



Balancing the queuing systems and improving the production throughput using Simulation in a job shop environment

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ARTICLE INFO	ABSTRACT
<p>Article History: Received 9 March 2021 Received in revised form 14 May 2021 Accepted 16 June 2021 Available online 21 June 2021</p>	<p>The management of production bottlenecks has become a critical issue in the effective planning and control of manufacturing systems, as bottlenecks directly constrain throughput, increase lead times, and reduce overall system efficiency. Simulation techniques provide a powerful and practical tool for analyzing and improving such systems, offering opportunities to test alternative scenarios and evaluate decision-making strategies without disrupting real operations. This study investigates the application of discrete-event simulation to a job shop production environment with the objective of enhancing productivity by identifying and mitigating bottlenecks. Using Arena simulation software, an initial model of the production line was developed and validated through both rough-cut capacity planning (RCCP) and expert judgment from the planning department. The bottleneck analysis employed a heuristic approach based on the Shortest Processing Time (SPT) rule to minimize average queue length and waiting times. Results obtained from five simulation replications demonstrated that, after two adjustment attempts, the production line achieved a balanced flow, significantly reducing queuing and waiting times. Consequently, system throughput increased from baseline level A to $A+448$, corresponding to an estimated financial gain of approximately one million U.S. dollars. These findings highlight the potential of simulation-based approaches for supporting data-driven decision-making and continuous improvement in job shop production systems.</p>
<p>Keywords: Simulation, Bottleneck, Production Line Balancing, Queuing systems</p>	

1. INTRODUCTION

One of the main objectives of every company is to improve production efficiency. In order to increase the efficiency and reduce the operating costs of the line, balancing activities among workstations are performed. They can be done by different methods, such as exact, heuristics, meta-heuristics methods, or simulation [1]. Increasing the number of workforces, extending time durations of the shifts, application of new technologies and machinery and many other possible approaches can enhance the production throughput [2]; however, the focus of industrial engineering is to avoid the additional costs which may come along. There always exist a few constraints, specifically the internal resources constraints, which prevent the system from having its desired production throughput. One of

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these constraints is having a bottleneck [2]. It directly affects the output and the production rate in a manufacturing system. A bottleneck can lead to the overstock of Work in process (WIP), an unbalanced flow of components and in some cases the extremely slow operations (when some of the stations are overworked and a number of them are idle) [3]. According to the Theory of Constraint (TOC), the efficient use of resources in manufacturing systems is limited by the capacity of the bottleneck resource [4].

1.1. heuristic methods

Balancing the flow can also cause the reduction of lead times. This objective cannot be reached but with precise planning and utilization of resources. Some of the popular tools for system analysis are linear programming, dynamic programming, integer programming, and simulation. There are many heuristic methods for solving NP-Hard Problems. Such as PEN Algorithm [5] but since queuing systems are not capable of modeling and solving NP and NP-hard problems, due to their complexities and the abundant number of constraints, simulation methods are employed. The simulation takes into account all the complications and random factors. Capacity evaluation, balancing, presenting a valid production schedule and designing an improved Master Production Schedule (MPS) are some of the advantages of this method. The role of simulation is to evaluate practical alternatives available either in support of major strategic initiatives which might involve a large financial outlay or in support of the continuous search for better performance at operational and tactical levels [6]. Sayed Ali evaluations' included changes to the machine setups, increases or decreases in customer demand, enhancements in cycle time efficiency, reduced lead times and improved customer response times, getting knowledge about the breakdowns in assembly line, the manpower requirement analysis [7].

1.2. Simulation Approach

G. Cheng evaluated bottleneck operations in the assembly line. It is capable of handling the complexity of large systems, even a whole factory. The simulation approach supports critical analysis by allowing rapid changes to the model logic and data [8]. Lanner Group Manufacturing Book suggested that the Simulation Software enables business process improvement for world-leading organizations. With simulation business managers can model, analyze and optimize processes to make superior decisions in a risk-free environment. Witness simulation is the key to improving productivity, efficiency and reducing cost [9]. Ramasesh provided research on dynamic job shop scheduling and sequencing problem to improve the performance of flexible manufacturing systems [10]. Yabin Li the use of Witness simulation software in the optimization of the thermal power plant. Transport of the coal was improved by improving the railway tracks. The model explains the construction of process and validates the feasibility of model [11]. Discrete event simulation (DES) is a method of simulating the behavior and performance of real-life processes, facilities or systems [12].

Simulation, as is known today, began throughout the 1970s and early 1980s in automotive and heavy industries. In the late 1980s, it began to be applied in business and gained a widespread recognition [13]. Using computer simulation in different fields such as manufacturing systems, construction projects and etc. can significantly improve the throughput, reduce the volume of stocks while ensuring the continuity of the production process and help save money [14][15]. Arena [16] has been the world's leading discrete event simulation software for 30 years. It was developed by System Modelling and acquired by Rockwell Automation in 2000[17]. it is most effective when analyzing complex, medium to a large scale of projects involving highly sensitive changes related to supply chain, manufacturing, processes, logistic, distribution, warehouse and service system[1]. The visibility of modeling and simulation in senior business management and as part of strategic operations planning has driven Rockwell Software to create these and other new products and adopt new technology to drive success at new levels [18]. Arena also enables users to build models and different scenarios based on job assignment patterns (allocation of jobs to machines) and put them on trial, it's used for plant layout modeling. Different processes are represented by rectangular and diamond boxes etc. and the starting and ending are represented by pentagons. These processes are connected by lines which show the flow of the product [19]. In this paper, simulation of a casting shop production line in MAPNA Group by Arena. Data come from reports which show the average waiting time and the average number in the queue for our products' components. Our aim is to analyze and enhance the production schedule with regard to constraints and to develop improved scenarios.

2. PROBLEM STATEMENT

Production process in the casting shop as is shown in figure 1 consists of 11 stations. First, wax models are built based on the production plan. Then they are covered by a layer of ceramics and after drying out, these ceramics shells are transferred to the casting station where wax models are removed and pouring takes place. After pouring, risers and gates are cut and cores (if used) are eliminated and leached so that the surface is made even. Furnaces are then utilized for heat treatment. Finishing which comes next prepares our components for Non-destructive Testing (NDT), a set of inspection procedures which are defined and carried out for examining the imperfections of components. NDT is followed by a final visual inspection and elements are then ready for delivery to the warehouse.

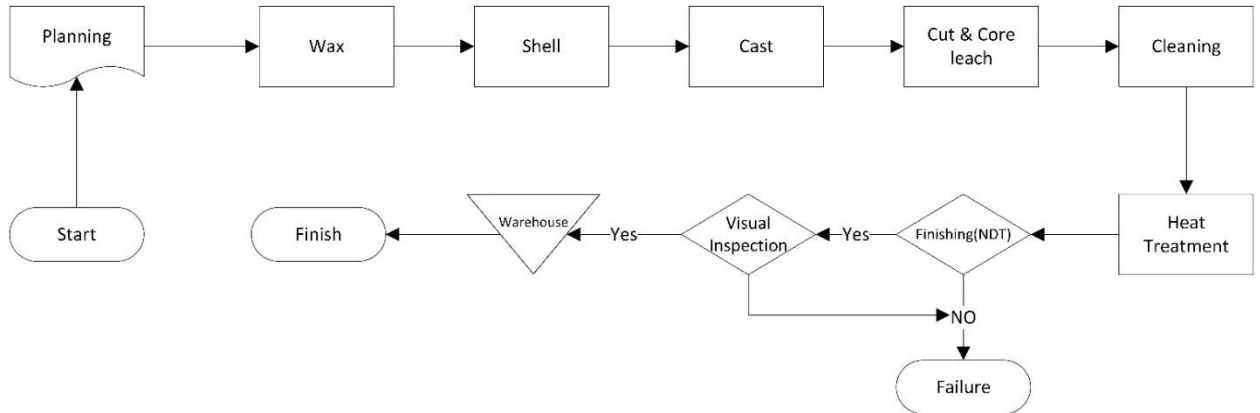


Fig.1. Chart of the production line

Observations implicated that some of the stations are idle while a number of them are overstock and have components queued up in front of them. Despite enabling the analysis of stations’ conditions (in terms of available and required capacity), Microsoft Excel cannot provide us with a momentary analysis.

With growing customer demands for more production (with limited resources) and on-time delivery, there was a need for the implication of simulation projects. All of the stations and constraints (i.e. capacity, machinery and their Failure Rate, standard production times, standard scrap rates and technical constraints) along with the amount of WIP and MPS were exported to Arena with Microsoft Excel and Read & Write module. In addition, 3 Excel files were prepared to keep a record of the outputs, lead times and daily Output of stations. Observations indicated that Wax Coordinate Measuring Machine (CMM), Core Leach, Fluorescent Penetration Inspection (FPI) Defect Removal and Finishing CMM were the bottlenecks of our production line and had the longest queues and throughout of production is called COFC. Indicators which would be analyzed and optimize are:

- Average waiting time
- Average number in queue

3. METHODOLOGY

At first, the production line of our casting shop was modeled in Arena. The effort was to enter as many constraints as possible in the model; these constraints include the machinery capacity, scrap rates, noncompliance level, the number of machines and also technical constraints such as components batches, heat treatment cycles and etc. Also an optimum utilization of the machines was considered. Applied modules in this software are basic process, advanced process, advanced transfer, and report. Based on the production schedule structure for a 10-month period, the software was run. Next step was to obtain outputs and analyze the bottleneck by means of average waiting time and average number waiting for reports. The effectiveness of each alteration was investigated through the output rate. Our production schedule procedure is “make to stock” (in a few cases “make to order”) in which recognized bottleneck stations are reviewed by Shortest Processing Time (SPT) method [18].

SPT is used to minimize the average job duration for jobs performed on a machine. In case N jobs are assigned to a machine, SPT works as follows: (giving priority to the job with least operation duration t)

$$t_1 \leq t_2 \leq \dots \leq t_n \tag{1}$$

Take S and S' as two desired operation sequences. These two sequences are identical except for the order of jobs i and j ($t_i < t_j$); in sequence S , i comes first and j comes second but in S' it's the other way round. B represents the set of jobs performed before i and j and A represent the set of jobs performed after i and j . $F_k(S)$ Stands for the flow time of K_{th} job in sequence S .

First proved that

$\sum_{k=1}^n F_k$ Has a smaller quantity in S .

$$\sum_{k=1}^n F_k(S) = \sum_{k \in B} F_k(S) + F_i(S) + F_j(S) + \sum_{k \in A} F_k(S) \tag{2}$$

$$= \sum_{k \in B} F_k(S) + (t_B + t_i) + (t_B + t_i + t_j) + \sum_{k \in A} F_k(S) \tag{3}$$

$$\sum_{k=1}^n F_k(S') = \sum_{k \in B} F_k(S') + (t_B + t_j) + (t_B + t_i + t_j) + \sum_{k \in A} F_k(S') \tag{4}$$

Thus

$$\sum_{k=1}^n F_k(S) - \sum_{k=1}^n F_k(S') = t_i - t_j > 0 \tag{5}$$

In other words, changing the order of i and j with each other decreases the quantity of F and sequences scheduled by SPT (sequence S) have the shortest flow times.

4. HEURISTIC MODEL

In meta-heuristic models, an initial model is built and then trying to improve the solution.

This model is applicable to all job shop production lines, and describe as below and Figure 2:

First: The first implementation of the model is taken, the number of parts in the queue and the output is recorded

Second: The longest queue is considered, then SPT methods is used and MPS is rearranged, then run the model again.

Third: If the output is increased to the desired number (restricted sales plan) the job is done.

Fourth: Return to the second step

Defining Variables:

Q_i : Queue length of Station i

X_j : Total output after j_{th} improvement

A : Queue length of longest queue

n : total number of stations

$$WIP = \sum_{i=1}^n Q_i$$

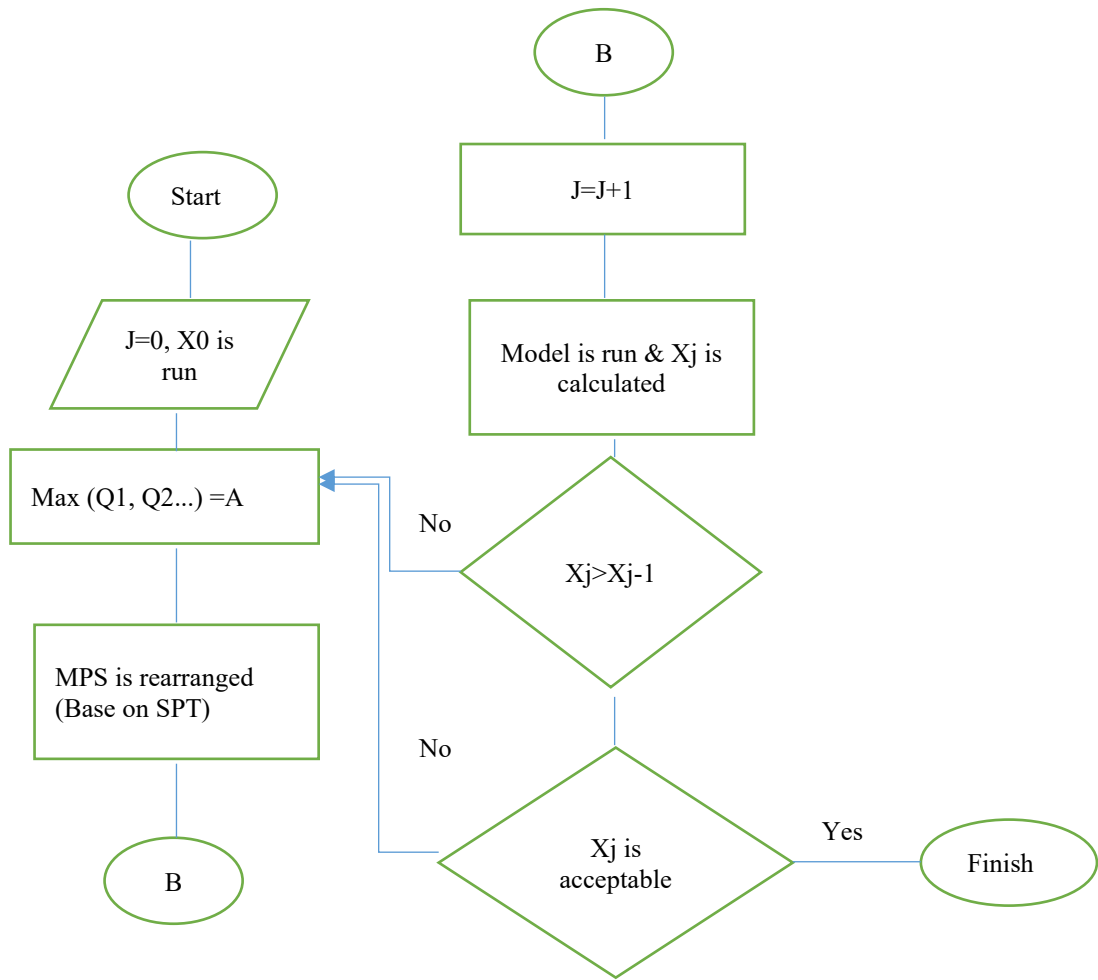


Fig. 2. solution process

5. SIMULATION MODEL BUILDING

After receiving the MPS, a comparison between available and required resources for months 2 to 10 in 2018 was carried out by means of Rough-Cut Capacity Planning (RCCP). This comparison suggested insufficiency in the capacity of a few stations in some periods. Based on the gathered information, a simulation model was built (on Arena) which illustrated the structure and conditions of our current state, so-called Zero condition Table 1. After exporting initial production information (initial production schedule, scrap rates, the total number of machinery and their capacities, standard times, etc.) to the model, results of the following table were found. Reports affirm that Finishing CMM, Core Leach and FPI Defect Removal have the worst outcome rates. Table 2 demonstrate the utilization percentage of bottleneck stations.

Table 1. Zero condition

Stations	Average Number Waiting	Average Time Waiting	Outputs
Wax CMM	48	0.7	COFC: A
Core Leach	732	21	
FPI Defect Removal	227	5	
Finishing CMM	421	8	

Table 2. Utilization percentage of stations

Stations		Total
Wax CMM	Available (min)	206388
	Needed (min)	48511
	Usage	24%
Core Leach	Available (min)	777505
	Needed (min)	515676
	Usage	66%
FPI Defect Removal	Available (min)	1674993
	Needed (min)	1395420
	Usage	83%
Finishing CMM	Available (min)	412776
	Needed (min)	388198
	Usage	94%

Balancing the alternatives is a capacity increasing method in simulation [2]. This approach enables a shift in the production flow of specific components when some of the stations are overworked and some others are idle. Observations indicated that core leach was the initial bottleneck in our system and the first attempt was to analyze hollow components’ plan which was unbalanced in a few of the months. Logically hollow components loads vary extensively, which requires us to reform this program by SPT.

Finishing CMM was the second bottleneck which was also removed with the help of SPT. After changes were made, another simulation project was performed. Results are available in the table 3.

Table 3. Improvement-1

Stations	Average Number Waiting	Average Time Waiting	Outputs
Wax CMM	46	0.8	COFC: A+8
Core Leach	345	12	Scraps: B-209
FPI Defect Removal	211	5	Total: C-201
Finishing CMM	563	12	

With these changes over 50% improvement was made in the number of components in queues and the average waiting time for the process in core leach station; however, the FPI Defect Removal station was not affected. The total number of outputs didn’t alter since the bottleneck had moved to Finishing CMM station. To eliminate this new bottleneck, CMM Wax station was employed. After picking out the optimum solution (transferring components to another station), based on try and error experiments, these formulations were applied:

In case of Finishing, CMM station has a queue length of more than 300 hundred elements, the queue length of Wax CMM station is investigated and if it has 50 items or more, component is returned to Finishing CMM. Results are shown in table 4.

Table 4. Improvement-2

Stations	Average Number Waiting	Average Time Waiting	Outputs
Wax CMM	70	1	COFC: A+448
Core Leach	295	9	
FPI Defect Removal	208	5	
Finishing CMM	186	4	

5. VERIFICATIONS AND VALIDATIONS

In order to carry out verifications, two important tasks need to be performed:

- Identifying the bottlenecks
- Analyzing the results of improvements

RCCP file and field observations are used as verification tools for the recognition of bottlenecks. The outputs of RCCP are confirmed by results of Arena. In addition, production line observations, which can also be acquired by SAP, prove Wax CMM, FPI Defect Removal, Core leach, and Finishing CMM to be the bottlenecks. Validating the improvements took 3 months. However actual outputs and collected data (from the software) have a deviation of about 20%, which is negligible due to the existing constraints. Table 5 gives us a comparison of the results.

Table 5. RCCP Report

Stations	Type	Date											
		1	2	3	4	5	6	7	8	9	10	11	12
Wax CMM	Available (min)	12483	17101	14955	16672	16430	16632	16403	14137	15886	18648	17136	17136
	Needed (min)	13944	13791	13056	13593	11257	13631	10346	11961	10385	12461	11995	8303
	Usage	112%	81%	87%	82%	69%	82%	63%	85%	65%	67%	70%	48%
Core Leach	Available (min)	66373	64084	65773	66378	66378	61332	69120	59028	59028	64074	69120	66816
	Needed (min)	39482	55138	58571	68425	50700	45343	52261	50950	19923	30853	40610	22465
	Usage	59%	86%	89%	103%	76%	74%	76%	86%	34%	48%	59%	34%
FPI Defect Removal	Available (min)	107541	150015	128712	139189	155266	129263	157472	129263	142576	146287	144704	144704
	Needed (min)	96667	124398	114304	124586	143898	143327	127488	116880	138184	96720	144706	119536
	Usage	90%	83%	89%	90%	93%	111%	81%	90%	97%	66%	100%	83%
Finishing CMM	Available (min)	26712	37296	32256	35784	37296	33264	37296	33264	33768	37296	34272	34272
	Needed (min)	24774	33543	31926	40260	46941	37418	40804	33553	37469	21935	30763	27994
	Usage	93%	90%	99%	113%	126%	112%	109%	101%	111%	59%	90%	82%

6. RESULTS & DISCUSSION

As it was explained in the previous section, the model was run for a number of times. Results suggested the need for a change in the schedule and application of different job assignment methods in editing annual sale programs which would bring along an impressive reduction in waiting time and queue length. In the next step, a comparison was conducted between real data and the attained results that were subsequently evaluated and validated. These improvements caused an increase of 448 components in our outputs. Stated results can exclusively be achieved by simulation. Figure 3, 4, clearly demonstrate and explain the outcomes.

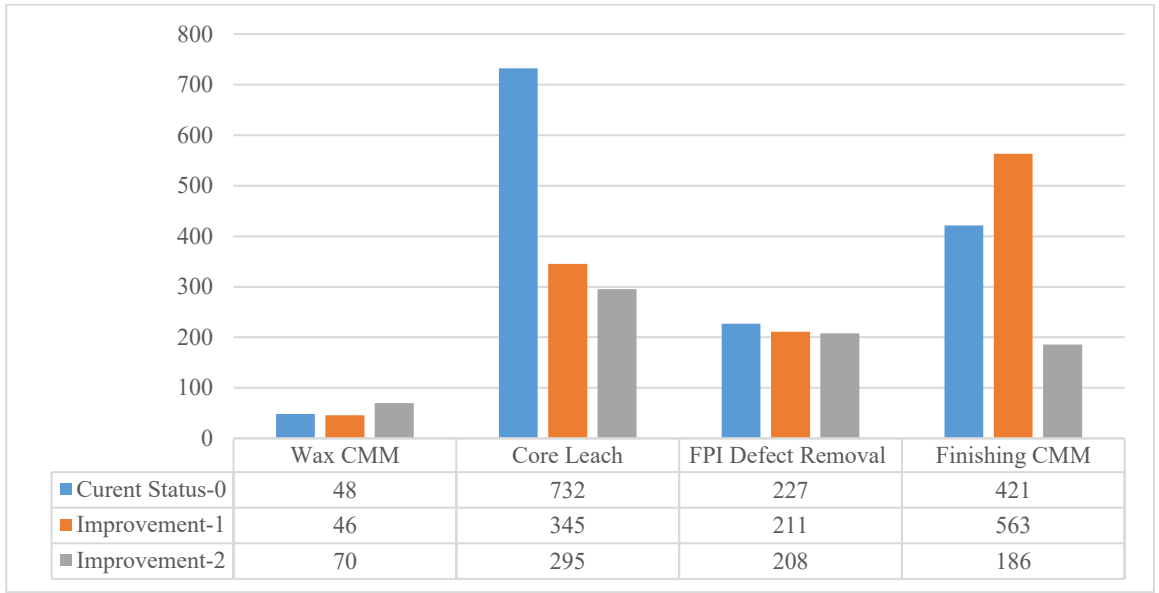


Fig. 2. Average number waiting

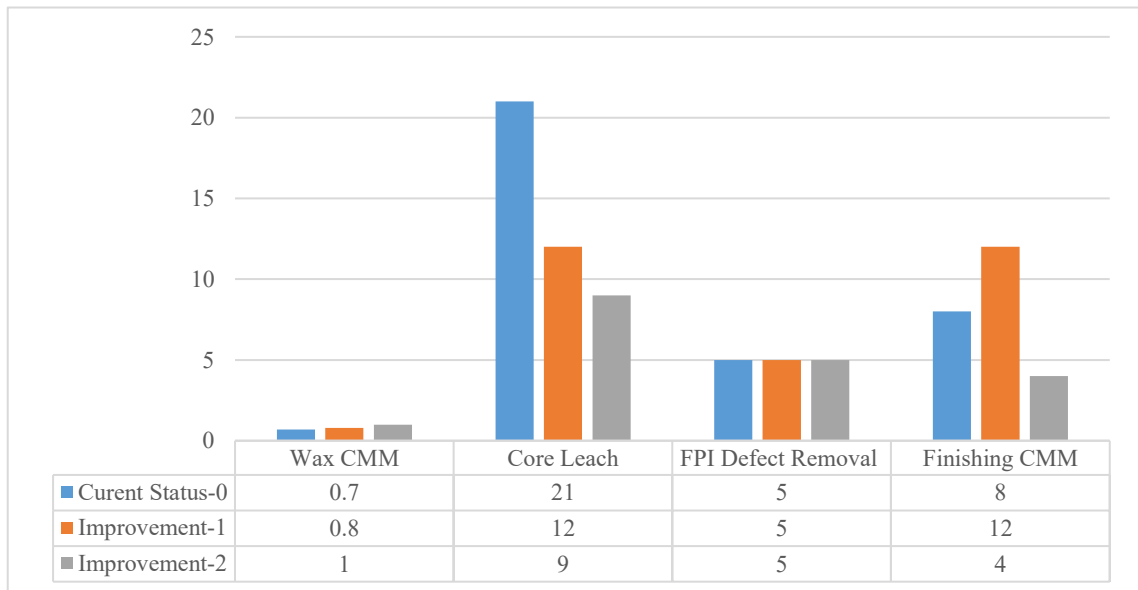


Fig. 3. Aaverage time waiting

In Improvement-1, the queue length of Core leach decreases by about 50% but it increases for Finishing CMM, so Improvement-2 is required. At this stage, the average number waiting in almost all of these four stations is

decreased (a slight increase in CMM Wax is negligible). The average number waiting decreases constantly in FPI Defect Removal.

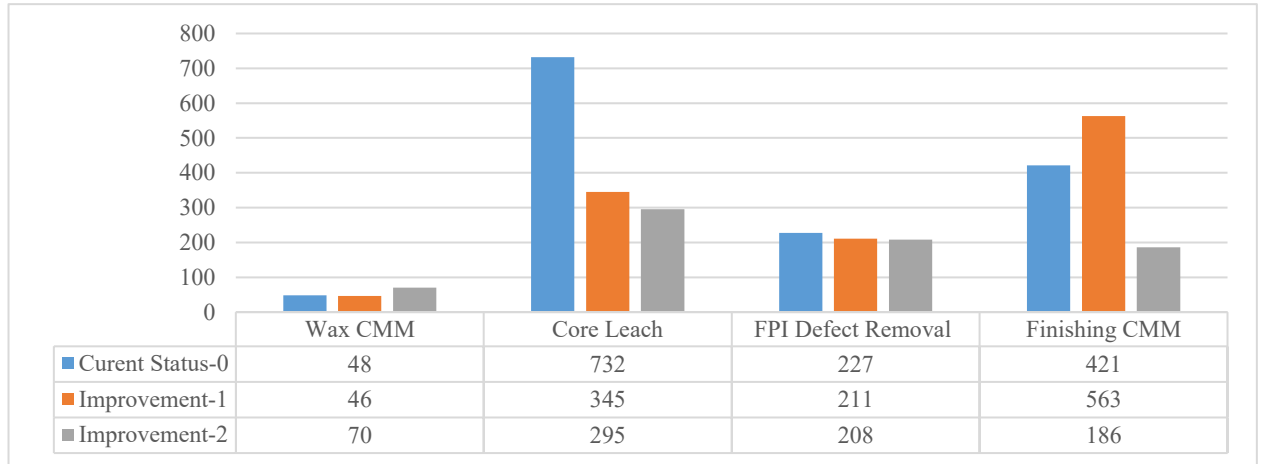


Fig. 4. operations Outputs

The output of the process, according to the aforementioned improvements, is as follows;

The final improvement shows the Certificate OF Conformity (COFC) increased about 448 parts. Afterward, the optimum production line is shown in figure 5.

7. CONCLUSION

In this paper, a simulation study of a casting shop production line in MAPNA Group was conducted in order to decrease the queue length in bottlenecks and increase the production throughout. This task is accomplished by Arena simulation program which is an effective way to evaluate the full implications of industrial decisions before they are put into practice. To eliminate the bottlenecks, an initial model was built using collected information. Improvements, with a change in the arrival sequence of components by means of SPT and a heuristic model, were made. After the model was run for a number of times, at first, the initial bottleneck was removed; however, the production throughout didn't increase and Finishing CMM became a new bottleneck. In the second (final) enhancement, with a more balanced production line, this stage which was much closer to the optimum condition. Finally, the outputs were exported from Arena to Microsoft Excel to be employed by planning experts.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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