utilization max %	Idle time max %	Block max %
Existing	9,166	0.41	63%	70%	68.51%

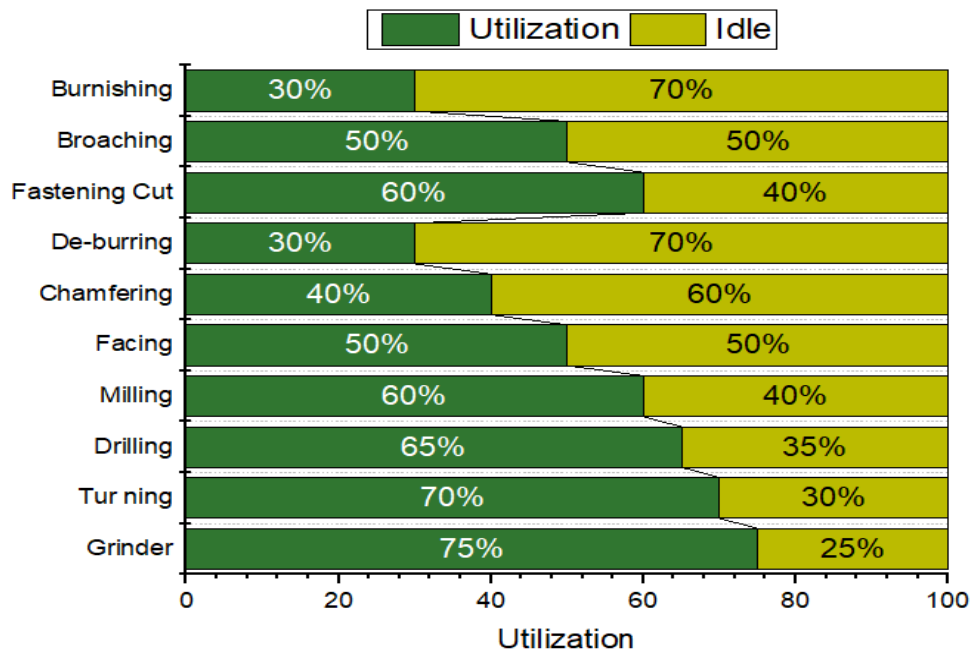


Figure 4: Resource Utilization

Results and Discussion

The simulation results indicate that the productivity of the assembly line is 9,166, and the average production for the last 4 months is 9,300. There is a negligible difference between

the average production value and the production value obtained from simulation. Different scenarios are to be developed using scenario managers to increase the production of the line as indicated in **Table 3**.

Table 3: Developed Scenarios

S. No.	Description	Change
1	Removal of the resources with low utilization and shifting his job to other resource to boost up the utilization. Worker 16 & 19 at Tapping and Date Coding are removed, and their task is assigned to other worker to improve the resource utilization.	Capacity, Production and Utilization Improved, Cost saved
2	Adding a machine in parallel at the bottleneck point of drilling operation as indicated by simulation results, as shown in Fig 5.	1→2

Scenario 1

All the changes suggested above directly affect the throughput of the production assembly line. The first scenario is developed without causing the expense of any capital investment. In this scenario, the resources that were being less utilization are removed from the production line and shifted somewhere else while their task is assigned to other workers which causes a significant increase in the utilization of their skills.

Scenario 2

In the second scenario, capital investment is proposed as a machine is added in parallel with the existing machine. The reason behind adding a machine resource is because simulation results proved that, it is a bottleneck process that limits the throughput of the assembly line. The effect of the different scenarios on the drilling operation is shown in **Fig 5**. Scenario-1 shows more blockage of the products which therefore slows down the forthcoming operations. Adding a machine parallel to the existing machine can decrease the blockage and improve the overall system.

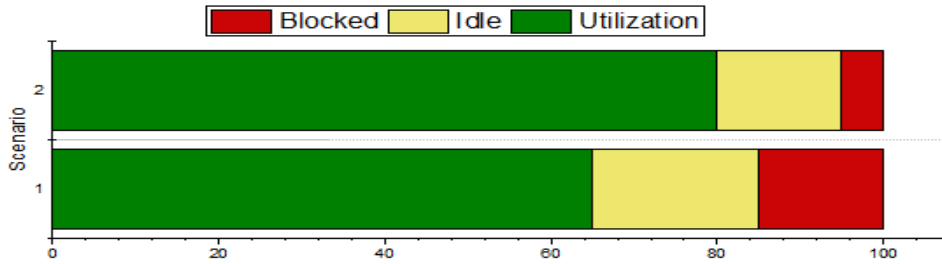


Figure 5: Drilling Operation

The simulation results disclosed that after potential changes were made in the assembly line, the production of the Exited quantities is adequate for the industry to meet the demand of the customers without any overtime expenditure. After applying the suggested alterations and running the improved **scenario 1** through simulation, the product produced at the exit of the assembly line is 9,766 units as shown in **Table 4**, and resource utilization increases as shown in **Fig. 6**. This clearly indicates that the demand of the customers can be meet by merely implementing the proposed changes without making any capital investment.

Scenario 2 revealed that productivity increases far beyond the demand by adding machine resources in parallel with the existing line. The Scenario Simulation results of the production line proved that there is a bottleneck in the production system. The addition of machine resources not only aided in improving throughput but also decreased the idle time of the forthcoming operations, therefore, improving the utilization of the other operations.

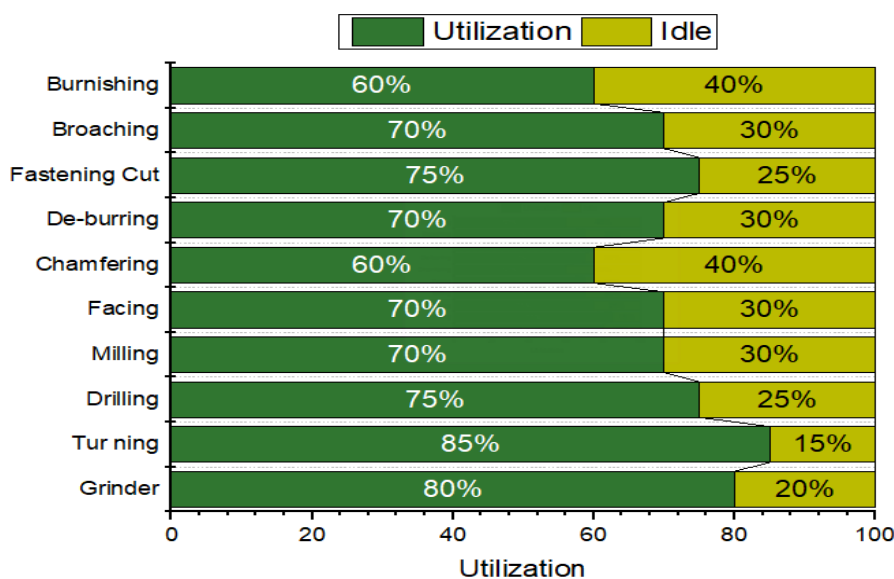


Figure 6: Resource Utilization after Improvements

Adding a machine could also be monetarily admissible since it brings about an improvement in productivity by a big margin which helps the company in meeting the customer’s demand and producing more than the demand to achieve higher profitability. Some other improvements made had no direct effect on the throughput of the assembly production line, but they caused the load to become balanced for other operations and workers by increasing their utilization.

Table 4: Results After Improvements

S.No.	Scenarios	Effect on Productivity	%age Increase	Effect on Utilization
1	Removing Human Resource	9,766	05%	45%
2	Adding a Machine	18,064	49%	77%

Comparison of the daily production fluctuations as shown in **Fig.7** implies there is significant increase in productivity after improvements made within simulation model as compared to existing system.

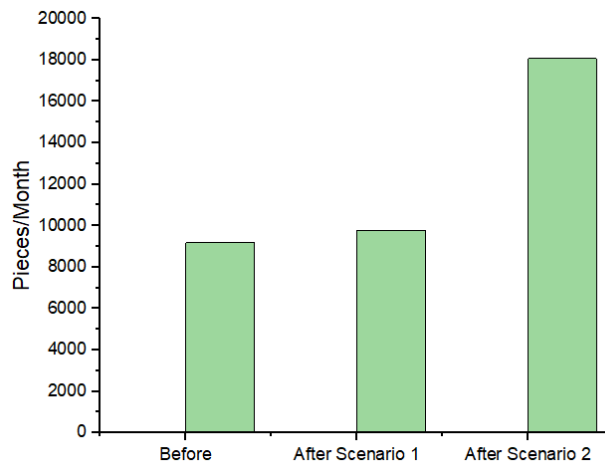


Figure 7: Production Comparison

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