International Journal of Industrial Engineering & Production Research (2019) 30: 489- 505
DOI: 10.22068/ijiepr.30.4.489

RESEARCH PAPER

Simulation and Optimization Model of the Performance of Processes at Signoff Units (A Case Study in Automotive Industry: Saipa Corporation)

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Received 07 July 2019; Revised 08 September 2019; Accepted 23 September 2019; Published online 01 December 2019

ABSTRACT

The present research aims to investigate the feasibility of improving the number and quality of final products at workstations using a simulation-based method. A major challenge faced by senior managers is how to identify bottlenecks of the operating processes. In this article, the signoff process was selected because this procedure was the bottleneck in the factory. The signoff process was modeled to identify the parameters affecting this process that include the number of workstations, manpower, Defect per unit, and logistic structure (Transferring cars at the Signoff Unit and supply of spare parts). In this structure, the car sequencing was determined based on the customer demand information during a one-year period (since 1397), as per the data extracted from the Saipa Corporation sales system, and mapped as a disc distribution function (indicating that 1 and 3 out of every 4 cars sold by the Saipa Corporation were X100 and X200, respectively). It was further assumed that one product unit entered the signoff unit every 2 minutes. The model was implemented and run by ARENA Software (Version 14). The fact that the software returned no error verified the model. In this paper, there are four scenarios: Ordering product by customers which is the input of the process of signoff, Equipment failure, Unavailability of the spare parts, and Allocated indirect Cost and allocated joint cost. Finally, equipment failure is the optimal scenario in this process. The results indicated that about 80% of the existing problems could be addressed by appropriately planning for human resources and optimizing the workstations that contributed the most to the working queues based on their Pareto graphs. By applying the mentioned solutions, improvements were also observed in the qualitative indices. For instance, the direct pass rate in busy areas increased from 60% to 90% while the defect per unit (DPU) decreased from 2 to 1.4% at both the wheel alignment and electrical defect identification units. In terms of quantity, the number of output cars increased by 10%.

KEYWORDS: *Simulation, Control Process Optimization, Quality, Automotive industry.*

1. Introduction

Throughout history, human beings have developed various systems for manufacturing and service-providing activities. Being initially simple, these systems have evolved into well-developed complex systems upon the population growth and diversification of the humans' needs. The expansion of the systems and the resultant increase in their components and interactions further added to their complexity, making the decision-making, leadership, and control processes highly sensitive and difficult. Accordingly, since long ago, various traditional techniques have been developed to understand and improve the system performance and related decision-making processes using, for example, mathematical analysis, actual observations, experimental studies, and different operational research techniques. In addition, during the recent past, the emergence of computers and the improvement of their processing power in terms of both the processing rate and cost efficiency have made the simulation technique an alternative to the traditional methodologies. A simulation study begins with designing a model of the considered phenomenon followed by analyzing the model through simulations [1].

In recent years, the manufacturing sector has encountered unprecedented levels of change with

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highly complex challenges. Manufacturing companies are competing in an interactively growing environment. These have led manufacturers toward adopting new methodologies for planning and controlling their manufacturing systems [2]. Today, business processes (*e.g.*, supply chain, customer service, and product development) have become extensively dynamic and complex, making them extremely difficult to understand and analyze even using spreadsheets and workflow diagrams. Interactions among resources and processes, products, and services create numerous scenarios and consequences, which were impossible to understand and evaluate without computerized simulations. Traditional methodologies were designed to address the question of *what* rather than *how*, *when*, or *where* [3].

This highlights the need for using better methodologies by which one can keep real operating systems from interruptions to avoid the associated costs that otherwise incur for the system, save time, and make the most out of existing opportunities. Real systems provide no opportunity for experimentation, as experimenting with such a system is extremely costly and may end up eliminating other opportunities. Accordingly, one must use a methodology that provides the ground for applying the proposed modifications to the system and evaluate expected behavior of the system accordingly. Simulation can address all of these requirements.

Research objectives including the goal, general objective, special objective, and applied objective are presented as follows:

1. Determining the optimal number of work stations and workforce at each station for maximal performance (product volume)
2. Optimizing the number of output cars
3. Optimizing the workforce and equipment productivities
4. Optimizing the procurement of appropriate material for product reworking
5. Optimizing the spaces allocated to different stations
6. Optimizing the items and factors affecting the inter-station transportation system and logistics process
7. Optimizing and reducing the working loops and designing an optimal model of station locations
8. Optimizing the activities in terms of standard times

Given the numerous factors affecting the production processes, such variables as product diversity impose direct impacts on the required number of workforce and the number of active test facilities. Considering the research works performed so far, dynamics and effective factors impose significant impacts on the optimization of the system, thereby enhancing the efficiency and completion time of the work in similar settings. However, these subjects have been only rarely considered in the scope of car manufacturing. This highlights the need for newer approaches in this sector to focus on numerous factors affecting the production processes and the impact of such variables as product diversity and likes on the required number of workforce and active test facilities in the future research.

2. Literature Review

2-1. Theoretical background

Simulation represents a particular type of system modeling with the system referring to a set of interacting components designed to achieve a common objective [4]. Indeed, simulation refers to the creation of an artificial history for an actual system and investigating the system for evaluating possible impacts of the artificial history in terms of the system performance under actual conditions [5]. The main objective of simulation is to adopt a probabilistic approach to describe uncertainty in the real world. An intelligent computer-assisted simulation environment allows the designers of manufacturing systems to provide and present tools for controlling interruptions associated with an acceptable level of evolution. Such tools enable us to automatically predict the system behavior under normal and extra throughput [6].

Inspired by the framework presented by Chase and Zhang [7], Laguna and Marklund [8] developed a simulation model for business process design projects. This framework is made of 8 steps [8] as follows:

1. Declaration of action and declaration of vision: Hammer and Champy [9] believed that this is a two-stage step. The declaration of action demonstrates why a company, as an organization, may not stop at its current position, while the declaration of vision describes the ultimate position where the organization is willing to achieve along with a list of objectives that must be met before the ultimate target can be reached [9].

2. Process identification and selection for a successful project design: Process selection is a very important and essential step. Firstly, attention must be paid to all of the processes involved, particularly those comprising the primary axis and core of the organization. Immediately following the occurrence of budget and resource limitations, the processes must be prioritized based on the following questions. Which process is currently problematic? What process is the most essential for adopting business strategies of the institution and imposes the largest impacts on the customers? Which process will most likely be designed and implemented successfully?

3. Achieving the management commitment: In the absence of the top management commitment to change and implementation of the process, the efforts for improvement are most likely doomed to failure [8].

4. Evaluating the design drivers: Hammer and Champy [9] argued that shortcut advances are usually not possible through automation only. A wrong action does not represent a solution even if it is taken rapidly. The team must address two questions: (1) how it is possible to use technology for improving the efficiency of what is being performed currently? (2) how does the technology allow us to perform new tasks that are currently impossible to perform? [9]

5. Understanding the process: Understanding the process is a key element of any attempt toward process design. Before one can attain such an understanding, it is necessary to address the following questions: what tasks are performed by the current process? How does the current process perform the tasks appropriately (or poorly)? What are the essential factors that control the process performance?

6. Creative process design: Creation of a creative plan refers to a combination of science and creative art. There is no single universal solution for designing a new project. Process designers must put together the values, rules, and instructions to develop new methodologies for process design.

7. Modeling and simulation of the process: Simulation is the most powerful tool for process modeling. Modeling and simulation of the process are performed in four steps: (1) preparing a simulated model of the process, (2) initializing the simulated model, (3) analyzing the performance criteria, and (4) evaluation.

8. Alternative scenarios for implementing a new process design: The following criteria are regarded when implementing a new design: time, cost, closeness to success, and general potential of the design. An implementation strategy may be revolutionary, evolutionary, or a combination of both. A revolutionary implementation strategy requires abrupt, cost-intensive changes for which a great management commitment is necessary. On the other hand, an evolutionary implementation strategy requires a longer time span during which changes may not necessarily end up with rapid improvements. However, one can reduce the cost, especially internal costs, by adopting a revolutionary strategy [8].

2-2. Researches in Iran and other countries

In 1997, Shady *et al.* [10] proposed the design of a new working cell for producing products at the desired level so that the production cycle time could decrease further and great deals of essential information were provided for working cell and process designers. Williams and Gevaert [11] analyzed the production system at an automotive spare part provision company. They found that new workflows and layouts must be designed to obtain more accurate estimations of the output rate and identify low-cost solutions for improving the design. This led to improved working performance and reduced count of required labors along the line. The aim was to present a novel working cell for producing a new product using simulation studies.

Later on in 1998, McMullen and Frazier [12] presented a study that used the simulation method for solving the problem of balancing multiple objectives of a production line with parallel workstations. In this research, the researchers focused on two performance objectives: total cost and cycle time. Findings of this study showed that the use of the simulation method leads to better solutions for the performance in terms of cycle time, although the methodology provides only moderate solutions when it comes to the total cost. Kang *et al.* [13] investigated the process of repairing an aircraft and presented two independent simulation models while redesigning the existing processes to provide the system with more low-cost parts.

In 1999, Springfield *et al.* [14] performed research to analyze the operation of manufacturing the electronics used in the power supply of the long-range HELLFIRE missile

using simulation- and experience-based designs. Based on their findings, they proposed that additional Operators must be added to the system, while particular items of equipment shall be eliminated from the testing rooms. This involves studying the optimization of the production line of a compressor using simulation and genetic algorithm.

In another work, Lee *et al.* [15] analyzed the operation of manufacturing the electronics used in the power supply of the long-range HELLFIRE missile using simulation- and experience-based designs. Based on their findings, they proposed that additional Operators must be added to the system, while particular items of equipment shall be eliminated from the testing rooms. This involves studying the optimization of the production line of a compressor using simulation and genetic algorithm.

In 2002, Tantivanich and Sudasna-na-Ayudthya [16] reported a study on the development of a simulation model for identifying solutions to improve the production in a hi-tech semi-conductor plant. Based on their results, the researchers formulated the following proposals for improving the productivity and cycle time of the production line: procuring an additional DTF machine, adding an engraving machine, adding a forming machine, reducing the installation and startup time, and reducing the maintenance time. The work was followed by another paper by Kijakic [17] who aimed to apply the simulation methodology for designing the layout of the production line for a bus manufacturing company so as to investigate and, then, optimize the line. Taking the modification of the layout as a general solution, he identified and analyzed the then-current production line in an early stage and proceeded to present three new layouts considering the existing issues such as bottlenecks, work-in-progress, and unfinished products. Finally, one of the proposed layouts was selected as the optimal layout.

Hauser [18] published a work aimed at optimizing and simulating the operation of a production line. He investigated and compared the then-current layout of the production line at Toyota with three other layouts, and introduced the optimal layout based on simulation results.

Gebus *et al.* [3] adopted a discrete-event simulation approach to product optimization along the production line of electronic products and ran the model for 40 rounds to ensure good relations and spacing. The findings showed that the timing strategy produced the poorest performance because no optimal criterion was selected. By adopting the second strategy, the production time was saved by 60%. However, the third strategy did not produce similar results. The researchers further demonstrated that adding Operators with supervisors imposed no significant effect on the overall performance of the production line.

Soleimanpour and Zeinalzadeh [19] proposed a three-objective discordant model for optimal control toward minimizing the cost of periodic operations and mean and variance of the manufacturing time. Their model showed significant results under uncertainty. Fandino Pita and Wang [2] investigated the production process and production line at a glass bottle manufacturing company using the simulation method to facilitate the production system. The validation of the simulation model highlighted the outstanding capability of the model for reconstructing the actual system accurately, leading to adequately satisfactory results. It was shown that their objective was successfully achieved in the production line. Fandino Pita and Wang believed that necessary modifications should be made to the machinery and resource allocation scheme before any improvement of the production line could be achieved by optimizing the loading platform and estimating the output rate using the simulation method.

Shokouhi and Shahriari [20] proposed a three-objective discordant model for optimal control to minimize the cost of periodic operations and mean and variance of the manufacturing time. Their model achieved significant results under uncertainty.

Villarreal and Alanis [21] adopted a simulation approach to improve the performance of the production line at a Mexican company. Results of the simulations performed by these researchers imposed positive impacts on the operations of the company: decreased load of the operations by 35% and increased utilization of productive resources by 20%, decreased space requirement by 27%, enhanced flexibility of the Operators following an interactive training course, improved response time by 16%, and decreased per-unit cost of production by 28%. The professed objective was to reduce the cycle time in an aircraft repair shop of the Navy.

In 2012, Azadeh *et al.* [6] were the first to investigate the performance improvement of a

multi-product manufacturing shop by integrated fuzzy simulations. Findings of this research showed that, compared to conventional simulation, the fuzzy simulation produced production rates that were much closer to actual values. Therefore, one may conclude that the fuzzy simulation contributed to the enhanced validity of the simulation results and provided better solutions than those of the conventional simulation method. Moreover, the fuzzy simulation method was found to better express the uncertainties. In addition, the researchers used fuzzy simulation to enhance the performance of the manufacturing shop considering the production problems, system constraints, and the provided objectives. The authors further presented solutions and strategies with particular attention to managerial and economic factors. Later on, Hosseii *et al.* [22] simulated the optimization of quality control along a mass production line in a car manufacturing company using the symphony method. According to their results, too long waiting time within a particular zone was the cause of dissatisfactory productivity of the production line. On the other hand, this zone used greater resources than the other zones, making the staff working in this zone somewhat unhappy. Their findings further showed that, by reducing the waiting time, satisfactory performance results were obtained and both the staff and the owner were happy with reduced consumption of resources and enhanced output of the production line.

Azar *et al.* [5] performed research with the aim of calculating minimum possible load shedding by generation relocation for taking the power transmission grid out of emergency. For this purpose, they tested and simulated an electrical energy generation network (including 8 energy generation stations). Results of the simulated models indicated the superiority and advantageousness of the method presented in this research over similar methodologies involving load shedding.

In their research, Ryde and Sundblad [23] used the simulation method for improving the production process, enhancing the product processing, and adding to the flexibility of the production process in telecommunication companies operating in Estonia and China, leading to numerous conclusions on optimal production planning. One of the most important improvements obtained in this research was the presentation of a novel test apparatus for reducing the assembling time by the operator. The enhancement in efficiency was made possible by sharing the bottlenecks for enhancing the utilization per square meter; this contributes to more flexible startup and decreases the need for extra production line.

Seyed Esfahani *et al.* [24] presented a mathematical model for the optimal allocation of excessive components in each stage from a multi-stage system with series-parallel and k-out of-n structures to maximize the system reliability, and found that the presented k-out of-n structure provided the system with higher levels of reliability. They aimed to develop a multi-objective model for optimizing the manufacturing time in a multi-stage manufacturing system.

In another work, Maleki and Aghazadeh Shabestari [25] performed a case study on an electric motorcycle production company. Firstly, they proposed a mathematical model for allocating inspection stations to the production processes. Subsequently, an exploratory approach was followed to simulate and optimize the model using Enterprise Dynamic Software. Finally, the mathematically developed and simulated models were compared to one another.

Sarda and Digalwar [26] modeled and analyzed the production line of a car manufacturing company in India to help managers evaluate the sensitivity of the production line performance to different parameters. For this purpose, conveyor speed, operator's fatigue, and quality of the procured material were selected from a pool of the parameters affecting the output of the production line. In the next step, design of experiments (DOE) was adopted to measure the impacts of input parameters on the outputs of the production line. The results were analyzed using response surface methodology (RSM) and analysis of variance (ANOVA). According to the analysis, the production line exhibited the highest level of sensitivity to the operator's fatigue followed by the material quality and then conveyor speed. This research provided a structural approach to the analysis of car production line in a car manufacturing company, offering an appropriate tool for the management to analyze the performance of a complex production system.

3. Methodology

3-1. Description of the main research problem

The main research problem was to simulate the signoff unit for two products of Saipa

Corporation, namely Tiba (X200) and Pride (X100) product families, according to the percentages shown in Fig. 1

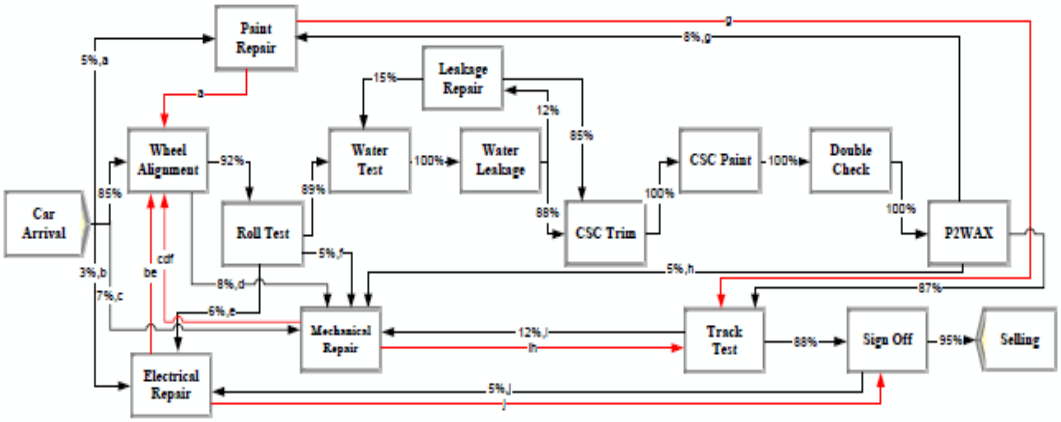

Fig. 1. Workflow through different stations in the signoff unit.

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The information for each station comes with a random parameter. This information must be collected and classified. Obviously, the need for producing a new product and releasing it to the market must be based on feasibility studies and numerous other factors. Design and production of a new car is not an exception to this general rule.

As such, different scenarios can be compared by the standard times obtained from the simulation of the most time-intensive activities in the entire process. Fig. 4 further provides the results of simulating the number of cars introduced to each repair process where reworking becomes necessary due to a defective part or process. Therefore, these results can be used to analyze the quality of the cars.

In order to optimize the system, it was necessary to investigate the stations that were responsible for the longest queues. This was performed to evaluate the feasibility of increasing the effective number of stations or operators. In this respect, the allocation of the required workforce and productivity of the workforce were analyzed. It is worth noting that maintenance and repair systems can be prioritized based on this factor so as to provide different stations with the required equipment to reduce the waiting time of cars at workstations.

The process can also be controlled by investigating the space occupied by the parked cars in the corresponding zone to each station. Accordingly, should the number of parked cars at a station increases, the expansion of the space and provision of control and protection systems for maintaining the products shall be considered as a priority.

As another control, one may keep track of the frequency of referrals to and the number of cars engaged at each station to evaluate and verify the adequacy of the workforce and equipment at that station.

Finally, maximum product transportation between workstations can be tracked as a criterion for evaluating optimal logistics for the signoff process. In this regard, maximum transportation times infer the processes associated with maximum reworking.

3-2. Research assumptions

The following assumptions are considered in this research:

- The time between successive car entries follows an exponential distribution function with a mean value of 2 minutes (EXPO(2)) (if a phenomenon follows the homogeneous Poisson's process, the exponential distribution describes the time between successive incidence of an event in the process. Discrete random variables include Bernoulli's, binomial, geometrical, Poisson's, hyper-geometric variables, among others. Accordingly, these variables have been most frequently used to solve probabilistic problems and those grounded on the queuing theory.)
- Succession of the entry of the produced products (Pride and Tiba) follows a discrete empirical cumulative distribution function (CDF), which is mathematically expressed as DISC (0.3, 1, 1.0, 2):

$$\text{DISC}\ (cp_1, v_1, cp_2, v_2, \ldots),$$

where cp_is and v_is are the pairs and $cp_i = P\{X \leq vi\}$r the CDF.

As a simpler description, this can be expressed as "*3-Pride, 1-Tiba entry succession*".

In this Model , the car sequencing was determined based on the customer demand information during a one-year period (since1397), as per the data extracted from the Saipa Corporation sales system, and mapped as a disc distribution function (indicating that 1 and 3 out of every 4 cars sold by the Saipa Corporation were Pride and Tiba, respectively).

- Transportation time is similar to the operation time for the initial station.
- Recurrence time is one month (*i.e.*, 30 days, for optimality).
- Each day is defined as a 7.5-hour short working shift.

3-3. Research variables

Independent variables include product quality, given the predefined minimum standards, and the factors affecting workforce productivity.

Dependent variables include work completion time and the number of manufactured cars.

Fig-2

3-4. Procedure

In order to identify the improvable key points in the signoff unit, all bottlenecks and times were analyzed according to the report extracted from the simulated model in ARENA Software. The results (the number of cars queued at each station and the number of the input and output cars at each station) were compared at the end of each period. Moreover, the maximum activity time in each process was identified and evaluated.

Given the simulation reports, one can see the number of cars entering (leaving) each repair process where reworks are performed due to defective parts or processes. Based on this report, the quality of the cars was further analyzed. Before the system could be optimized, one should identify the most queue-forming stations (to evaluate the feasibility of increasing the effective numbers of stations and workforce). It is worth noting that maintenance and repair systems can be prioritized based on this factor so as to provide different stations with the required equipment to reduce the waiting time of cars at workstations. In all stages, the scenarios performed were classified and the system outputs were used to analyze the results and select the optimal set of conditions.

4. Results

Upon implementing the actual system according to the new optimized layout and logistic structure of the stations and work processes while allocating the human resources appropriately, the results were indicative of a 30% improvement in the quality indices across the working domains. In this respect, the value of direct pass percentage (the number of products passed at a particular station without referring to retouching and/or reworking units to the total input to that station times by 100%) at the stations with the longest waiting times increased from 60% to 90% and the value of defect per unit (DPU, the number of defects observed in each station (electrical, water leakage, mechanical, track test, wheel alignment, etc.) divided by the total input to that station times by 100%) at the wheel alignment and electrical fault detection stations decreased from 2 to 1.4%. Moreover, in terms of quantity, it was observed that the number of output cars per unit time increased by 10%. Figs. 3 to 5 and Tables 1 to 5 show detailed results of the present study.

Accumulated Wait Time	Average	Half Width	Minimum Average	Maximum Average
CSC Paint	56.7333	12.67	42.5667	67.1000
CSC Trim	66.2000	18.57	48.4000	79.0333
Double Check	37.8133	9.43	30.4000	46.8667
Electrical Repair	170.24	9.19	162.70	181.37
Mechanical Repair	38.0600	9.16	25.8333	44.8000
P2WAX	35.6333	9.39	27.4667	45.0333
Paint Repair	24.0600	6.96	18.0000	29.6667
Roll Test	32.3933	3.07	29.0000	35.8667
Sign Off	37.1467	4.85	31.2333	41.9000
Track Test	32.6800	7.88	28.4000	43.8667
Water Leakage Repair	7.8800	3.72	5.3667	12.1333
Water Leakage Test	116.74	25.25	85.7667	134.47
Water Test	29.7400	6.25	23.2667	36.8000
Wheel Alignment	283.21	12.60	271.63	297.40

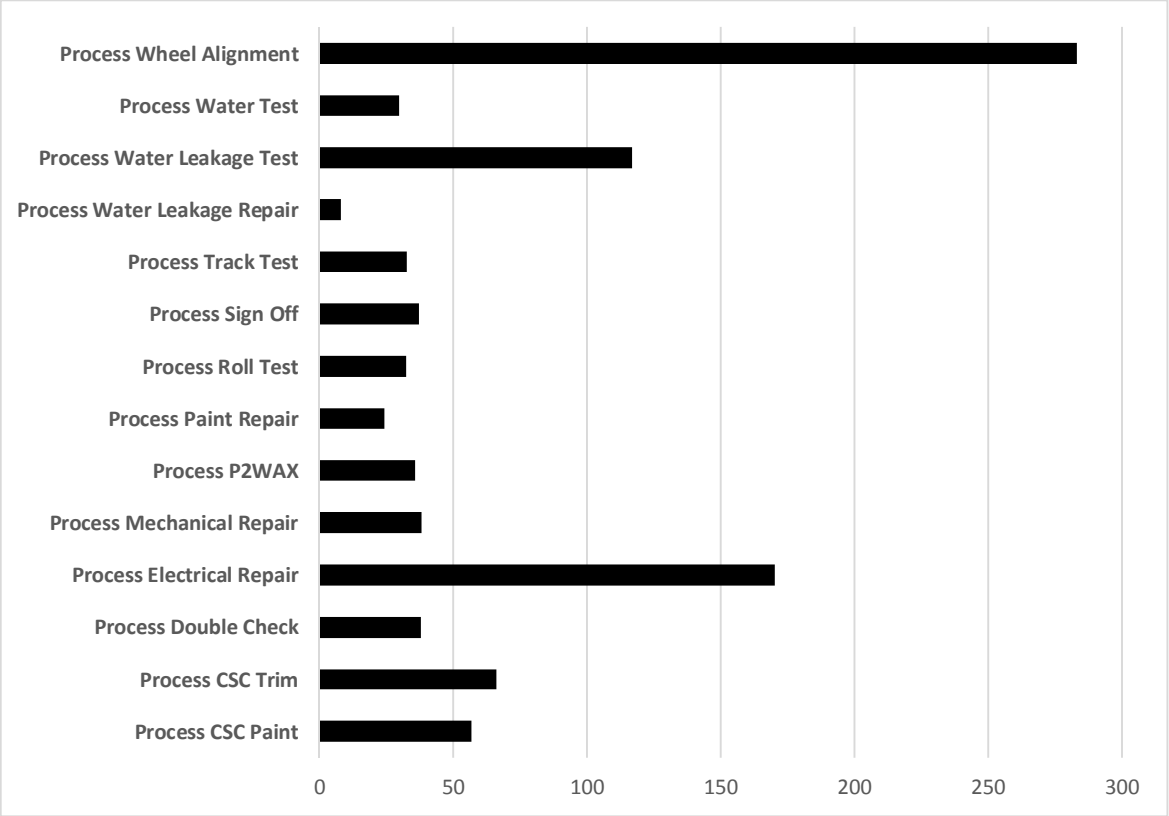

Fig. 3. Waiting times in each of the processes performed in the signoff unit.

Number In	Average	Half Width	Minimum Average	Maximum Average
Process CSC Paint	5597.00	54.62	5542.00	5642.00
Process CSC Trim	5600.80	55.83	5544.00	5650.00
Process Double Check	5595.00	55.52	5542.00	5641.00
Process Electrical Repair	2752.60	56.38	2701.00	2811.00
Process Mechanical Repair	2408.80	99.10	2275.00	2467.00
Process P2WAX	5593.80	55.81	5541.00	5640.00
Process Paint Repair	768.60	15.64	757.00	784.00
Process Roll Test	6324.20	78.98	6241.00	6373.00
Process Sign Off	7044.80	17.63	7026.00	7065.00
Process Track Test	6467.80	73.37	6369.00	6521.00
Process Water Leakage Repair	673.00	30.38	646.00	700.00
Process Water Leakage Test	5712.20	72.66	5645.00	5772.00
Process Water Test	5729.80	75.49	5662.00	5795.00
Process Wheel Alignment	6882.80	90.54	6789.00	6953.00

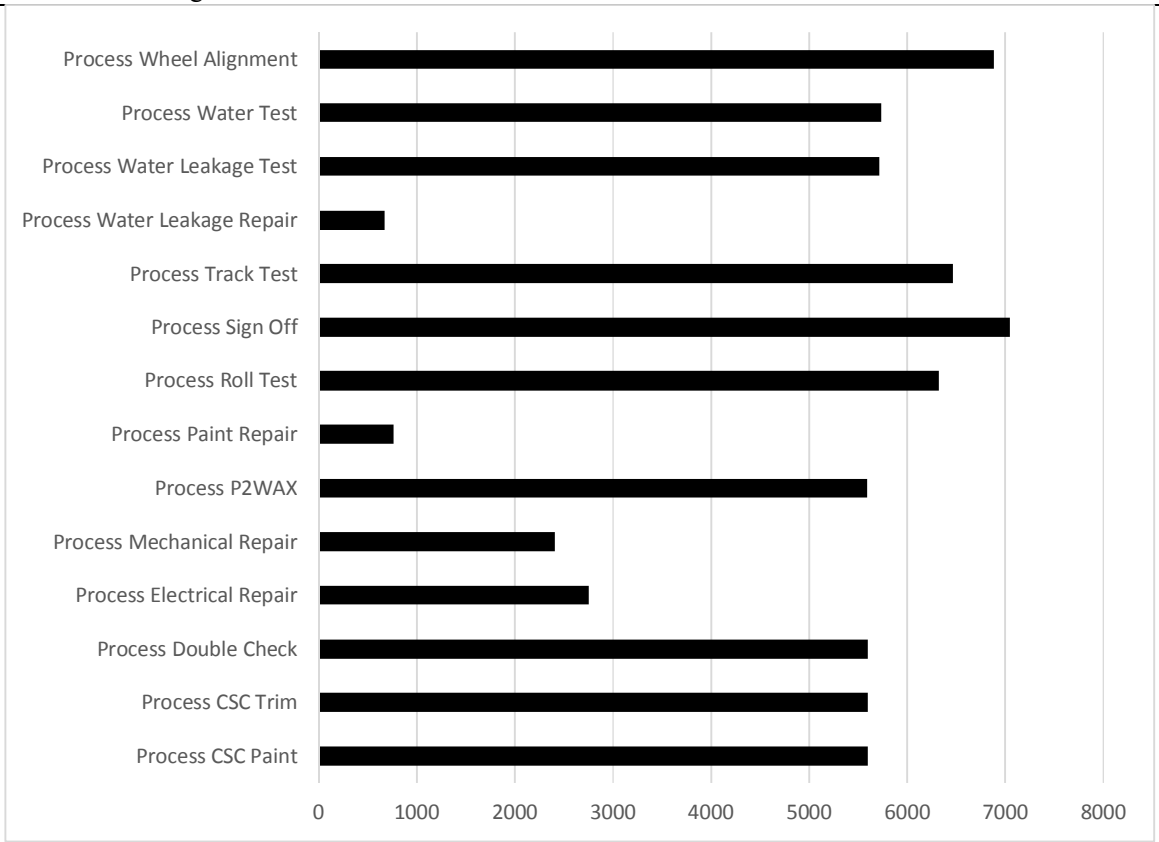

Fig. 4. Number of cars referring to each repair station.

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
CSC Paint	5597.00	54.62	5542.00	5642.00
CSC Trim	5600.80	55.83	5544.00	5650.00
Double Check	5595.00	55.52	5542.00	5641.00
Electrical Repair	2752.60	56.38	2701.00	2811.00
Mechanical Repair	2408.80	99.10	2275.00	2467.00
P2WAX	5593.80	55.81	5541.00	5640.00
Paint Repair	768.60	15.64	757.00	784.00
Roll Test	6324.20	78.98	6241.00	6373.00
Sign Off	7044.80	17.63	7026.00	7065.00
Track Test	6467.80	73.37	6369.00	6521.00
Water Leakage Repair	673.00	30.38	646.00	700.00
Water Leakage Test	5712.20	72.66	5645.00	5772.00
Water Test	5729.80	75.49	5662.00	5795.00
Wheel Alignment	6882.80	90.54	6789.00	6953.00

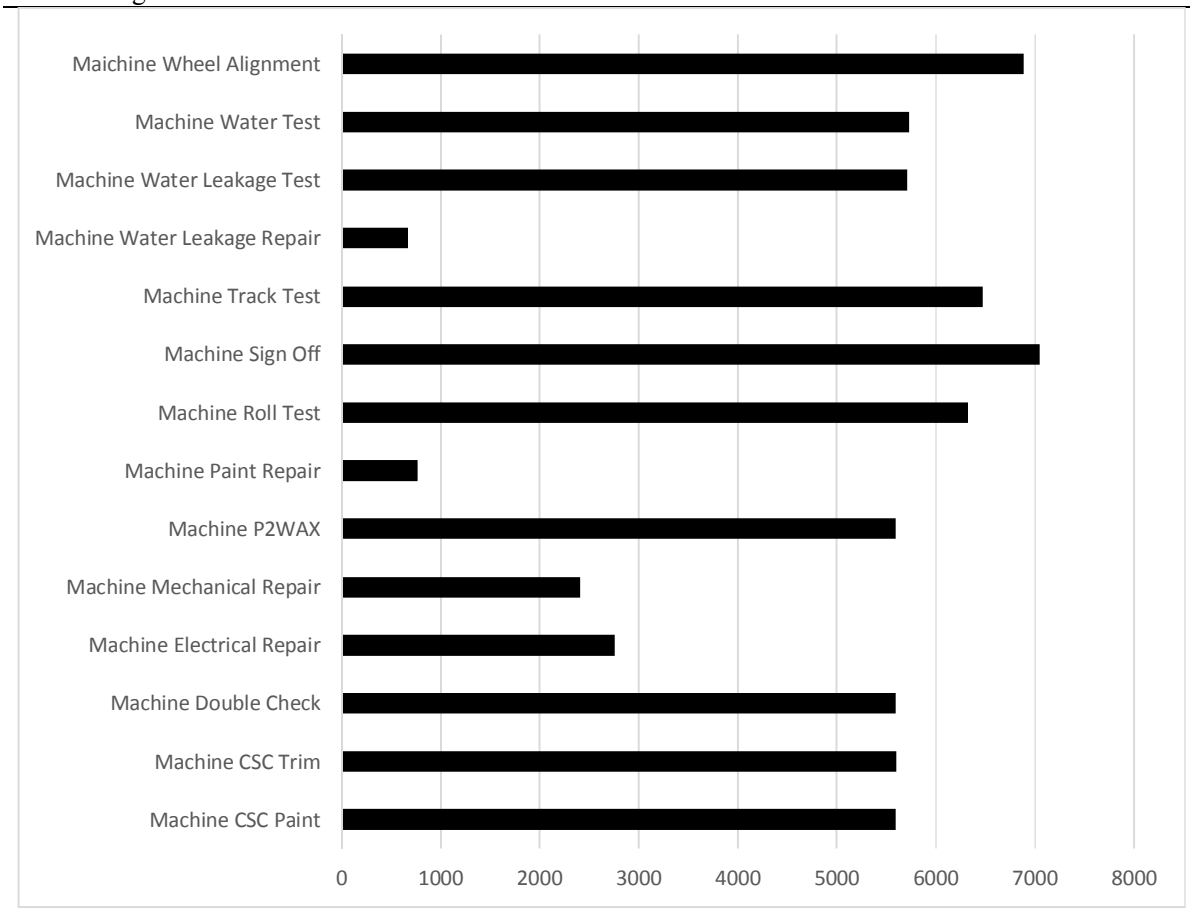

Fig. 5. Stations with the most seized resources in the signoff process

Tab. 1. Probable distribution types based on similar studies.

Adjustment Station	Model	Standard Time	Repair Station	Model	Standard Time
Wheel Alignment (WA)	X100	Tria (2.1, 2.5, 2.9)	Electrical Repair (ER)	X100	Tria (5, 20, 80)
	X200	Tria (2.1, 2.5, 2.9)		X200	Tria (5, 24, 85)
Roll Test (RT)	X100	Tria (2.3, 2.5, 2.6)	Mechanical Repair (MR)	X100	Tria (10, 21, 100)
	X200	Tria (2.1, 2.3, 2.5)		X200	Tria (10, 24, 80)
			Paint Repair (PR)	X100	Tria (5, 31, 85)
				X200	Tria (10, 38, 90)
Water Leakage Test (WLT)	X100	Tria (1.4, 1.6, 1.8)	Water Leakage Repair (WLR)	X100	Tria (5, 15, 30)
	X200	Tria (1.8, 2, 2.2)		X200	Tria (5, 20, 35)
Double Check (DC)	X100	Tria (3, 3.5, 4)	CSC Trim (CSCT)	X100	Tria (3, 3.48, 4)
	X200	Tria (3, 3.5, 4)		X200	Tria (3.5, 4, 5)
P2WAX (P2WAX)	X100	Tria (0.6, 0.8, 0.9)	CSC Paint (CSCP)	X100	Tria (3.8, 5.2, 5.5)
	X200	Tria (0.4, 0.5, 0.6)		X200	Tria (4, 5.2, 6)
Track Test (TT)	X100	Tria (9, 10, 12)	Sign Off (SO)	X100	Tria (5, 15, 30)
	X200	Tria (9, 10, 12)		X200	Tria (5, 20, 35)

Constant Standard Times :

Adjustment Station	Model	Standard Time
Water Test (WT)	X100	**7.87**
	X200	**7.87**

Tab. 2. Overall waiting times in the signoff unit

Car Line Production						
Replications:	5		Time Units:		Hours	
Entity						
Time						
VA Time	Average	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
Car	0.00	0.00	0.00	0.00	0.00	0.00
NVA Time	Average	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
Car	0.00	0.00	0.00	0.00	0.00	0.00
Wait Time	Average	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
Car	6.5851	0.26	6.3905	6.9217	0.01666667	32.1833
Transfer Time	Average	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
Car	0.1660	0.00	0.1643	0.1676	0.03333333	1.0000
Other Time	Average	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
Car	0.00	0.00	0.00	0.00	0.00	0.00
Total Time	Average	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
Car	6.7511	0.26	6.5572	7.0865	0.05000000	32.5667
Number In	Average	Half Width	Min. Average	Max. Average		
Car	6751.00	0.00	6751.00	6751.00		
Number Out	Average	Half Width	Min. Average	Max. Average		
Car	6379.80	16.53	6367.00	6401.00		
WIP	Average	Half Width	Min. Average	Max. Average	Min. value	Max. Value
Car	202.00	7.65	195.82	211.88	0.00	384.00

Tab. 3. Waiting time in the queue formed at each working process

Queue: Time						
Waiting Time	Average	Half Width	Min. Average	Max. Average	Min.	Max.
Process CSC Paint.Queue	0.01012705	0.00	0.00768074	0.01191618	0.00	1.0000
Process CSC Trim.Queue	0.01180356	0.00	0.00873016	0.01398820	0.00	1.0000
Process Double Check.Queue	0.00675244	0.00	0.00548538	0.00832445	0.00	1.0000

Process Electrical Repair.Queue	0.06183883	0.00	0.05975389	0.06452034	0.00	1.0000
Process Mechanical Repair.Queue	0.01582434	0.00	0.01047156	0.01827825	0.00	1.0000
Process P2WAX.Queue	0.00636357	0.00	0.00495699	0.00800024	0.00	1.0000
Process Paint Repair.Queue	0.03127503	0.01	0.02374670	0.03918978	0.00	1.0000
Process Roll Test.Queue	0.00512064	0.00	0.00462520	0.00562791	0.00	1.0000
Process Sign Off.Queue	0.00527293	0.00	0.00443718	0.00594664	0.00	1.0000
Process Track Test.Queue	0.00505963	0.00	0.00439017	0.00688753	0.00	1.0000
Process Water Leakage Repair.Queue	0.01166077	0.01	0.00830753	0.01794872	0.00	1.0000
Process Water Leakage Test.Queue	0.02041205	0.00	0.01519339	0.02343033	0.00	1.0000
Process Water Test.Queue	0.00518718	0.00	0.00410492	0.00635030	0.00	1.0000
Process Wheel Alignment.Queue	0.04114884	0.00	0.03906707	0.04298309	0.00	1.0000
Request CSC Paint.Queue	0.01526477	0.01	0.00430651	0.02667969	0.00	0.2000
Request CSC Trim.Queue	0.04796733	0.02	0.02938240	0.06137349	0.00	0.3333
Request Double Check.Queue	0.00865386	0.01	0.00035416	0.01844287	0.00	0.2000
Request Electrical Repair.Queue	0.01221875	0.00	0.01115916	0.01465671	0.00	0.2667
Request Mechanical Repair.Queue	0.00098806	0.00	0.00070330	0.00135999	0.00	0.1000
Request P2WAX.Queue	0.00005215	0.00	0.00	0.00014804	0.00	0.1000
Request Paint Repair.Queue	0.00044845	0.00	0.00021988	0.00072279	0.00	0.06666667
Request Roll Test.Queue	0.00000107	0.00	0.00	0.00000534	0.00	0.03333333
Request Sign Off.Queue	5.5810	0.31	5.3400	5.9482	0.00	11.8000
Request Track Test.Queue	0.00111055	0.00	0.00094301	0.00121989	0.00	0.1000
Request Water Leakage Repair.Queue	0.00000986	0.00	0.00	0.0000493	0.00	0.03333333
Request Water Leakage Test.Queue	0.08341976	0.03	0.05410465	0.1040	0.00	0.4667
Request Water Test.Queue	0.3091	0.03	0.2727	0.3297	0.00	1.0000
Request Wheel Alignment.Queue	0.04647273	0.00	0.04257868	0.04868719	0.00	0.4667

Tab. 4. Number of cars waiting in the queue after each working process

Number Waiting	Average	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
Process CSC Paint.Queue	0.2521	0.06	0.1892	0.2982	0.00	7.0000
Process CSC Trim.Queue	0.2942	0.08	0.2151	0.3513	0.00	10.0000
Process Double Check.Queue	0.1681	0.04	0.1351	0.2083	0.00	7.0000
Process Electrical Repair.Queue	0.7566	0.04	0.7231	0.8061	0.00	18.0000
Process Mechanical Repair.Queue	0.1692	0.04	0.1148	0.1991	0.00	8.0000
Process P2WAX.Queue	0.1584	0.04	0.1221	0.2001	0.00	7.0000
Process Paint Repair.Queue	0.1069	0.03	0.08000000	0.1319	0.00	6.0000
Process Roll Test.Queue	0.1440	0.01	0.1289	0.1594	0.00	4.0000
Process Sign Off.Queue	0.1651	0.02	0.1388	0.1862	0.00	5.0000
Process Track Test.Queue	0.1452	0.04	0.1262	0.1950	0.00	4.0000
Process Water Leakage Repair.Queue	0.03502222	0.02	0.02385185	0.05392593	0.00	3.0000
Process Water Leakage Test.Queue	0.5188	0.11	0.3812	0.5976	0.00	15.0000
Process Water Test.Queue	0.1322	0.03	0.1034	0.1636	0.00	2.0000
Process Wheel Alignment.Queue	1.2587	0.06	1.2073	1.3218	0.00	25.0000
Request CSC Paint.Queue	0.3814	0.31	0.1061	0.6677	0.00	7.0000
Request CSC Trim.Queue	1.1965	0.44	0.7240	1.5307	0.00	11.0000
Request Double Check.Queue	0.2162	0.27	0.00888889	0.4615	0.00	7.0000

Request Electrical Repair.Queue	0.1496	0.02	0.1341	0.1831	0.00	16.0000
Request Mechanical Repair.Queue	0.01060741	0.00	0.00711111	0.01481481	0.00	6.0000
Request P2WAX.Queue	0.00130370	0.00	0.00	0.00370370	0.00	5.0000
Request Paint Repair.Queue	0.00154074	0.00	0.00074074	0.00251852	0.00	4.0000
Request Roll Test.Queue	0.00002963	0.00	0.00	0.00014815	0.00	2.0000
Request Sign Off.Queue	174.39	9.95	166.49	186.34	0.00	361.00
Request Track Test.Queue	0.03191111	0.00	0.02725926	0.03511111	0.00	7.0000
Request Water Leakage Repair.Queue	0.00002963	0.00	0.00	0.00014815	0.00	1.0000
Request Water Leakage Test.Queue	2.1268	0.74	1.3573	2.6609	0.00	15.0000
Request Water Test.Queue	7.8769	0.80	6.8660	8.5000	0.00	30.0000
Request Wheel Alignment.Queue	1.4221	0.11	1.2847	1.4972	0.00	29.0000

Tab. 5. Stations with the largest flows of transportation in the modeled report of the process.

Transporter						
Utilization	Average Value	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
CSC Paint _Lifter	0.8289	0.01	0.8210	0.8358	0.00	1.0000
CSC Trim _Lifter	0.8293	0.01	0.8211	0.8359	0.00	1.0000
Double Check _Lifter	0.8288	0.01	0.8210	0.8356	0.00	1.0000
Electrical _Repair Lifter	0.2039	0.00	0.2000	0.2082	0.00	1.0000
Mechanical Repair .Lifter	0.1784	0.01	0.1684	0.1827	0.00	1.0000
P2WAX_Lifter	0.4144	0.00	0.4104	0.4178	0.00	1.0000
Paint Repair _Lifter	0.05693333	0.00	0.05607407	0.05807407	0.00	1.0000
Sing Of _Lifter	0.9944	0.00	0.9934	0.9950	0.00	1.0000
Roll Test	0.3123	0.00	0.3081	0.3147	0.00	1.0000
Track Test _Lifter	0.4790	0.01	0.4717	0.4830	0.00	1.0000
Water Leakage Repair _Lifter	0.04985185	0.00	0.04785185	0.05185185	0.00	1.0000
Water Leakage Test _Lifter	0.8451	0.01	0.8357	0.8551	0.00	1.0000
Water Test _Lifter	0.8463	0.01	0.8364	0.8552	0.00	1.0000
Wheel _Lifter	0.5098	0.01	0.5029	0.5149	0.00	1.0000
User Specified						
Utilization	Average Value	Half Width	Min. Average	Max. Average	Min. Value	Max. Value
X100 Flow Time	6.7237	0.24	6.4666	7.0149	0.06666667	31.3333
X200 Flow Time	6.7629	0.27	6.5761	7.1176	0.05000000	32.5667

5. Discussion

In order to identify the improvable key points in the signoff unit, all bottlenecks and times were analyzed according to the report extracted by the simulated model in ARENA Software. The results indicate that the number of products retained at workstations due to a queue and, also, the number of input and output cars in each stage exhibit significant differences (6,751 inputs and 6,401 outputs), with the maximum waiting time in the system being 32.544 hours.

According to the reports on simulation, the longest activity times were those of wheel alignment and electrical repair.

Now, different scenarios can be evaluated by considering the times obtained from simulating the most time-intensive activities throughout the process. According to the simulation report, the number of cars introduced to each repair process,

where reworking becomes necessary due to a defective part or process, could be evaluated. Therefore, these results can be used to analyze the quality of the cars.

In order to optimize the system, it is necessary to investigate the stations that are responsible for the longest queues. This was performed to evaluate the feasibility of increasing the effective number of stations or operators. It is worth noting that maintenance and repair systems can be prioritized based on this factor so as to provide different stations with the required equipment to reduce the waiting time of cars at workstations.

The process can also be controlled by investigating the space occupied by the parked cars in the zone of each station. Accordingly, should the number of parked cars increase at a station, the expansion of the space and provision of control and protection systems for maintaining the products must be considered as a priority. Accordingly, the number of cars on the report signals to the designer about the consideration of the workspace.

According to the usage report, one can simply track the volume of referrals and the number of cars engaged at each station. This report helps us evaluate and verify the adequacy of the workforce and equipment at each station.

Finally, maximum transportation of the products at the workstations can be deduced from the extracted report to evaluate the optimal state of logistics in the signoff process. Accordingly, the processes associated with the largest volumes of the report can be identified by considering the longest transportation times.

6. Conclusions and Recommendations

Considering all of the improvable key points on the report received from the simulated model and also the entire set of key points of the working process, it seemed necessary to develop the equipment and working spaces, increase working force, and eliminate particular working loops to increase productivity at the signoff unit.

Line balancing is an important issue along every production line, making it extensively studied during the past decades. Analysts are employed to analyze the system and present solutions for reducing the lost time at bottlenecks. Results of the present research indicated that the particular attention paid by the practitioners to the testing room was reasonable as the queue at this station made large contributions to the lost time. Presented in previous sections, qualitative and quantitative results of the current research showed that the use of a new testing room was expected to impose significant results so that it is highly recommended to provide the unit with a new testing room. In addition, given the potential results of the simulation, it is recommended that at least one system analyst be employed who is capable of performing modeling and simulation studies at the analysis department of similar companies. Moreover, a simulation-based analysis must be performed on a regular basis to develop an up-to-date understanding of the system in the form of a virtual model; this accelerates the forecast of upcoming conditions. Finally, it is hereby recommended that training conventions and workshops be held to get the concept of simulation and its large potentials appropriately introduced to management and system analysts.

Based on the study of the production line in this research, in addition to the above-mentioned findings, other important issues were observed that imposed large impacts on the output rate of the finished products, attracting attention from the researchers. Three of such issues are indicated in the following:

1. **Appropriate planning for Job shop.** The Operators working along the production lines often enjoy adequate levels of technical knowledge. This is expressed even better along the customized production lines where the Operator must have even higher levels of technical knowledge given the nature of such production lines and available resources that must supply the production of multiple product types. Accordingly, existing and potential unwanted bottlenecks can be avoided adequately by appropriate planning for and timing of different tasks.
2. **Better planning for the material supply system.** In complex systems such as customized production lines where special problems are likely to be encountered, the controllable factors must be considered with extreme care to keep the line protected against any extra pressure. In customized systems, there are cases where particular parts are supposed to be procured by the customer. This may end up interrupting the reworking operation along the production line if the customer fails to produce such material on time. This provides a ground for the accumulation (queuing) of unfinished products at the signoff unit. Since the

primary objective of the present research was to determine optimal signoff time, this study ignored the modeling of this factor and similar factors as exceptions to the model. However, planning for such issues significantly contributes to the regular and continuous operation of the line.

3. **Elimination of redundant transportations.** Minor modifications could be made into the working stages to reduce the burden of transportations. For instance, bringing the workstations of the largest traffic closer to one another should be prioritized. Generally speaking, efforts must be made to minimize the transportation time as this time provides the signoff process with no significant value-added.

7. Future Study

1- In order to enhance their competitiveness, automotive manufacturing firms need to utilize novel capabilities of modern production systems and an up-to-date set of tools used in the automotive industry so as to outperform their rivals by means of their strengths. During the recent past, the automotive industry has experienced an ever-expanding growth thanks to the evolution of the knowledge of productivity production systems. Simulation systems eliminate the need for dealing with human resources, equipment, machinery, production cost, etc. for implementing various scenarios in an attempt to find an optimal pattern in terms of productivity in the automotive industry. As such, timely delivery of the products at an efficient and market demand-oriented cost represents a serious challenge to today's premiers of the automotive manufacturing industry. As such, it is herein suggested that simulation systems be used for designing the whole production line and identifying bottlenecks causing interruptions to the production processes (*e.g.,* the production line in Saipa Corporation, which is composed of body manufacturing, painting, and assembling lines, to name a few).

2. The supply chain is among the most challenging and sensitive spots in the automotive industry. Today, access to an effective supply chain that can realize optimal resource allocation across the organization (sets of vendors and associated auto part manufacturers, engineering and quality systems, auto part production systems, car handing, planning, and logistics systems, etc.) contributes to the production of more competitive products. Therefore, a productive supply chain would be the one exhibiting a consistent and well-structured behavior in terms of linking the supply chain management system and respective production management systems. Accordingly, it is hereby suggested that an appropriate supply chain be designed, modeled, and implemented based on the input and output requirements of the Saipa Corporation.

8. Acknowledgement

This research was supported by Saipa Training Management Department and Saipa Industrial Engineering Department who provided insight and expertise that greatly assisted the research. I appreciate all the colleagues who have contributed to the research.

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