

Production Flowline Optimization Using Simulation

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Abstract

This paper focuses on improving the flow efficiency of a production line using simulation software. The aim of this study is to simulate the actual flow using advanced simulation software and improvement in productivity was done by increasing the utilization of the underutilized facilities. Simulation modeling was used to evaluate the equipment and manpower performance for the manufacturing system. Each individual facility in the flow has to be analyzed carefully and allocated to stations in a balanced way over the available workstations. The paper is divided into 3 parts, the first part consists of data collection and distribution selection in which selection of best data distribution was carried out, the second part is about simulation modeling, analysis of the simulated model in which underutilized facilities were identified, and cause of the underutilization was identified, in the third part, the results of the model were analyzed, validated and finally, best modifications for the flow were suggested to improve the efficiency of the flow. And finally, Cost-benefit Analysis was performed to determine the tenure of recovering the total investment. Based on the simulation results, the top under-utilized facility was M5, M6, M7, M9, and M3 and the existing production was struggling to meet the customer demand due to machine shortages. So, to overcome this underutilization problem, we suggested some modifications by generating different scenarios in the flowline described in the proposed improvement section.

Keywords

Simulation, Productivity, Bottlenecks, Optimization and Flow Efficiency.

1. Introduction

An unbalanced production line is one of the biggest and most common problems facing manufacturing industries today. In most manufacturing companies, only 50-60% of time is spent on production, the rest is wasted due to lots of unplanned downtime. Production losses not only affect the efficiency of flowline, but also affect the growth costs of the production system, finished product quality, worker safety, work environment and worker satisfaction (Padhi et al., 2013). In manufacturing due to lack of availability of advanced simulation software's and relying on conventional methods for analysis of efficiency of the manufacturing facility had always led to wrong decision making. For a smooth production flow and the most efficient use of manpower and equipment a balanced manufacturing is the answer.

The digital manufacturing problem is solved through simulation in a single step. This is due to the simulation software's multifunctionality, which allows users to experiment with and test their models as well as create them. (Mourtzis et al. 2014).

For a balanced manufacturing system, it is essential to capture important operational features of a real system, which is only possible by using advanced simulation software. Simulation modelling is a common standard for analysing complex systems. It helps to finding the deficiencies between the actual output to the required output.

The objective of this research paper is to improve the efficiency of flowline, by modelling the actual production flow in a simulation software, generate simulation reports and analyze it, identify bottlenecks and inefficiency, identify causes of inefficiency and generate multiple scenarios of optimized models by apply the best optimized solution to improve the flow efficiency and finally performing Cost Benefit Analysis (CBA) for evaluating the return-on-investment period to justify the worthiness of the investment.

What is Simulation?

Simulation is an important design tool for creating, understanding, and managing products and process. Simulation is a generally used term in orientation to computer models that denote physical systems (products or processes). It is the process of creating a model of an event or system, often to predict its outcome. Simulation is used in many industries such as engineering, architecture, and military training. Simulation can be applied to all types of systems, such as business, social and economic models. In the field of scientific modelling and engineering simulation has been traditionally called "computer simulation" or "simulation modelling". With its many built-in features and customization available, it can be the perfect solution for modelling both simple and complex production flows. It is typically carried out for the purposes of understanding, prediction, and control. (Williams, E. et al. 2015).

In Industry 4.0 i.e., the fourth industrial revolution simulation is one of the most important and crucial pillars amongst all which allows to predict and analyze the problem so that failures and losses can be overcome. Simulation can shorten cycle times and result in fewer failures during the first stages of production. (Simons et al. 2017). Schuh et al. (2014) noted that using simulations will make it simple and effective to make decisions, and that doing so will greatly increase the decisions' quality.

Computer simulation is widely used analytical tool which breaks the limitations of conventional methodologies (mathematical and statistical methods) of analysing complex models. Simulation has a tendency to regulate the state of manageable inputs to a system that will cause system output to be at their most favourable or best conditions. (Chramcov, B. 2013).

1.1 Objectives

The objective of this research paper is to

- Build actual model in simulation software.
- Simulate the model and analyze the results.
- Generate different scenarios for optimization.
- Analyze the effect of each scenario on process and efficiency.
- Select the best optimized scenario and simulate it.
- Collect the optimized result and compare it with the initial results.
- Perform a Cost Benefit Analysis.

2. Literature Review

Vysocký et al. (2017) created a simulation model of the workplace, which contains three manufacturing areas. The author simulated the flow using two different simulation software. In these simulation workplaces were monitored the productivity and efficiency of work were based on the number of machines. After analysis, it was found that there was inefficiency in the workplace. The machines were idle for many hours due time taken to transport material from one machine to another. By using simulation software, the author had analyzed the problem to counter this loss by adding more machines, conveyors between two workstations or by increasing conveyor capacity.

Chramcov (2013) proposed increase in productivity of a production system. Short barrels for pistols were the main product in the assembly line simulation. The objective function was to maximize the marginal profit which was determined by subtracting the operational costs and staff costs from the marginal revenue received from selling the products. The optimum solution was determined by identifying the optimal number of machines in an individual workplace. For optimization simulation optimizer Hill Climb optimization algorithm was used to verify the

experimental results. For the above problem, the solutions suggested were to eliminate the number of machines in the selected workstations or increase the number of operational shifts. This solution not only increased productivity but also contributes to saving on staff and production costs.

Michlowicz & Smolińska (2019) the objective was to analyze production system using computer simulation software & obtained highest productivity in a mixed (series-parallel) production system which consist of optimization of inventory in interoperable buffer and reducing downtime of operators and machines. In simulation software the cycle time has been represented by variable as the cycle time varies according to the type of component being processed. The cycle times are described distributions used in simulation software. After simulating the model and analyzing the statistical results it was found that setup time has to be reduced to maximize punching machine operation time utilization.

Briano et al. (2010) helped in obtaining the most suitable features or parameters regarding the buffer capacities or the number and types of machines and facilities. During the design and implementation of new plant layout several factors has been considered like distance, buffer capacities and No. and types of machineries, ancillary facilities and human resources. For this the author has proposed the application of witness simulation in design of industrial plant layout so that flow, bottlenecks and criticalities can be analyzed. The model developed presents a unique forklift serving all the machines and the flow inside the plant also includes the possibilities to take semifinished products from outside, moving along predefined segments which connects machines, buffers and entry points. Different methods like active period method, turning point method, arrow-based method, criticality indicator-based method was were used to determine the bottleneck and finally most appropriate method was chosen.

Leporis & Zedenka (2010) explained in detail the advantages of principal analytical simulation to find bottlenecks. They use Witness simulation software using different methods such as active period method, turning point method, arrow-based method and critical index-based method. The pros and cons of using the above methods were explained briefly and finally the most suitable methods were selected for the bottleneck analysis.

Nadirah Roslin et al. (2008) proposed a new manufacturing plant layout using simulation software and compared with the old layout and analyzed that the new layout is efficient and able to meets the company target. Time study was conducted as the data needed during simulation of layout emphasizes more on time instead of distance. Using simulation software amount of output required was calculated and according to the desired output required modifications in the layout was conducted. The modifications were performed by eliminating the bottlenecks via adding buffers between two stations, and U-shaped flow pattern was proposed to reduce the manufacturing time, improve space utilization, increases the efficiency utilization of labor and equipment.

Mirzapourrezaei et al. (2011) improved the throughput and efficiency of the flow system by reducing idle time. This was achieved by adding additional facility parallel to the bottleneck in the flow, as the bottleneck was inefficient and was not able to meet the customer demand. This approach improved the number of outputs from 3247 parts to 4167 parts. Also, production rate and efficiency were improved and the work in progress was reduced.

Švančara & Králová (2010) studied real production line operated in an electronic company. The aim was to improve the available production resources to reduce the total processing time to increase the average capacity of the system. For this the author first introduced the description of production system and block diagram of production line to explain the problem statement. Further the modelling of real flow was done using simulation software by providing various input parameters like cycle time, setup time, and batch size. After simulating the model allocation of the workers to the workplace, and order of processing the orders were the two main factors which was having significant impact on the capacity. The simulated model was validated by comparing the model output and the real factory output for a specific time period. For this user-friendly interface in MS-Excel was built to analyze the simulated model. Finally, by analysis of simulation results using indicators like busy, idle, clocked etc., improvement suggestions were provided. The simulation module optimizer was used for creation of various optimized results.

Prajapat et al. (2016) demonstrated how system performance can be optimized by production managers using technical advances in simulation. To improve production processes, the Witness program supplied a discrete event simulation model.

Mehta and Rawles (1999) gave information about how to use witness software and how to implement it in a business for improved outcomes. It employs modelling and an internal consulting method to describe the many attributes and business applications of testimony. Even though the study is quite insightful, it has little information on applications in real life.

By using simulation software one can simulate, analyze, and optimize the complex production process which cannot be solved by using conventional numerical techniques. For a complex production process as the cycle time varies according to the different conditions faced by the manufacturing plant, simulation software provides different distribution for input parameters like cycle time which are essential for building realistic and valid model that yield correct results and optimized model. Optimization of the production flow can be obtained by experimentation tool in the simulation software. This tool generates multiple scenarios with different optimized results, and according to our capability and need the best optimized result must be chosen to improve the flow efficiency.

3. Methods

- Data Collection
- Simulation modelling
- Results and discussion
- Proposed Improvement

A Multinational company has a top-class manufacturing facility that makes world-class Fluid handling equipment like Pumps, Separators, Decanters, and Fitting equipment. Currently, the organization is facing low productivity for one of the flowlines, which has created a need to analyze the flow and identify the root cause of the low productivity. The company has multiple manufacturing flowlines for processing different components of pump and fluid controlling valve parts and components, Component 1 such as Butterfly valve body, Component 2 Non-returning valve body, Component 3 Non-returning valve cone, impeller, backplate, housing, compression ring manufactures on highly advanced CNC machines. Each flowline consists of independent processing units to produce the pump and valve components. The flowline consists of different types of general-purpose machines (turning, milling, grinding, washing, printing, etc.). Each flowline facility has a fixed batch size, and allotted shifts.

The input data that is required for the simulation of the model was provided by the planning department. Interviews were conducted with operators and the maintenance departments on the shop floor working with the actual system to collect the data about production disturbance.

This article focuses on the BFV and NRV production line which has a takt time of about 3.4 min. The line layout (workflow diagram) for this part is shown in Figure1. The workplace consists of two different flowlines with 11 machines. Also, there is buffer storage between these machines having a storage capacity of around 200 units each, which safeguards the constant flow of parts, and it avoids the mixing of different components from one facility to the next facility without any delay throughout the flow.

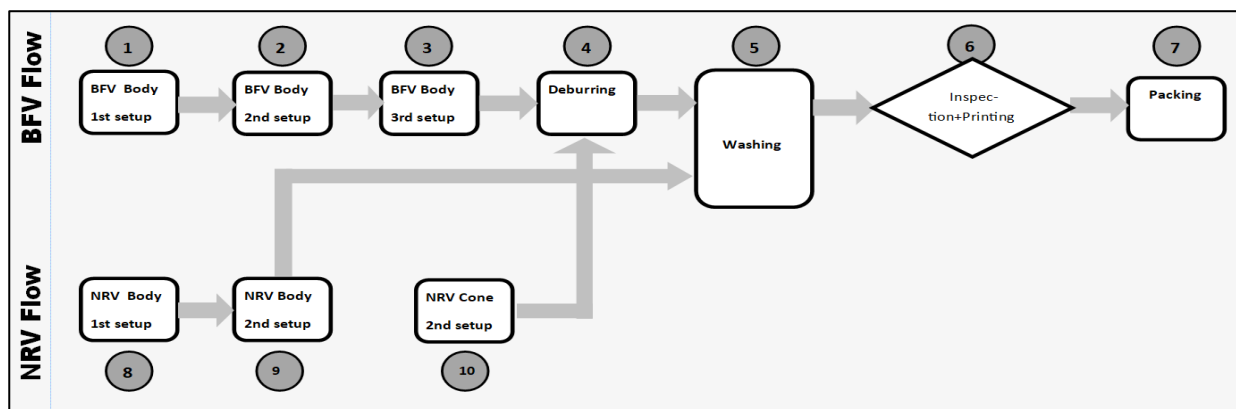


Figure 1. Flowline Layout

The material flow is analyzed in a plant engaged in manufacturing fluid valves which consist of two flows known as Butterfly Valve (BFV) flow and Non-Returning Valve (NRV) flow. In BFV flow, the Component 1 is processed, while in NRV flow, the Component 2 and Component 3 are processed simultaneously. For both the flows, M4, M5, M6, and M7 processes are common. The plant operates with the PULL system, where each completed order is instantly shipped to the customer. Both the valves i.e., Components 1,2 and 3 are available in different sizes (25, 38, 51, 63, 76, 101) which have different demand, cycle time, takt time, and throughput time. The first flow consists of eight facilities in which the last five facilities are common to both BFV flow and NRV flow and the second flow consists of two separate facilities for machining Component 2 and a single facility for machining Component 3. The distribution that the cycle time follows and the attributes like available shifts, batch size of each facility are as shown in Tables 1 and 2 respectively.

3.1 Data Collection

The unit for cycle time and time available is in minutes. Each facility has allotted different shifts, some facilities work for all three shifts, some for two shifts, and some for only one shift. Each shift is 8.00 hrs. in which there are two breaks of 15 minutes each and one 30 minutes lunch break. In the first shift, there is another planned downtime of 30 minutes for the meeting on the shop floor. Daily production data was collected from the production planning department. After getting the number of parts processed at each facility, cycle time per part is calculated by dividing the number of available hours by the number of components produced.

In MINITAB software using Individual Distribution Identification distribution type is identified which the cycle time follows with respect to each facility. Around 14 different distributions were generated, and the most appropriate distribution was selected by the most appropriate scatter plot and P-value of each distribution.

Table 1. BFV flow parameters

BFV Flowline							
Facility	M1	M2	M3	M4	M5	M6	M7
Type of M/C	Turning CNC	Turning CNC	Milling CNC	Portable drill	Washing	Printing +Inspection	Packing
Cycle time distribution	Exponential	Exponential	Lognormal	Exponential	Exponential	Exponential	Exponential
Distribution parameters	$\mu=14.95$	$\mu=16.26$	$\mu=54.41$ $\sigma=25.61$	$\mu=7.63$	$\mu=47.59$	$\mu=0.56$	$\mu=0.56$
Batch Size	1	1	4	1	24	1	10
Time available/day (min)	1170	1170	1170	780	780	390	390

Table 2. NRV flow parameters

NRV Flowline			
Facility	M10	M9	M8
Type of M/C	Turning CNC	Turning CNC	Turning CNC
Cycle time distribution	Lognormal	Exponential	Exponential
Distribution parameters	$\mu=12.68$ $\sigma=8.63$	$\mu=12.69$	$\mu=27.85$
Batch Size	1	1	1
Time available/day (min)	1170	1170	1170

After determining the distribution for the cycle time follows, the parameters have been obtained which are essential to give input values to the distribution. The parameters like mean and standard deviation are determined by using the descriptive statistics in data analysis too in MS Excel. The cycle time distribution type, distribution parameters, batch size and the time available per minute for each facility that are going to be used as an input parameter for model building are arranged in tabular form is as shown in Table 1 for BFV flowline, and in Table 2 for NRV flowline.

3.2 Simulation modelling

Different facilities in the flow were represented using different visuals, this makes the model easier to understand, and it also makes the model more realistic as shown in Figure 2. The components that are present in the model are also given different visuals via adding different colors so that during the testing of the model we can confirm that the components are flowing as per the rules they have given with respect to different facilities. As buffers are present between each facility, we have allocated the rule that initially the part will be pushed to the first buffer and then the successive facility will pull the part from the buffer as per the batch size. After the M4 process, we have applied the “SEQUENCE” rule to make sure that the Component 1 and Component 3 get separated and pushed into a separate buffer. At the M5 center, we applied the Input rule “IF” to make sure that a batch of 24 sizes Component 1/ Component 2/ Component 3 will be processed in the M5 center without mixing. Each facility is shift enabled according to the data.

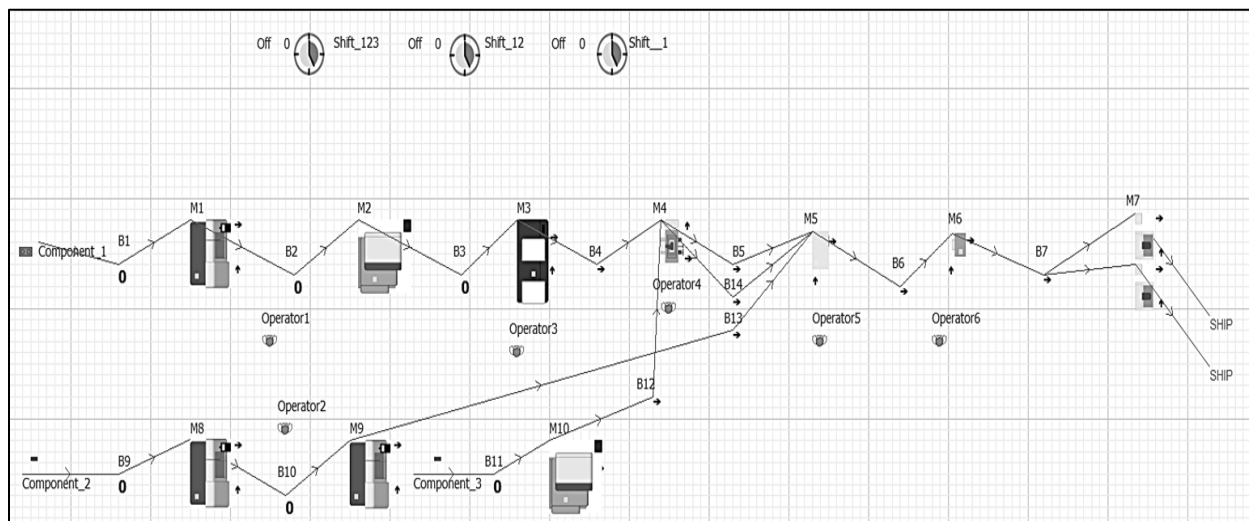


Figure 2. Simulation modelling in WITNESS horizon

The process of improving efficiency starts with understanding the flow of production and plotting the layout of the flow as shown in Figure 3. The second step and most important and crucial step is the collection of data on all the attributes of each facility (No of pieces produced, cycle time distribution, batch size, and available time for production). The next step is building a simulation model using the parameters acquired during the data collection. With the most appropriate input parameters, the next step is running the simulation model for about 1440 unit. After running the simulation model tried to validate the simulation model by the number of outputs per day of the simulated model and the actual output. If the number of outputs in the simulated model is closer to the number of outputs in the collected data, then again building of simulation model with corrected attributes procedure will take place, or otherwise move to next step of identifying the root cause of unbalanced line via analyzing the utilization of facilities. After identifying the root causes next step will be optimizing the model via generating different scenarios then successively moving towards simulating the generated scenarios and analyzing the statistical generated reports. The solution with minimum investment and with maximum utilization of the facility is selected as an optimum solution for the improvement of the facility utilization. And finally, the Cost Benefit Analysis and the Return on Investment (ROI) period is to be calculated.

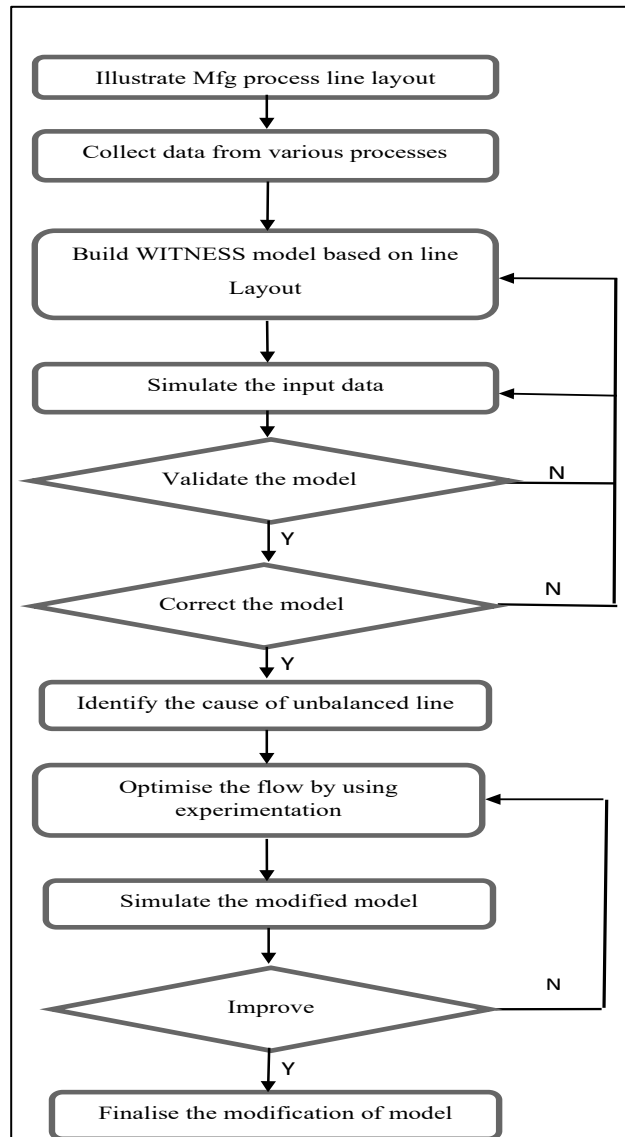


Figure 3. Flowchart of improving process efficiency

4. Results and Discussion

Based on the generated reports after simulating the flow using simulation software the M7, M6, and M5 were the top underutilized facilities. This was until the component gets processed up to M4 process the remaining available time is very less. The M7, M6, and M5 facility was remain underutilized because this facility remains in working status during the first shift only, which is of 390 minutes. Therefore, there will be no flow of material within these facilities for next two shifts. The solution to this problem can be either we can change the shift time of these facilities, or we can utilize these facilities for processing the other components from the other flow. Therefore, our next focus will be to improve the next underutilized facilities like M9 in NRV flow and M3 in BFV flow. M9 of NRV flow which remains idle for about 49.33% of its total available, this was due to the high process cycle time of M8 facility which delays the material supply to the next facility i.e., M9. Then comes the next facility M3 of BFV flow which remains idle about 27.71% of its total time the reason for underutilization was same as mentioned in above case. Due to high cycle time of Mazak 100S there was delay of material supply to M3 facility.

4.1 Numerical Results

The below statical results (Table 3) is collected after successfully building the simulation model using the parameters which has been collected in the data collection section. This result contains the facility status like facility name, percentage idle, percentage busy, number of operations performed, and the total number of components produced per day.

Table 3. Simulation report (Before optimization)

Name	% Idle	% Busy	No. Of Operations	No of pcs
M7(1)	100.00	0.00	0	0
M7(2)	100.00	0.00	0	0
M6	100.00	0.00	0	0
M5	82.63	17.38	3	72
M9	49.33	50.67	40	40
M3	27.71	72.29	15	60
M4	11.07	88.93	88	88
M2	1.75	98.25	72	72
M1	0.00	100.00	86	86
M8	0.00	100.00	40	40
M10	0.00	100.00	97	97

The Table 4 contains the statistical results of the facilities in which the improvement in utilization was observed. The results clearly implies that by improvement in the facility utilization there will be improvement in the productivity, i.e., increase in No of components per day. The improvements can be observed for the facilities M3, M4, M5 and M9.

Table 4. Improved statistical results

Name	% Busy (Before)	% Busy (After)	Improvement in utilisation (%)	Productivity Improvement (%)
M9	50.67	97.32	46.65	33.33
M3	72.29	97.06	24.78	112.5
M5	17.38	23.20	5.82	0
M4	88.93	95.37	6.44	9.09

4.2 Graphical Results

The graphs shown below have been generated using statistical results generated in the software before and after improvement in the flow. This graph clearly describes the status of the facility in terms of percentage of idle and busy. For presentation purposes, these facility statuses are coded using different colors and patterns. The first graph (Ref Figure 4) is generated using the problem's initial conditions.

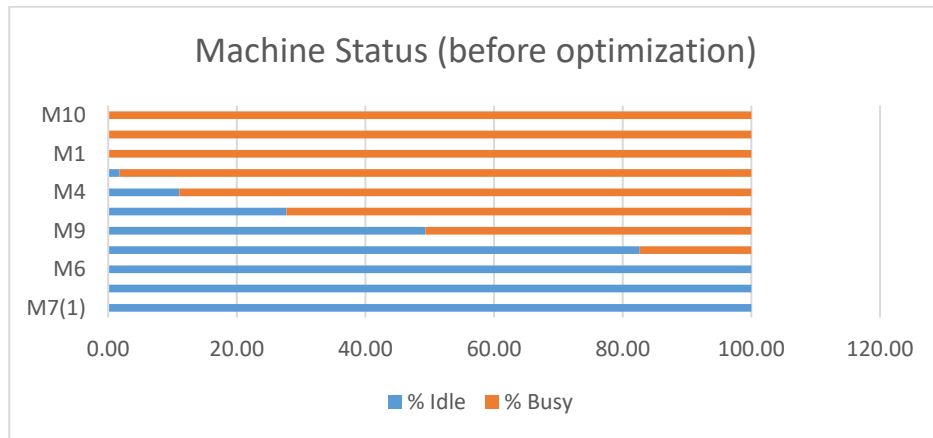


Figure 4. Graphical results of machine status (Before optimization)

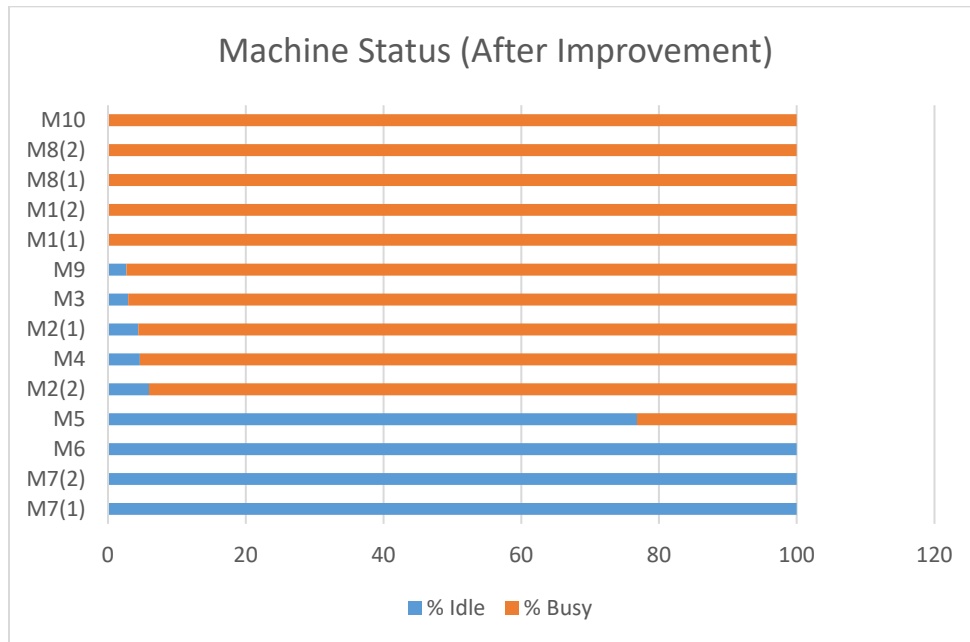


Figure 5. Graphical results of machine status (After optimization)

The graph shows that the facilities like M9, M3, M5 and M4 are underutilized facilities, and this can be improved by modifying the line layout. Therefore, in the improvement process as described in the previous section via adding more facilities the desired improvements have been achieved by adding three more facilities in the flow. After introducing M1(2), M2(2), and M8(2) one more simulation result was generated and the improvement in the above-mentioned underutilized facility was observed as shown in Figure 5. The utilization of M9 was improved by 46.65 %, M3 by 24.78 %, M5 by 5.82 %, and M4 by 6.44 %.

4.2 Proposed Improvements

After analyzing the initial statistical results, we come to know that in BFV the line is balanced from M1 to M4 process but after the M4 process, the M5 facility is underutilized (Ref. Table 3). This is due to the lack of flow of the components to the M5 facility, which directly affects the next processes (i.e., M6 and M7), and therefore to improve the further flow of material M5 facility must be properly optimized. The M5 facility remains idle for 82.63% of the total time in one shift which shows the facility is underutilized. So, to improve the utilization of M5, M6, and

packaging the suggestion is that during the ideal times these facilities it has to be used for processing other components from the other flow.

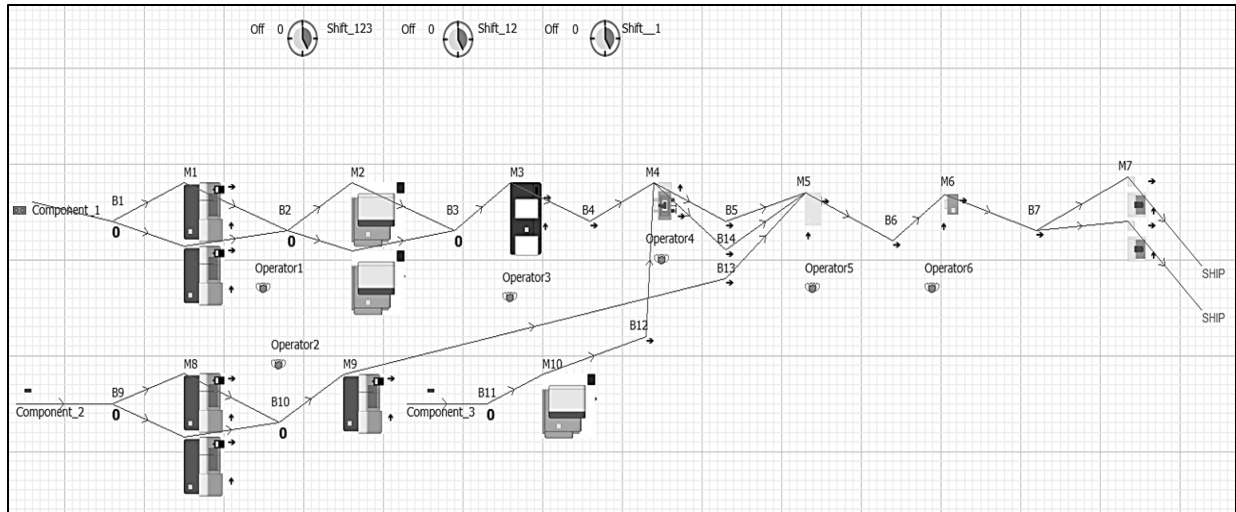


Figure 6. Proposed model

Table 5. Simulation report after modification

Name	% Idle	% Busy
M7(1)	100	0
M7(2)	100	0
M6	100	0
M5	77	23
M2(2)	6	94
M4	5	95
M2(1)	4	96
M3	3	97
M9	3	97
M1(1)	0	100
M1(2)	0	100
M8(1)	0	100
M8(2)	0	100
M10	0	100

The next is M9 facility of NRV flow which remains idle for about 49.33% of its total time. This is due to the large cycle time of the M8 facility which makes the next facility to wait until the first part finishes. Based on the scenarios generated in the simulation model we have tried to improve the efficiency of M9 by adding one more similar facility parallel to M8 this will make sure that continuous material flow to the next CNC, so there will be increases in the utilization by about 46.65%. and reduces the idle time of the facility as shown in Figure 5. Further an additional facility has to be implemented in the BFV flow for improving the utilization of M3 facility, therefore an addition two CNC has to be implemented parallel to M1 and M2 which will contribute to improving the 1st setup and 2nd setup of the BFV flow. Thus, by incorporating more facilities in the flow as shown in these changes can lead an improvement of about 24.78 % in utilization of M3 can be achieved, also there will be improvement in the productivity by a huge amount as shown in Table 4. The improved flow layout after introducing additional facilities

is as shown in Figure 6. The simulated statistical result after modification is as shown in Table 5. The statistical results shows that how the facility utilization was improved by adding additional facility parallel to facility M1, M2, and M8.

5. Cost Analysis

Currently the company works on margin of around 10% of the total cost. The cost price of Component 1 single part is about INR 1,544/-, and Component 2 is around INR 1,800/- and the sales price is about 1,716/- Rs and 2,000/- Rs as shown in Table 6. So, by producing a greater number of components a total profit of 12,440/- per day is achieved by the company, and annually if we calculate it is about ₹ 35,47,094.40 as the number of working days yearly are 274 days. For improving the flow efficiency, the company must make investment on 3 new facilities which are dual axis turning CNC. Each facility costs around ₹ 1,13,33,116. So, the total investment costs around ₹ 3,39,99,348 have to be done by the company to improve its flow efficiency (Table 7).

Table 6. Total Profit Analysis

Component	Cost Price/Piece	Selling Price	Profit	Increase in production/day (units)	Total profit/day	Annual profit
Component 1	₹ 1,544.00	₹ 1,716.00	₹ 172.00	20	₹ 3,440.00	₹ 9,42,560.00
Component 2	₹ 1,800.00	₹ 2,000.00	₹ 200.00	45	₹ 9,000.00	₹ 24,66,000.00
					Annual total Profit	₹ 34,08,560.00

The Return on Investment (ROI) period comes out to be 9.97 years i.e., it will take around 119 months to recover the amount of money that the company has invested in purchasing the new CNC in the factory.

Table 7. Total Investment Cost

Item	Cost per CNC	Required Quantity of CNC	Total Cost of investment
Dual axis turning CNC	₹ 1,13,33,116	3	₹ 3,39,99,348

6. Conclusion

After the final analysis of simulated model, it was possible to detect the inefficiency of workplaces by simulated model results. In particular, it was possible to identify how much each workplace contributed to total inefficiency. Since the aim of this study is to improve the throughput and efficiency of the system through reducing the idle time and improving the material flow, In the first simulated model result it was observed that the M5, M9 is the main reason to the inefficiency of the flow. This is due to the high M4 process timing per part, the M5 machine remains idle until a batch of 24 parts come from M4 process to the buffer. So, to overcome this inefficiency of M5 process the first option is to combine the M5 process and M4 process so that there will be no buffer waiting for M5 operation for a long time or the next alternate solution is that we can simply utilize the M5 facilities for M5 other components which are in the queue for M5 from other production flows. And for improving the effective utilization of M9 and M3 generation of multiple scenarios were carried out and obtained optimum solution was determined via adding additional facilities or CNC. Finally Cost Benefit Analysis was performed, and a period of 9.97 years was estimated for the recovery of total investment that the company has made.

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