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im. IGNACEGO ŁUKASIEWICZA

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KAZIMIERZ LEJDA, PAWEŁ WOŚ

Seria: INŻYNIERIA MECHANICZNA

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BEZPIECZEŃSTWO I MATERIAŁY EKSPLOATACYJNE

WYBRANE ZAGADNIENIA

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10. DETERMINATION OF EFFICIENCY OF OPTIMIZATION MEASURES IN THE CAR SERVICE SYSTEM

TARANDUSHKA Liudmyla, KOSTIAN Nataliia, RUD Maksym, LAVRYK Ivan, MATEICHYK Petro

The paper investigates the problem of determining the socio-economic efficiency of the car service system at the macro level. A mathematical model has been developed to calculate the efficiency function of a car service system in a general way, taking into account fifteen morphological features of the system. The multiple regression equation has been constructed, which makes it possible to determine the dependent parameters of the system through its basis. The parametric identification of the components of the socio-economic efficiency function for specialized car service enterprises has been carried out. Indicators of socio-economic efficiency before and after optimization of a specialized car service company have been determined.

INTRODUCTION

Car service systems provide support for the technically sound condition of vehicles. A high-quality execution of technological processes within the framework of the system is the key to its competitiveness in the car service market. Therefore, the optimization of operation of car service systems is an urgent task requiring a solution based on a scientific approach and modern technologies. The process of optimizing the functioning of car service systems should be preceded by a process of determining the effectiveness of the proposed changes. To describe car service systems in work [1], a list of essential parameters was proposed and a morphological matrix was formed, which makes it possible to describe $5{,}6\cdot 10^{11}$ variants of morphological structures of car service systems and to determine the level of quality of technological processes in these structures. To limit the number of morphological structures, it is appropriate to determine the optimal parameters of the system state, taking into account not only the quality of the technological processes, but also the socio-economic efficiency of the car service.

Periodic optimization of the functioning of car service systems allows to update the production and technical facilities, improve the qualifications of the personnel, and, accordingly, ensure the competitiveness of the system in the market. Therefore, an important stage of the study is the development of a methodology for determining socio-economic efficiency, taking into account the parameters describing the system state.

ANALYSIS OF LAST RESEARCHES AND PUBLICATIONS

In work [2], to improve operations performance, the methodology related to an increase in the level of the production and technical facilities use of a car service center is considered, ensuring the implementation of the service segments performed more often. Therefore, in the algorithm for efficiency determining, only the parameters characterizing the segment of the most frequently performed services are considered. The author [3] defines the production efficiency through the criteria of the car service efficacy: the socio-economic efficiency of a car service, meeting the consumer needs, meeting social needs, efficient use of resources. However this work does not contain reference to the parameters characterizing the entire car service system. In work [4], a method for calculating the synergistic effect of a service system is proposed, which is aimed at long-term relations between vehicle owners and a car service company. The paper [5] shows the main contradictions and reasonable goals and priorities for the development of the national industry in the plane of world trends, the quality of domestic industrial policy, innovation and technological, financial and investment, organizational and production, personnel and environmental problems. The author [6] argues that the car service system is likely to operate more efficiently if it is based on advanced training of employees, applying innovative servicing technologies for vehicle maintenance and repair, improving methods and forms of work organization, as well as improving self-control. However, the work lacks the method for efficiency calculation. In work [7] it is noted that in order to increase the operation efficiency of a car service enterprise, it is advisable to keep equipment in a technically sound condition and regularly update the software, thereby reducing the cost of maintenance and all types of repairs.

PARTS OF GENERAL PROBLEM, WHICH WEREN'T SOLVED BEFORE

In modern market conditions, car service systems must perform technological processes efficiently and at the same time be economically and socially effective. Therefore, the optimization of the car service system functioning is the key to improving the quality of technological processes. This goal can be achieved by developing a methodology for determining the socio-economic efficiency of the system functioning before and after optimization, taking into account the parameters describing the system.

Currently, a large number of scientific studies have been implemented, the results of which contain structural models developed by the authors that reflect various aspects of a car service enterprise functioning [8-11], but despite this, the construction of a method for determining of their functioning efficiency remains relevant.

The object of the research is methods for determining the functioning efficiency of a motor transport enterprise.

The purpose of the research is to develop a methodology for determining the socio-economic efficiency of a car service system functioning at the macro level based on parameters corresponding to the morphological characteristics of functional elements.

To achieve this goal, the following tasks were solved:

- mathematical formulation of the problem of determining the socio-economic efficiency of a car service in general, taking into account the parameters of the system at the macro level;
- obtaining analytical expressions for calculating the input parameters of the model in the form of linear multiple regression equations;
- identification of the mathematical model of the social and economic efficiency function for a typical car service system;
- calculation of the criterion for the feasibility of implementing the target quality level for a specialized car service system at the macro level.

PRESENTATION OF THE MAIN RESEARCH MATERIALS

The analysis of the feasibility of the implementation of optimization activities is based on the calculation of the value of the increase in the indicator of the socio-economic efficiency of the car servicing in car service systems. In [1], the authors determined a set of input parameters of the car service system model at the macro level: x_1 is the type of a car service company, x_2 is the capacity of the car service company, x_3 is the level of space availability, x_4 is the level of the technological equipment availability, x_5 is the level of personnel availability, x_6 is the level of material resources availability, x_7 is the level of information support, x_8 is the level of environmental safety, x_9 is the form of production organization, x_{10} is the gross vehicle weight, x_{11} is the type of a power plant, x_{12} is the vehicle age, x_{13} is the location, x_{14} is the population density, x_{15} is the level of motorization, x_{16} is the capacity saturation, x_{17} is the level of logistics potential, x_{18} is the customer loyalty coefficient, x_{19} is the income level of vehicle owners. The parameters x_1, x_2, x_9-x_{16}, x_{19} are qualitative and equal to the number of the implementation variant of the corresponding morphological characteristic, and x_3 – x_8, x_{17}, x_{18} are quantitative ones. The quality level of technological processes K_q is taken as an initial parameter of the system.

It is proposed to determine the socio-economic efficiency of a car service according to the criterion of the feasibility of implementing the target level of quality, which is calculated as a function of the car service income and the total customer expenses of the received services [12]:

$$E_f = f(I, Ex), \qquad (1)$$

Where:

I - the income of the car service per year;

Ex - customer expenses of the services per year.

Components (1) in the general case depend on the parameters of the system; therefore, the model presented in [12] should be refined taking into account the results of the study of various types of car service systems. The income of a car service in the area of the client's radius is calculated using the formula (2):

$$I = N_p \cdot C_c \cdot P_{cc}, \tag{2}$$

Where:

$N_p = f_1(x_2)$ - the number of posts in the car service system;

$C_c = f_2(N_c, Age_c) = f_2(x_{12}, x_{14}, x_{15})$ - the average number of car-races per one post per year, car-check-in / post;

N_c - the number of cars in the service area;

$Age_c = x_{12}$ - an average age of cars;

$P_{cc} = f_3(x_4, x_5, x_6)$ - an average price of one car-check, UAH / car-check.

The expenditures incurred by clients in the area of the client radius per year are calculated using the formula (3):

$$B = K_{call} \cdot [L_{km} \cdot P_{km} + (T_j + T_{TMP} + T_w + T_{com} + T_{aw} + T_{sp}) \cdot P_t], \tag{3}$$

Where:

$K_{call} = f_4(x_1, x_{18}, K_q) = f_4'(x_1, x_2, x_5, x_9, x_{10}, x_{11}, x_{12}, x_{18}, x_{19})$ - the number of calls from one customer to the car service per year;

L_{km} - a mileage to the service, km;

$P_{km} = f_5(x_{12}, x_{19})$ - the price per kilometer, UAH / km;

$T_j = f_6(R_{cl\,j}, x_{14}, x_{15})$ - the traffic jam time when receiving services, hours;

$R_{cl\,j} = const$ - a client radius within the j-th service field and fields equal in area to it;

$T_{TMP} = f_7(x_4, x_5, x_6, x_7, x_{17})$ - the time of maintenance and repair, hours;

$T_w = f_8(x_2, x_{14}, x_{15})$ - the service waiting time, hours;

$T_{com} = f_9(K_q) = f_9'(x_2, x_5, x_9, x_{10}, x_{11}, x_{12}, x_{19})$ - the time spent on complaints, hours;

T_{aw} - the time spent on solving additional maintenance procedures, hours;

$T_{sp} = f_{10}(x_2, x_{17})$ - the time spent on finding and delivering spare parts, hours;

$P_t = f_{11}(x_{19})$ - the price of a unit of time, UAH / hour.

The time spent on the search and delivery of spare parts, T_{sp} is determined as the sum of the unit time spent on the supply of spare parts from a private warehouse, from a regional warehouse and from a manufacturer [9]. Thus, the following formula was applied to calculate T_{sp}:

$$T_{sp} = \alpha \cdot tA_S + \beta \cdot tB_S + \gamma \cdot tC_S, \tag{4}$$

Where:

α, β, γ is the particles of spare parts of categories A, B and C supplied from a private warehouse, from a regional warehouse and from a manufacturer, respectively;

tA_S, tB_S, $tC_S = f_{12}(x_2, x_{17})$ - an average delivery time for spare parts of category A from a private warehouse, category B from a regional warehouse, category C from a manufacturer, respectively.

Thus, when (3) - (4) are substituted into formula (2), the following analytical expression is obtained for calculating the socio-economic efficiency of the functioning of the car service system at the macro level:

$$E_f = f_1(x_2) \cdot f_2(x_{12}, x_{14}, x_{15}) \cdot f_3(x_4, x_5, x_6) - f_4'(x_1, x_2, x_5, x_9, x_{10}, x_{11}, x_{12}, x_{18}, x_{19}) \cdot$$
$$[L_{km} \cdot f_5(x_{12}, x_{19}) + \left(f_6(R_{cl\,j}, x_{14}, x_{15}) + f_7(x_4, x_5, x_6, x_7, x_{17}) + f_8(x_2, x_{14}, x_{15}) +\right.$$
$$\left. + f_9'(x_2, x_5, x_9, x_{10}, x_{11}, x_{12}, x_{19}) + T_{aw} + f_{10}(x_2, x_{17})\right) \cdot f_{11}(x_{19})]. \quad (5)$$

In the work [1], the authors established that $x_2, x_5, x_9, x_{10}, x_{11}, x_{12}, x_{19}$ is the basis of the system, therefore all other parameters are expressed through them. On the basis of statistical data [1], the equation of the linear multiple regression [13] was obtained for the dependent parameters of the system included in functions (5), which in a general way for the j-th dependent parameter can be represented as follows:

$$x_j = a_0^j + a_2^j x_2 + a_5^j x_5 + a_9^j x_9 + a_{10}^j x_{10} + a_{11}^j x_{11} + a_{12}^j x_{12} + a_{19}^j x_{19}.$$

The coefficients in front of the basic variables in the corresponding regression equations are given in table. 1.

Table 1. Coefficients of linear equations for determining dependent parameters included in the functions of socio-economic efficiency

Dependent parameter x_j	Regression coefficients for independent parameters							
	a_0^j	a_2^j	a_5^j	a_9^j	a_{10}^j	a_{11}^j	a_{12}^j	a_{19}^j
x_1	0,82166	0,77471	-1,68673	0,02865	0,27801	-0,57500	0,30085	0,77626
x_4	0,90198	-0,03403	0,41598	0,00883	0,03057	0,03235	-0,17425	-0,04044
x_6	-0,14023	0,02198	0,32502	0,04112	0,16201	0,04675	-0,05086	-0,06524
x_7	0,01963	0,08383	0,04411	-0,00345	0,13682	0,03629	-0,06833	0,00953
x_{14}	1,61422	-0,12798	0,80125	0,06280	0,41621	0,18354	0,04965	-0,10589
x_{15}	1,55743	0,06793	-0,09093	0,35889	0,10519	0,08030	-0,23656	-0,09888
x_{17}	0,34481	-0,00259	0,11979	0,00335	0,05817	0,04660	-0,02721	-0,00762
x_{18}	1,24184	-0,00660	0,10446	-0,01036	-0,00583	0,03626	-0,24313	-0,04969
K_q	0,50551	0,01372	0,22627	0,02162	0,0796	0,01524	-0,1229	-0,01889

Based on the results of an experimental study of specialized car service enterprises in [1], the authors built a nonlinear mathematical model of the Sugeno type for a car service system at the macro level. Following from this model, the optimal values of independent parameters of typical car service systems are determined. An example of visualization of the optimal operating modes of a subsystem corresponding to a functional element of a "car service enterprise" of a specialized car service system is shown in Fig. 1.

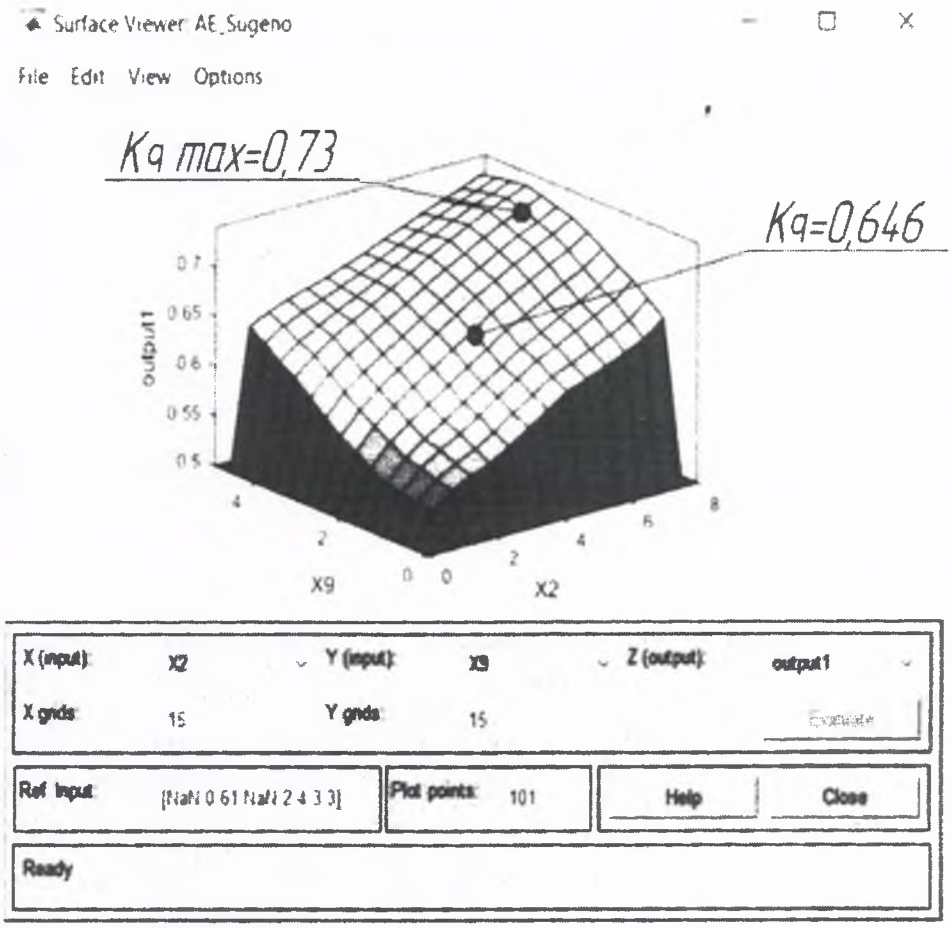

Figure: 1. Dependence of K_q on power (X_2) and the form of production organization (X_9) of a specialized car service enterprise.

Based on the information about the optimal morphological structure of a specialized car service system and data from Table 1, analytical expressions for the functions $f_1 - f_{11}$ are obtained (Table 2).

The proof of the expediency of carrying out optimization measures in order to obtain the maximum quality level of technological processes was carried out on the example of a specialized auto service enterprise "Autoreika", Cherkasy. The output parameters for calculating efficiency indicators for production optimization and after optimization are given in table. 3.

Table 2. Analytical expressions of the components of the function of socio-economic efficiency

$f_j(X)$	Analytic view
$f_1(X)$	$1,33 + 1,67x_2$
$f_2(X)$	$-192,75 + 465x_{12} - 96,375x_{14} - 88,875x_{15} = -486,737 + 6,29658x_2 - 69,1391x_5 -$ $-37,9492x_9 - 49,4612x_{10} - 24,8252x_{11} + 481,24x_{12} + 18,9932x_{19}$
$f_3(X)$	$-12164 + 19438x_4 + 4644x_5 - 13192x_6 = 7218,683 - 954,499x_2 + 8442,104x_5 -$ $-370,709x_9 - 1542,99x_{10} + 12,09033x_{11} - 2716,28x_{12} + 74,54599x_{19}$
$f_4'(X)$	$0,2 - 0,05645x_1 - 1,85x_{18} + 5,2K_я = 0,48489 + 0,03983x_2 + 1,07859x_5 + 0,12999x_9 +$ $+0,40902x_{10} + 0,04463x_{11} - 0,20629x_{12} - 0,05012x_{19}$
$f_5(X)$	$0,84444x_{12} + 2,48889x_{19}$
$f_6(X)$	$0,16 + 0,01R_{кл} - 0,08x_{14} - 0,03x_{15} = -0,01586 + 0,0082x_2 - 0,06137x_5 - 0,01579x_9 -$ $-0,03645x_{10} - 0,01709x_{11} + 0,00313x_{12} + 0,01144x_{19} + 0,01R_{кл}$
$f_7(X)$	$-5,4 + 3,1x_4 - 11,625x_5 + 31,2x_6 - 21,2x_7 + 3,5x_{17} = -6,188474 - 1,205919x_2 -$ $-0,710652x_5 + 1,395129x_9 + 2,4524803x_{10} + 0,9526787x_{11} - 0,773554x_{12} - 2,389633x_{19}$
$f_8(X)$	$0,8 - 0,015x_2 + 0,295x_{14} - 0,073125x_{15} = 1,162308 - 0,05772x_2 + 0,243019x_5 -$ $-0,00772x_9 + 0,11509x_{10} + 0,048272x_{11} + 0,031944x_{12} - 0,02401x_{19}$
$f_9'(X)$	$0,302 - 0,4K_q = 0,099794 - 0,00549x_2 - 0,09051x_5 - 0,00865x_9 - 0,03184x_{10} -$ $-0,0061x_{11} + 0,049161x_{12} + 0,007556x_{19}$
$f_{10}(X)$	$-5,84464x_2 + 66,12662x_{17} = 22,8011 - 6,01563x_2 + 7,921351x_5 + 0,221792x_9 +$ $+3,846347x_{10} + 3,081714x_{11} - 1,79944x_{12} - 0,50401x_{19}$
$f_{11}(X)$	$-424 + 181x_{19}$

The increase in the indicator of socio-economic efficiencyΔE_f is defined as the difference between the corresponding indicators of efficiency before and after optimization of the car service system. Thus, the criterion for the feasibility of implementing the target quality level is determined by the following expression:

Table 3. Values of socio-economic efficiency indicators before and after optimization of the car service system

№	Parameter designation	Before optimization	After optimization	№	Parameter designation	Before optimization	After optimization
1	$N_p = f_1(X)$	8	13	12	tA_S	0,15	0,15
2	$C_c = f_2(X)$	741	756	13	tB_S	6	6
3	$P_{cc} = f_3(X)$	750	863	14	tC_S	312	168
4	$K_{call} = f_4'(X)$	1	0,6	15	α	0,7	0,7
5	L_{km}	5	7	16	β	0,24	0,25
6	$P_{km}=f_5(X)$	10	10,8	17	γ	0,06	0,05
7	$T_j = f_6(X)$	0,16	0,2	18	$T_{sp} = f_{10}(X)$	20,27	10,01
8	$T_{TMP} = f_7(X)$	2,7	2,5	19	$P_T = f_{11}(X)$	119	300
9	$T_w = f_8(X)$	0,62	0,25	20	I	4446000	8481564
10	$T_{com} = f_9'(X)$	0,03	0,01	21	Ex	3117,23	2739,06
11	T_{aw}	2	2	22	E_f	4442882,78	8478824,94

$$\Delta E_f = \Delta E_{f_2} - \Delta E_{f_1} > 0.$$

Where:

ΔE_{f_1}, ΔE_{f_2} is the socio-economic efficiency of the car service before and after optimization of the car service system, respectively.

With the values of indicators in table. 3 for a specialized auto service enterprise ΔE_f = 4035942.17. That is, the expediency of optimization works for the "Autoreika" car service company has been proven.

CONCLUSIONS

The developed methodology for calculating the socio-economic efficiency of the car service system takes into account fifteen morphological signs of its functional elements. When calculating the predicted values of efficiency, the values of the system parameters optimal in terms of the quality of technological processes were used. To test the proposed methodology, a specialized car service company was selected. The approbation results prove the feasibility of the enterprise work improvement. The annual efficiency of the car service is predicted to increase by UAH 4035942. The research results can be applied in the process of making decisions on the advisability of optimizing the car service system at the macro level.

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OKREŚLENIE SKUTECZNOŚCI ŚRODKÓW OPTYMALIZACYJNYCH SYSTEMU OBSŁUGI SAMOCHODÓW

Streszczenie

W artykule przedstawiono problem określenia społeczno-ekonomicznej efektywności systemu obsługi samochodów na poziomie makro. Opracowano model matematyczny służący do obliczania funkcji wydajności systemu obsługi samochodów. Opracowano równania regresji wielorakiej, które pozwalają na jej podstawie określić zależne parametry układu. Dokonano parametrycznej identyfikacji składowych funkcji efektywności społeczno-ekonomicznej dla wyspecjalizowanych przedsiębiorstw usług samochodowych. Wyznaczono wskaźniki efektywności społeczno-ekonomicznej przed i po optymalizacji wyspecjalizowanego przedsiębiorstwa samochodowego.