https://doi.org/10.3311/PPtr.23546

Periodica Polytechnica Transportation Engineering

Innovative Work Order Planning with Process Optimization Using Computer Simulation in the Automotive Industry, in the Case of Repair Workshops

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Received: 28 September 2023, Accepted: 12 January 2024, Published online: 17 April 2024

Abstract

This article introduces a novel approach to enhance the efficiency of work schedule management in automotive repair shops during the planning phase, leveraging computer simulation techniques. The primary focus of this study is the optimization of the scheduling process, specifically the sequencing of car repairs, aimed at minimizing the average repair time. The proposed simulation model harnesses the power of the FlexSim simulation environment, incorporating an embedded optimization module. The article outlines the fundamental stages involved in constructing the simulation model, encompassing essential input data and information. Furthermore, the article presents empirical results demonstrating the significant impact of various simulation scenarios on resource utilization, production costs, and process duration.

Keywords

process management, car workshop management, simulation, FlexSim, optimization

1 Introduction

In today's world, managing work schedules in a car repair shop is one of the key elements of business success. Therefore, more and more companies are starting to use advanced tools such as computer simulations and optimization models to optimize their processes and increase work efficiency (Beaverstock et al., 2017). Decisions regarding the work schedule in a vehicle repair shop are crucial for the quality of services provided and the operational efficiency of the company (Ingaldi, 2022). Due to dynamic changes in the market, increasing customer requirements, and growing competition, the use of advanced tools is becoming more and more important (Ingaldi and Klimecka-Tatar, 2022). In this context, computer simulations and optimization models are tools that allow for increased efficiency in managing work schedules and optimizing processes in repair shops (Gopalakrishnan et al., 2013).

This literature review presents several examples of scientific publications that deal with the topic of managing work schedules in car repair shops using computer simulations and optimization models. The authors studied, among other things, operational processes in vehicle repair shops (Gupta and Williams, 2004), dynamic scheduling of work (Castane et al., 2019), optimization of the scheduling process (Revina and Trifonova, 2021), and optimal scheduling of maintenance work in a service center (Kardos et al., 2021). All studies indicate the high value and effectiveness of using computer simulations and optimization models in managing work schedules in repair shops. The authors emphasize the need to take into account many factors in the models, such as the variability of repair time and resource availability, as well as integration with the optimization system to achieve the best results (Frantzén et al., 2011; Revina and Trifonova, 2021). In the described articles, the authors focus on minimizing the average repair time by proper scheduling, which is an important goal for car repair shops (Gupta and Williams, 2004; Knop and Ulewicz, 2022). The proposed method based on computer simulation and optimization models allows for the precise determination of the repair sequence and effective use of resources, which translates into cost and time savings (Krynke, 2021b).

A literature review suggests that managing the work schedule in a vehicle repair shop is a significant problem

Cite this article as: Krynke, M., Mazur, M. (2024) "Innovative Work Order Planning with Process Optimization Using Computer Simulation in the Automotive Industry, in the Case of Repair Workshops", Periodica Polytechnica Transportation Engineering, https://doi.org/10.3311/PPtr.23546

that affects the efficiency and profitability of the enterprise. Traditional approaches to scheduling work in repair shops often result in suboptimal use of resources, prolonged repair times, and dissatisfied customers. In today's world, where customers are increasingly demanding and competition is growing, inefficient management of the work schedule can lead to financial losses and loss of customers (Krynke et al., 2021).

One approach proposed in the literature is to use computer simulation and optimization models to improve the process of scheduling work in a vehicle repair shop. This approach allows for the creation of a virtual environment that reflects the actual process of repairing a car, making it possible to experiment with different scenarios and choose the one that minimizes repair time while using resources in the most efficient way (Castane et al., 2019; Schmid et al., 2022).

Therefore, an article describing a new decision-support method for managing the work schedule in a car repair shop at the planning stage, based on computer simulation, is very important for the development of this field. The developed simulation model uses the FlexSim simulation environment with a built-in optimization module, which allows for testing different scenarios and choosing the best one (Beaverstock et al., 2017). Presenting the results that show the impact of selected simulation scenarios on resource utilization, production costs, and process duration confirms the effectiveness and usefulness of this method (Daroń, 2022).

Fig. 1 shows a graphical keyword map created using VOSviewer software (Centre for Science and Technology Studies), presenting the relationship between optimization and FlexSim simulation in the Scopus database.

The analysis of the keyword map created using VOSviewer software (van Eck and Waltman, 2017), representing the relationship between optimization and FlexSim simulation based on data from the Scopus database, demonstrates that these two concepts are strongly related in scientific literature. The keyword map consists of 52 nodes, representing different keywords, and 1303 edges, representing the relationships between them.

Nodes related to optimization are located in the central part of the map, along with other concepts such as "simulation", "manufacture", "decision making" and "heuristic method". These nodes are connected to other nodes related to data analysis, such as "efficiency" or "scheduling"

Nodes related to FlexSim simulation are distributed around the central area related to optimization,

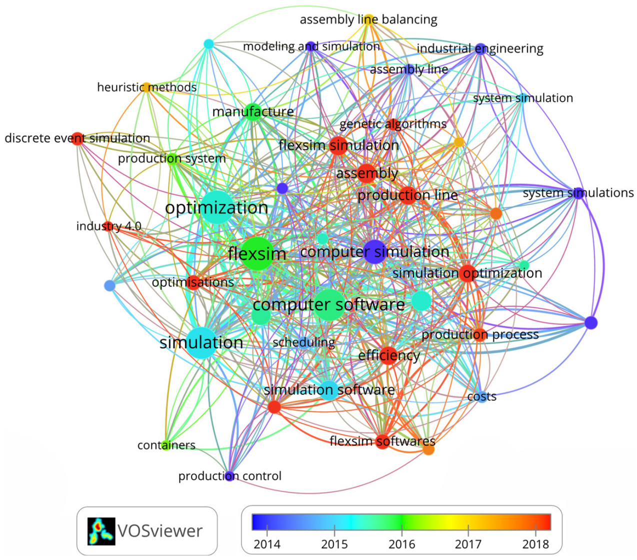


Fig. 1 Co-occurrence map of keywords associated with FlexSim and optimization (Centre for Science and Technology Studies)

indicating a strong relationship between these two concepts. These nodes include concepts such as "discrete event simulation", "business process simulation" or "process modeling".

The keyword map indicates that optimization and FlexSim simulation are used together in scientific research, particularly in fields related to process management, logistics, and production engineering. This analysis can help researchers and practitioners identify concepts related to optimization and FlexSim simulation and their applications in various fields of science and industry.

2 Process analysis

In order to improve performance and customer satisfaction, the company decided to identify key performance indicators directly related to the issues faced by the company. After conducting an analysis, the project team identified four performance indicators:

1. Overall productivity = labor hours sold / available hours,
2. Labor utilization = actual hours worked / available hours,
3. Customer satisfaction, as measured by surveys given all departing customers,
4. Overtime = hours required to service all customers – regularly scheduled working hours.

Services can be conveniently classified in two ways. From the customer's perspective, a service can either be a regular preventive maintenance (ensuring proper vehicle operation) or an on-demand repair (restoring the vehicle to proper technical condition). From the service provider's perspective, repairs can be minor repairs (short duration) or major repairs (long duration). Typically, minor repairs are inspections, and major repairs are the replacement or renovation of one or several vehicle systems mentioned earlier (Ingaldi, 2014; Siwiec et al., 2022).

To identify the direct causes of the problem, fishbone diagrams were used. Fishbone diagrams are a tool used to analyze problems and identify their causes. On the diagram depicting a fish, the main problem is at the end of the "bones", while each of the branches represents possible causes of the problem. This approach allows for an insight into the entire situation and easier understanding of the factors that affect the problem (Dziuba et al., 2021; Knop and Mielczarek, 2018).

The main causes that turned out to be low productivity and low customer satisfaction are indicated in the diagrams presented below in Figs. 2 and 3.

Fishbone diagram analysis helped to identify two main causes of the problem: low productivity and low customer satisfaction. Further analysis of these causes led to the identification of several factors that can be controlled and changed to improve the situation.

The first factor identified was ineffective and undisciplined planning. Proper planning of work, time, and tasks is crucial for increasing productivity and efficiency.

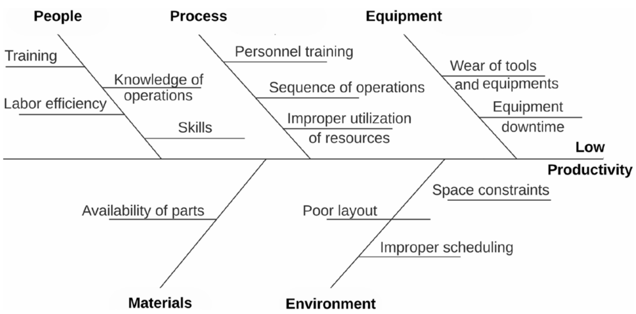


Fig. 2 Low Productivity Fishbone Chart

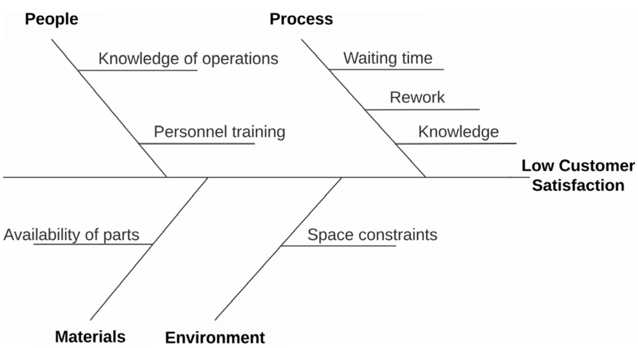


Fig. 3 Low customer satisfaction Fishbone Chart

Attention should be paid to the planning tools used, the goals set, and the methods used to evaluate the results.

The second factor that needs to be controlled is the training of operators. Operators are a crucial link in the production process, so their proper education, training, and preparation are necessary to achieve high-quality products. Proper training helps to avoid errors, increase productivity, and improve working conditions.

The last factor worth considering is sporadic and ineffective equipment maintenance. Devices and machines used on a daily basis require regular inspections, cleaning, and maintenance. Improper use, lack of repair or maintenance leads to faster wear and tear, breakdowns, and ultimately to loss of value. Proper equipment management allows for preventing failures, increasing work efficiency, and reducing repair costs (Krynke, 2021a).

In summary, identifying the direct causes of the problem using fishbone diagrams allowed for a more accurate understanding of the situation and identified several factors that can be controlled and changed to improve the situation. It is worth remembering that using appropriate tools and approaches to problem analysis is crucial for achieving success in business.

3 The simulation model and analyses

This article focuses on presenting a model that aims to establish a repair schedule in an automotive workshop. The goal of the model is to plan the process of individual repair tasks and make decisions about the order of servicing cars, so that the total cost of the process is as low as possible while the task is completed in a short time. To solve this problem, the 3D FlexSim simulation environment and itsbuilt-in OptQuest optimization module was used (FlexSim, 2017; Laguna, 2011). As part of the research analysis, the following problem was considered. The car workshop needs to establish a repair schedule for 20 cars. The company's resources include 5 service stations and 5 mechanics. It was assumed that the servicing process can take place at 5 service stations. The types of individual faults and their approximate repair times are listed in Table 1.

In addition, the Table 1 also lists the possible number of mechanics needed for removing individual faults. It was assumed that in the case of some faults, the repair time depends on the number of mechanics.

The key stage of any optimization task is to create an appropriate simulation model that accurately reflects the process as it occurs in reality. In the case of

Table 1 Types of individual malfunctions and their approximate repair time

Type of failure	Failure name	Repair time [h]	Number of mechanics
1.	Oil change	0.5÷1	1÷2
2.	Air filter replacement	0.5÷1	1÷2
3.	Brake system repair	2÷4	1÷2
4.	Exhaust system repair	2÷4	1÷2
5.	Battery replacement	0.5÷1	1
6.	Cooling system repair	2÷4	1÷2
7.	Wheel replacement	0.5÷1	1
8.	Suspension system repair	4÷8	1÷2
9.	Gearbox repair	06÷10	1÷2
10.	Engine repair	10÷20	1÷2
11.	Air conditioning system repair	2÷4	1÷2
12.	Fuel system repair	2÷4	1
13.	Electrical system repair	2÷4	1÷3
14.	Light replacement	0.5÷1	1
15.	ABS system repair	2÷4	1
16.	Brake disc replacement	1÷2	1÷2
17.	Brake pad replacement	1÷2	1÷1
18.	Steering system repair	2÷4	1÷2
19.	Serpentine belt replacement	0.5÷1	1
20.	Gearbox oil change	2÷4	1

the FlexSim simulation environment, appropriate elements should usually be selected from the object library located on the left side of the program's main window (FlexSim, 2017). These elements are responsible for simulating machines, raw materials, or products that are produced in reality. The process flow logic is created by adding appropriate connections that allow elements to move within the simulation, such as repaired cars in this specific case. An example simulation model for the problem being solved is presented in Fig. 4.

In this model, standard program library objects were used and programmed according to the task conditions. It can be intuitively assumed that the function of individual service stations should be performed by *Processors* here. The processing time for each station is set according to its efficiency. The Uniform statistical distribution function was used here. Using this distribution, continuous variables are generated, which take values from the minimum to the maximum with equal probability

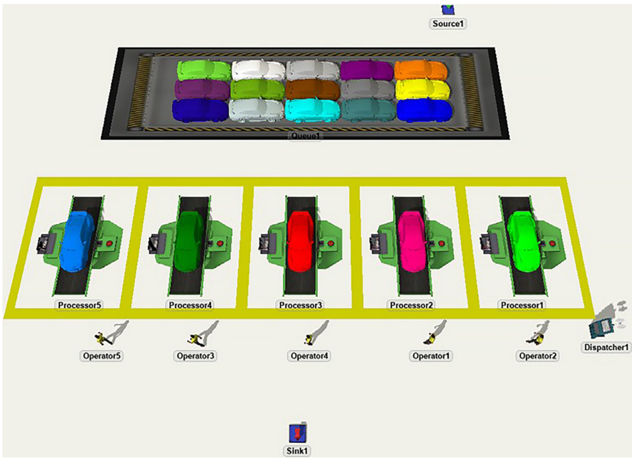


Fig. 4 Simulation model for the discussed problem built in the FlexSim environment, (FlexSim Software Products, Inc.)

(FlexSim, 2017). Source objects are usually generators of multiple flow elements. In this model, the source operates in *Arrival Sequence* mode, where 20 sample cars are generated for repair. In this particular case, the flow element symbolizes the next car for repair. Mechanics were simulated by 5 *Operators*, and each mechanic is managed by a *Dispatcher*.

The objective function is defined by variable costs dependent on the mechanics' working time and fixed costs related to maintaining workstations (Krynke and Klimecka-Tatar, 2022). In the considered case, the cost of working or standing at one station was set at a constant level of 5 monetary units/hour. The cost of 1 working hour for all mechanics is the same and amounts to 40 monetary units/hour. To calculate these costs in FlexSim, one needs to add the *Financial Analysis* chart to the Dashboard and specify the cost for all *Processors* and *Operators*. This parameter must be defined by adding it from the *Toolbox* library as a *Performance Measure* variable. This objective function must be assigned as *Financial Analysis-Total* for the previously defined *Financial Analysis* chart (see Fig. 5). An additional parameter investigated in this analysis is

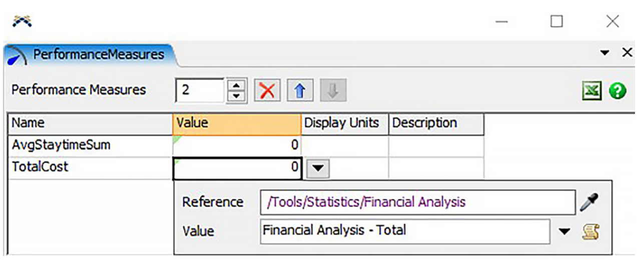


Fig. 5 Definition of the objective function - the output variable for the average service time and costs

the average repair time. In order for the optimizer to determine the optimal repair sequence for each type of flow element generated by the source, it needs one input parameter-the repair sequence order established in the global table and assigned to the source. This is a variable that will be used in the optimization process to determine the optimal order of servicing individual cars.

This sequence determines the order in which individual types of flow elements generated by the source will be repaired. The optimizer can use this sequence as one of many variables in the optimization process to find the best repair schedule for a given objective function.

For example, if the objective function is to minimize the downtime of cars during repairs, the optimizer may look for a repair sequence that minimizes the total downtime for all cars. Another example could be maximizing the number of cars repaired during a workday-in this case, the optimizer may search for a repair sequence that allows for the repair of as many cars as possible during the available work time.

In any case, in order for the optimizer to determine the optimal repair sequence, it needs the repair sequence order established in the global table and assigned to the source as an input parameter. Additional parameters are variables assigning individual mechanics to repairs, which need to be defined by adding them from the *Toolbox* library. Then, in the Value column, the input variable type should be set to *Integer* (Fig. 6). The length of the sequence should be set according to the logic of the task-for determining the repair sequence order, it is a range from 1 to 20, while in the case of choosing the number of mechanics to service one car, it is usually either 1 or the range 1÷2, according to Table 1.

The optimizer settings are shown in Fig. 7.

The objective function in this task is minimized, as the company is interested in reducing costs. Additionally, the

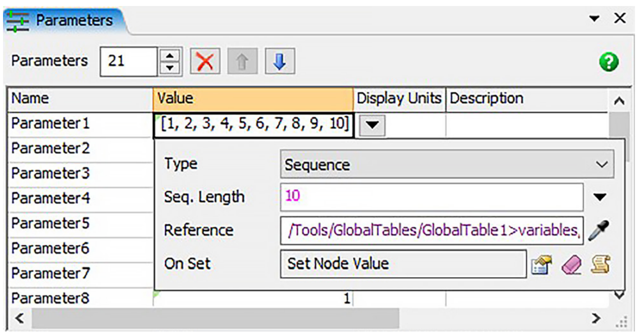


Fig. 6 Definition of variables includes the sequence of repair order and the number of mechanics assigned to a particular repair

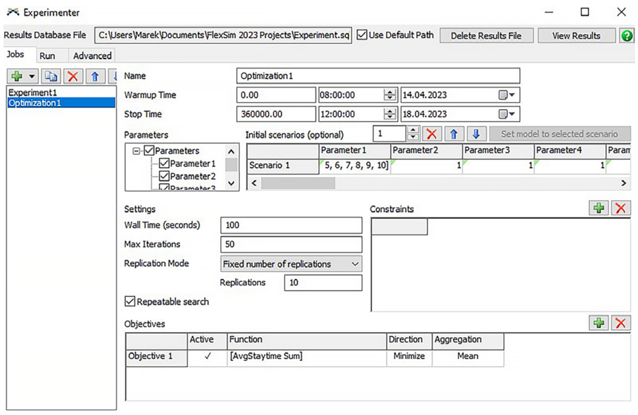


Fig. 7 The settings of the FlexSim Optimizer

average repair time is also minimized. The optimizer will adjust the values of the defined parameters until the optimal value is reached, at which point the average repair time and costs will be minimized.

4 Analysis of results

As a result of the optimizer's work, the best combination of the order of car repairs and assignment of mechanics for minimizing costs and average repair time was obtained. The results are presented in Table 2, which is divided into three parts showing the combinations of the type of malfunction, the number of mechanics, and the order of repairs. The first part shows the results without optimization, the second part shows the minimization of the average service time, and the third part shows the minimization of costs.

The order of repairs was determined based on the optimization algorithm, which took into account the repair time of individual malfunctions, the number of available mechanics, and the cost of repair. As a result of optimization, the best combinations of the order of repairs and assignment of mechanics were obtained, which allowed for the minimization of costs and average service time.

In the first part of Table 2, which shows the results without optimization, the order of repairs was based on standard values, resulting in higher costs and longer service time.

In the second part of Table 2, which shows the minimization of average service time, the repair time of individual malfunctions was adjusted so that the average service time was minimized. In some cases, it was necessary to increase the number of mechanics. As a result of optimization, the average service time was reduced, while the cost of repair was similar to the case without optimization. In the third part of Table 2, which shows the minimization

Table 2 Results of optimization of the order of car servicing and allocation of mechanics for minimizing costs and average repair time

Repair order	Without optimization		Min. average service time		Min. total cost	
	Type of failure	Number of mechanics	Type of failure	Number of mechanics	Type of failure	Number of mechanics
1.	1	1	1	2	20	2
2.	2	1	20	2	19	2
3.	3	1	6	2	18	2
4.	4	1	2	1	17	1
5.	5	1	19	1	14	1
6.	6	1	5	2	7	1
7.	7	1	16	1	10	1
8.	8	1	14	2	13	2
9.	9	1	17	2	6	2
10.	10	1	15	2	8	2
11.	11	1	4	2	15	2
12.	12	1	3	1	16	1
13.	13	1	13	2	4	2
14.	14	1	18	1	5	1
15.	15	1	11	1	12	1
16.	16	1	7	2	2	1
17.	17	1	8	1	9	1
18.	18	1	9	2	11	2
19.	19	1	12	1	3	1
20.	20	1	1	1	1	1

of costs, the repair time of individual malfunctions was adjusted so that the cost of repair was minimized. In some cases, it was necessary to reduce the number of mechanics. As a result of optimization, the cost of repair was reduced, but the service time was slightly longer than in the case of minimizing the average service time.

The production time depends on many factors, including the materials used, tools, machines, operator skills, etc. In the calculations presented, the process time was described by a Uniform distribution function, which randomly selects any numbers from a specified range according to Table 1. The strategy of uniform distribution covers numbers with decimal places (FlexSim, 2017). Therefore, for the obtained optimal solution, 10 repetitions (replications) were performed, and confidence intervals for service costs and average execution time were obtained. The graphical interpretation in the form of charts for three optimization cases is presented in Fig. 8.

The presented results were determined as a 95% confidence interval for the phenomenon under investigation. In practice, this means that with 95% probability, it can be said that the unknown population parameter (in this case,

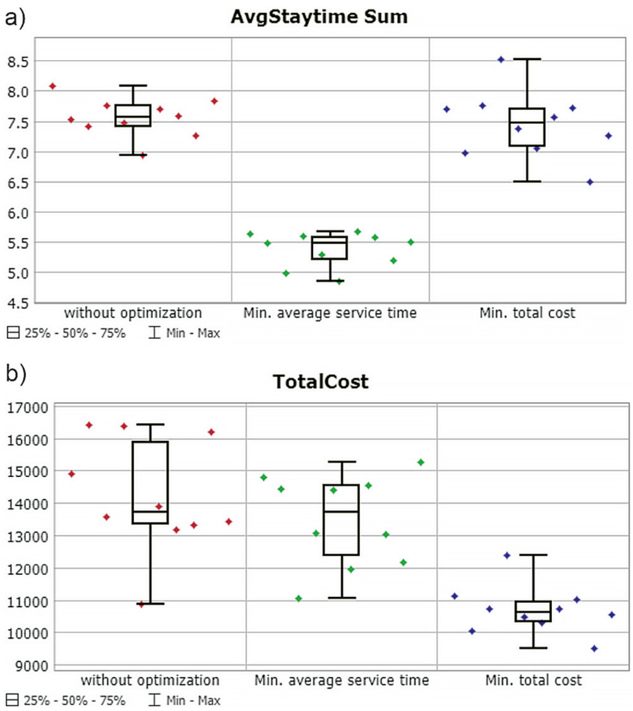
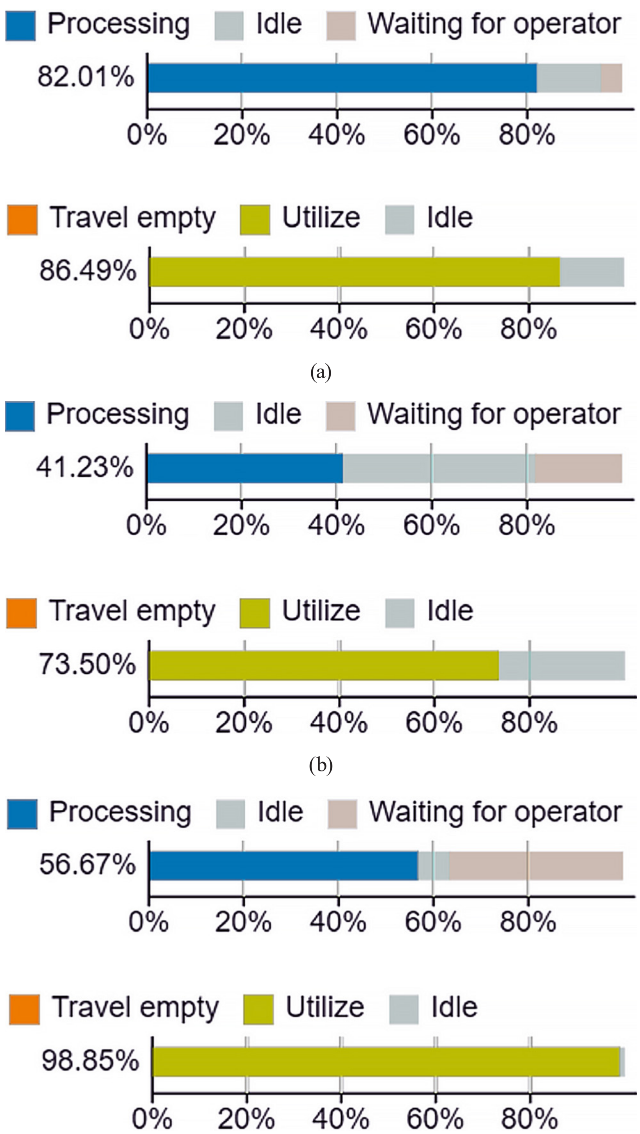


Fig. 8 Confidence intervals for: a) average service time [h], b) service costs [monetary units]

the cost and production time) will fall within the determined numerical range.

Fig. 9 shows the utilization of service stations and mechanics in three different scenarios: a) without optimization, (b) minimizing the average service time, (c) minimizing service costs. The figures show the total utilization of all workstations at the top and the utilization of all mechanics at the bottom.

In Fig. (a), the case without optimization is presented, where workstations are used at 80% and mechanics at 86%. This means that despite having free resources, employees are not fully utilized, which leads to inefficiencies in the workshop's operations.



(c)

Fig. 9 Utilization of service stations (at the top) and mechanics (at the bottom): a) without optimization, b) minimization of average service time, c) minimization of service costs]

In Fig. (b), a random minimization of the average service time is shown, where workstations are utilized at 41% and mechanics at 73%. In this case, workshop resources are used more efficiently, as some repairs are carried out by several mechanics simultaneously, leading to faster task completion.

In Fig. (c), the minimization of service costs is shown, where workstations are utilized at 57% and mechanics at almost 99%. In this case, the use of resources is the most efficient because costs are minimized, and mechanics are fully utilized, leading to more efficient workshop operations.

The differences in the utilization of resources between the individual cases result from the fact that in case (a), each fault was repaired by one mechanic, while in cases (b) and (c), several mechanics worked on the repair of one car simultaneously, which led to better use of time and resources.

Fig. 10 shows a repair schedule for individual cars, using a Gantt chart, which is a graphical tool for displaying time schedules. The optimization based on cost minimization was applied in this schedule.

The horizontal axis represents time, expressed in hours. The vertical axis shows individual cars whose repairs have been planned. For each car, the assigned tasks, i.e., repairs of individual faults, are marked on the chart.

The Gantt chart also shows five workstations labeled as Processor 1 to 5, where car repairs are carried out. For each workstation, the chart shows the time when it is used to perform repairs.

By using this schedule, the workshop manager can control and monitor the progress of work and the time required for individual repairs, which allows for minimizing costs and optimizing the workshop's work.

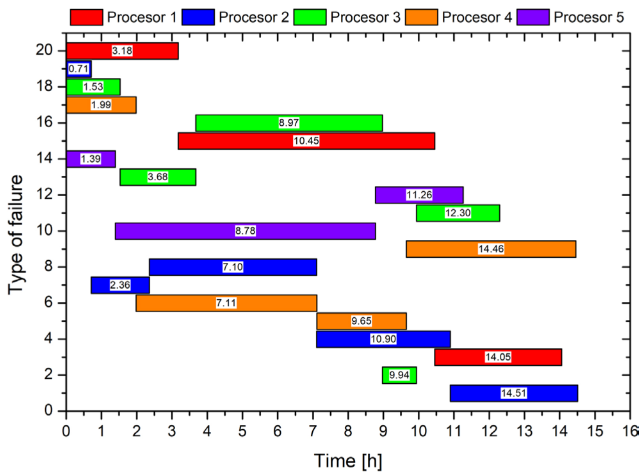


Fig. 10 Repair schedule for individual cars presented on a Gantt chart optimized for cost minimization objective

5 Conclusion

The decision support method for managing the work schedule in a car repair shop presented in the article is based on the use of a simulation model that allows testing various scenarios and selecting the optimal schedule. It is worth noting that this method can be applied not only in the automotive industry but also in other industries where planning and managing human and material resources are important. The analysis of the problem in the repair shop presented in the article identifies three main factors influencing low productivity and customer satisfaction: inefficient and undisciplined planning, improper operator training, and sporadic and inefficient equipment maintenance. By identifying these factors, the article can serve as inspiration for other companies facing similar problems. In addition to production costs, the time of production is also an important aspect because it affects the timely completion of the task. This analysis can also be helpful in the case of custom production, where it is necessary to optimize the process so that customers receive their ordered products in the shortest possible time.

The conclusions of the article confirm that proper planning of work, time, and tasks is crucial for increasing efficiency and productivity, and that adequate operator training and equipment management can prevent errors, increase efficiency, and improve working conditions. It is important to note that the article emphasizes the importance of controlling and changing factors affecting the production process in order to improve the situation.

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