Car Service Optimization Based on Simulation

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Abstract. The article presents the results of optimizing the service center operation. The IDEF3 notation was used to analyze the logical sequence of processes performed in the car center divisions. The developed discrete-event simulation model "AS-IS" made it possible to identify "bottlenecks" in the work of the car center. The involvement of experts and the use of the method of apriori ranking of factors allowed determining the impact of a number of factors on the work of the service center and the directions for improving the work. Changes in organizational, material and technical factors and the development of "TO-BE" simulation model allowed determining the optimal parameters for the service center operation. As a result of the business process reengineering, the following changes were made: staff schedule and assignment of employees to work; the number of service posts; an electronic queue and document management system. These changes allowed increasing the profit of the service center by 1.9 times.

1. Introduction
Optimization is a method of finding the best solution of many options available. The best way to find such an option is to compare all possible ones. For production systems, optimization criteria can be: costs, profit, time, output volumes, etc. [1].

The efficiency of the service center is determined by the following indicators: the customer's time spent on servicing and waiting in line; the number of post-repair complaints; the reliability of service; the cost of services; profit [2, 3]. The following parameters can be changed to achieve optimal values: organizational, material and technical, technical and economic, and other parameters of the car center operation.

The vehicle fleet in Russia increases every year. In 2020, it will be 58.7 million units. The largest segment of the fleet consists of passenger cars. The largest share in the vehicle fleet is occupied by passenger cars (44.5 million units) with a service life of more than 10 years [4]. Thus, the demand for car services is obvious.

Simulation modeling is the process of modeling the real system behavior, experimenting with a model to understand the functioning of this system within certain limitations and identify optimal parameters of operation [5]. Simulation allows one to implement discrete-event and agent models, system dynamics models. In addition, hybrid simulation models combining two or more methods have recently been used to study complex systems [7]. Simulation models used in emulation mode allow evaluating the effectiveness of production systems control. However, the accuracy of such a model depends on the completeness of the information used in the development of the model [8].

Simulation modeling is successfully used to evaluate the performance of service and dealer car centers. The developed simulation model in [9] allowed determining the number of service channels (posts) for a service station. Models with the technological sequence of service station processes are presented in [10, 11]. In [12], the optimal form of organizing a dealer and service center was chosen based on the number of service posts and the number of workers. However, these papers do not
provide an economic justification. Besides, the models consider certain aspects in service center operating.

The method of apriori factor ranking allows identifying the influence of each factor (by rank value) on the process under consideration based on expert assessments. The apriori ranking method is successfully used in risk assessment [13, 14], determining the development strategy [15], etc. The combined use of the method of expert assessments and simulation modelling allowed developing an effective strategy for managing a transport organization [16].

The purpose of this work is to assess the impact of organizational and logistical factors on the parameters of the service center and choose the best ones. Choosing the optimal parameters will allow reengineering the business processes operating in the service center.

2. Process description and problem statement

The service center consists of two structural divisions. One of the divisions provides maintenance and repair services, performs all types of diagnostics and repairs. Another structural division carries out car washing. The service center provides services to the population and organizations that have concluded service contracts. Table 1 shows the production operations performed in the maintenance and repair division. Table 2 shows the operations in the car wash division.

| Process name in the model       | Operation execution time |
|---------------------------------|--------------------------|
|                                 | Minimum, min | Maximum, min |
| Enter the parking lot           |              |              |
| Specify the reason for visiting | 5            | 10           |
| Draw up a service contract      | 15           | 25           |
| Drive the car in a service site | 7            | 10           |
| Auto diagnostics                | 20           | 60           |
| Specify the scope of repairs    | 5            | 10           |
| Make an order for car repairs   | 15           | 30           |
| Get the necessary units from the warehouse | 15  | 30 |
| Perform repairs                 | 60           | 180          |
| Check the work done             | 20           | 45           |
| Sign documents and pay          | 6            | 10           |
| Take the car to the parking lot | 5            | 8            |

| Process name in the model       | Operation execution time |
|---------------------------------|--------------------------|
|                                 | Minimum, min | Maximum, min |
| Enter the parking lot           |              |              |
| Sign a car wash agreement and pay | 6         | 10           |
| Drive to the car wash           | 5            | 8            |
| Wash the car                    | 30           | 60           |
| Take the car to the parking lot | 6            | 8            |
| Check the work done             | 5            | 10           |

The maintenance and repair division receives both public cars (randomly – once every 90 minutes, from 1 to 2 cars can arrive at a time) and corporate cars (randomly – 1 in every 240 minutes). Arriving vehicles of organizations have a priority in service. They are served out of turn. In the wash division, cars arrive in a uniform distribution with a minimum value of 40 minutes and a maximum value of 70 minutes.

To achieve this research purpose, the following tasks are to be performed:
1. Based on expert assessments, identify problems in the operation of the service center and consider possible ways to eliminate them.
2. Choose the optimal number of posts for maintenance and repair, as well as auto diagnostics.
3. Choose the optimal number of workers.
4. Determine the profit, the amount of wage for various types of work.

The modeling stages are defined by the set tasks and consist of the following sequence:

1. Describe the flow of work in IDEF3 notation.
2. Develop a "AS-IS" simulation model of the processes.
3. Based on apriori ranking of factors, identify the most significant ones in the operation of the service center.
4. Develop a "TO-BE" simulation model of the processes.

For each simulation model, the following parameters should be defined: the number of served vehicles; the length of the queue; waiting time in queue; average length of vehicle stay in the service center; the workload of employees; size of employees remuneration; income received for work performed.

Table 3 shows the value of hourly wages for employees of the service center. According to the staff schedule, the positions indicated in table 3 are for 1 staff unit. The average price tag for repairs is $650, and car wash work is $120. The simulation models reproduce the operation of the car center in one shift (8 hours).

**Table 3.** The value of operators hourly pays.

| Employee     | Hourly pay for work performed, $ / hour | Hourly pay for forced downtime, $ / hour |
|--------------|-----------------------------------------|------------------------------------------|
| Manager      | 3.5                                     | 3                                        |
| Car locksmith| 4.0                                     | 3.5                                      |
| Auto mechanic| 4.8                                     | 4.0                                      |
| Foreman      | 6                                       | 4.5                                      |
| Director     | 8                                       | 8                                        |

For simulation modeling, the Arena Rockwell software product is used. It allows implementing discrete-event models [17]. IDEF3 notation is performed using the AllFusion software product.

3. **Description of the work flow and development of the "AS-IS" simulation model**

In figures 1 and 2 a description of work flows for two structural divisions of the service center is presented. A feature of models in IDEF3 notation is a logical sequence of work performed.

The feature of the notation shown in figure 1 is two inputs to the process. This is due to the fact that the car center receives for service both cars belonging to organizations and the population. In service, incoming cars have different priority (intersection J1). The J2 intersection determines whether or not there is a node that needs to be repaired. The intersection J3 shows that the completion of all previous works allows signing documents and paying for the work performed.

The process model shown in figure 2 is linear in nature and displays the processes performed when washing the car.
Create (Enter the parking lot) modules are used to initiate the procedure for contacting the service center. Assign modules allow giving a new value to attributes of entities that pass through these modules. The subsequent Process (Clarify the reason for contacting) module primarily processes entities with high priority (organization cars).

The introduced additional modules Decide (Whether to leave the queue) set the conditions "2-way by Condition". If the queue is more than one car, then customers leave the car service. These modules are used in the model of two service flows for a service center.

Hold modules hold entities until resources performing subsequent maintenance and car wash operations in the corresponding processes are free.

The Decide (The ability to carry out repair work) module sets the condition "2-way by Chance – 70%". Maintenance and repair services are provided to only 70% of the applying customers. 30% of customers is refused in it due to the lack of necessary nodes and components, after auto diagnostics and updating the scope of repair work.

4. Results of "AS-IS" simulation and identification of significant factors affecting the operation of the service center
During the simulation of the car service center (8 hours), 9 cars applied for the car wash service, 7 of them were serviced, and 2 cars left without waiting for the service. 2 cars of organizations and 6 cars of individuals applied for the service of maintenance and repair; 4 cars of the applied ones left without waiting for the service. In addition, 2 cars were not repaired due to the lack of necessary components. Thus, for the car wash division, the number of unserved cars was 22%, and for the maintenance and repair division, the number of unserved cars was 75% of the number of applicants. The efficiency of the maintenance and repair division is extremely low. The amount of profit for the car wash division was $ 840, and for the maintenance and repair division it was $1300.

Figure 4 shows the report on the "AS-IS" simulation model with the total average time from 43.608 to 162.01 minutes spent by vehicles in the service center. The waiting time for cars varies from 18.2588 to 60.7535 minutes. The employee load factor varies from 0.8723 (car mechanic) to 0.04148552 (director), i.e. the employee load is very uneven.

The economic parameters of the model are determined by the labor payment, which consists of the one for work performed (Bust Cost) and for forced downtime (Idle Cost) (figure 5), as well as profit from the sale of services. The amount of remuneration is $ 197.55 ($84.64 is payment for work, $ 112.91 is payment for forced downtime). The net profit is $ 1942.44.

When using the method of expert assessments, to identify significant factors that affect the operation of the service center, experts (specialists in the transport industry) were asked to answer the questions. Four experts were interviewed. During the survey, the experts ranked the factors from 1 (least significant) to 12 (most significant).

Table 4 shows the total rank for each factor, obtained by summing the expert ratings. To assess the agreement of experts’ opinions, the concordance coefficient was determined:

\[
W = \frac{12S}{m^2(k^2 - k) - m \sum T_j^2}
\]  

(1)

\(m\) is the number of experts interviewed; \(k\) is the number of factors; \(S\) is the sum of square deviations; \(T_j = \sum (r_j^2 - t_j)\); \(t_j\) is the number of identical ranks in the \(j\) – ranking.

\[
W = \frac{12 \cdot 1650}{4^2(12^2 - 12) - 4 \cdot 156} = 0.738
\]

The value of the concordance coefficient is 0.738. We check the significance of the coefficient by the \(\chi^2\) criterion. With a probability of 0.95(95%), \(\chi^2\text{ tabl} = 19.68\), and \(\chi^2\text{ calc} = 32.3\), i.e. \(\chi^2\text{ tabl} < \chi^2\text{ calc}\). Therefore, it can be said that the experts’ opinions are consistent with a 95% probability.

Thus, the method of expert assessments allowed identifying significant factors that affect the operation of the service center. According to experts, factors having a high rank should be eliminated first.
Factors 1 – 3 (table. 4) relate to the organizational parameters of the service center. Their optimal values can be chosen using simulation modeling. The use of electronic document flow will reduce the time required for drawing up contracts and the number of approvals. In addition, the document flow will be more understandable. The use of an electronic system for recording maintenance and repairs will eliminate queues or downtime in the service center, i.e. it will ensure a uniform flow of requests for repairs.
Revision of technological operations is carried out on the basis of timekeeping and when replacing part of the technological equipment. Timekeeping will eliminate non-production losses of working time, and the replacement of equipment will increase labor productivity. At the same time, professional development of employees is an important factor.

Conclusion of contracts for long-term car maintenance will allow having a more complete picture of the technical condition of the serviced fleet. This, in turn, will allow predicting the needs for the necessary components.

**Table 4.** Results of expert evaluations.

| №   | Factors                                                        | Total rank |
|-----|---------------------------------------------------------------|------------|
| 1   | Increasing the number of maintenance and repair posts         | 43         |
| 2   | Reallocating employees for work                              | 45         |
| 3   | Increasing the number of employees                           | 24         |
| 4   | Using electronic document flow                                | 36         |
| 5   | Using an electronic appointment system for maintenance and repairs | 31         |
| 6   | Reviewing technological operations                            | 29         |
| 7   | Increasing the range of nodes stored in the warehouse         | 6          |
| 8   | Using a fast delivery system for necessary nodes             | 9          |
| 9   | Predicting the need for required nodes                       | 24         |
| 10  | Concluding contracts for long-term car maintenance            | 26         |
| 11  | Professional development of employees                        | 26         |
| 12  | Assessment of the car’s post-repair condition (phone call to the customer) | 13         |

5. Development of the "TO-BE" simulation model

Table 5 shows the production operations performed in the maintenance and repair division after the business process reengineering.

**Table 5.** Production operations performed in the maintenance and repair division after the business process reengineering.

| Process name in the model | Operation execution time Minimum, min | Maximum, min |
|---------------------------|---------------------------------------|--------------|
| Enter the parking lot     | -                                     | -            |
| Clarify the reason for contacting | 1                        | 3            |
| Draw up a service contract | 7                                     | 15           |
| Drive to the service site | 3                                     | 5            |
| Auto diagnostics          | 20                                    | 30           |
| Specify the scope of repairs | 5                                  | 7            |
| Perform repairs           | 40                                    | 120          |
| Check the work done       | 15                                    | 20           |
| Sign documents and pay    | 3                                     | 5            |
| Take the car to the parking lot | 3                          | 5            |

Vehicles are submitted to the maintenance and repair division on the basis of a single electronic queue, by appointment. Car service is available in 80 minutes. For the car wash division, there is also an electronic queue with an interval of 70 minutes.

Predicting the need for the necessary nodes and components allowed reducing the share of customers not provided with the repair service due to the lack of necessary ones to 5% (the Decide (The ability to
carry out repair work) module sets the condition "2-way by Chance – 95\%”). Figure 6 shows a simulation model for the "TO-BE" process of the service center.

Figure 6. Simulation model for the "TO-BE" process of a service center.

6. Results and discussion
The developed "TO-BE" simulation model for the service center allowed one to determine the optimal parameters for the following indicators: the number of posts for maintenance and repair, as well as auto diagnostics; the number of employees. The report on the simulation experiment results with the selected optimal parameters is shown in figure 7.

During the simulation of the car service center (8 hours), 7 cars applied for maintenance and repair services, of which 1 car was not repaired due to the lack of necessary nodes. In addition, 1 car was in the process of working (Check completed work module). Thus, 5 cars were fully serviced in the maintenance and repair division for 8 hours of service center operation. The number of posts for maintenance and repair has been increased to 3. Posts for auto diagnostics were left unchanged in the amount of 1 piece. The maximum waiting time in the queue before repair work (Carry out repair work module) is 22.19 minutes.

In the car wash division, 7 cars applied for the service, and 6 cars were serviced. The number of car wash posts remained unchanged. There are no queues in the division.

The number of employees involved in these production processes has not been changed significantly – car mechanic (three people). The director stopped approving contracts and was excluded from these processes. The employee load factor (figure 7) varies from 0.31 for the manager to 0.89 for the auto mechanic.

The report in figure 7 shows that the total average time spent by vehicles in the service center is from 71.2737 to 166.26 minutes. The waiting time for cars varies from 0.2942 to 25.5883 minutes.

The economic parameters of the model are determined by the labor payment, which consists of the one for work performed (Bust Cost) and for forced downtime (Idle Cost) (figure 7), as well as profit on the sale of services. The amount of remuneration is $208.79 ($160,33 $ is payment for work, 48.46 $ is payment for forced downtime). The amount of profit for the car wash division was $720, and for the maintenance and repair division it was $3250. Thus, the net profit was $3761.21. In compare with the "AS-IS" process, where the net profit is $1942.44, the economic efficiency of business processes reengineering operating in the service center was $1818.77 per shift (8 hours).
Conclusion

Using the IDEF3 notation allowed understanding the logical sequence of processes performed in the service center divisions. The involvement of experts and the use of the method for apriori ranking of factors allowed determining the impact of a number of factors on the work of the service center and the directions for improving the work.

The use of such methods as timekeeping, automation of production processes, reallocation of work, and professional development of employees allows increasing productivity, i.e. reducing the time to perform operations. The division of the production process into the main and auxiliary ones made it possible to exclude such operations as "Get the necessary units from the warehouse" and "Make an order for car repairs". This made faster the customer service process. The electronic queue ensures
uniform receipt of cars for repairs and allows not losing customers. The use of electronic document management allowed reducing the time for signing contracts.

The performed discrete-event simulation allowed building the "AS-IS" and "TO-BE" models and evaluate the dynamics of changes. The best option is a service center that uses 3 posts for maintenance and repair. The optimal number of employees is 6 people. This organization of the service center will increase the profit from 1942.44 $ ("AS-IS" model) to 3761.21 $. ("TO-BE" model), i.e. by 1.9 times. The number of serviced vehicles in all structural divisions increased by 22% (from 9 to 11 units). The waiting time for cars in the queue, as a result of business process reengineering, changed from 18.2588 – 60.7535 minutes to 0.2942 – 25.5883 minutes. Thus, the optimal parameters of the service center operation were obtained.

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