Досліджено задачу ідентифікації залежності рівня якості технічного обслуговування та ремонту автомобілів від параметрів, що враховують внутрішній стан автосервісного підприємства та зовнішні фактори, що характеризують середовище його функціонування та автомобілі, які обслуговуються підприємством. В процесі дослідження виконано морфологічний аналіз системи автосервісу, в результаті якого визначено функціональні елементи системи, суттєві морфологічні ознаки даних елементів та варіанти їх реалізації. З метою виявлення ступеня впливу зазначених морфологічних ознак на якість виконання технологічних процесів проведено обстеження типових підприємств автосервісу України та побудовано математичну модель системи у вигляді рівняння лінійної множинної регресії. Завдяки попередній перевірці вхідних параметрів моделі системи на мультиколінеарність за алгоритмом Фаррара-Глобера стало можливим виокремити серед них незалежні та знизити складність подальших розрахунків. Коефіцієнти рівняння регресії характеризують ступінь важливості врахування відповідних параметрів при проектуванні автоматизованої системи управління якістю. Для підвищення адекватності моделі та зменшення складності процесу моделювання виконано розбиття масиву вихідних даних на навчальну та контрольну вибірки за алгоритмом, що базується на розрахунку значень вибіркової дисперсії. З метою отримання найбільш адекватної моделі побудовано нелінійні моделі досліджуваної системи типу Мамдані та Сугено. Для цього застосовано пакет Matlab та його модуль Fuzzy logic Toolbox. Функції належності вхідних та вихідного параметрів задано у трапецієвидному вигляді. Реалізацію нелінійних моделей здійснено для різних методів дефазифікації вихідного параметру. Найменша середньоквадратична похибка результуючої характеристики отримана при реалізації моделі типу Сугено та склала 1,07 %. Це свідчить про доцільність інтеграції зазначеної моделі в систему управління якістю з метою визначення оптимальних режимів роботи. Результати досліджень можуть бути використані для оцінки якості наданих послуг систем автосервісу на мікро- та макрорівні

Ключові слова: автосервісне підприємство, рівень якості, морфологічний аналіз, лінійна множинна регресія, нечітке логічне виведення

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ASSESSING THE QUALITY LEVEL OF TECHNOLOGICAL PROCESSES AT CAR SERVICE ENTERPRISES

L. Tarandushka
PhD, Associate Professor, Head of Department*
E-mail: tarandushkal@ukr.net
V. Mateichyk
Doctor of Technical Sciences, Professor
Department of Ecology and Safety of Vital Functions
National Transport University
M. Omelianovycha-Pavlenka str.,1, Kyiv, Ukraine, 01010
E-mail: wmate@ukr.net
N. Kostian
PhD*
E-mail: 348knl@gmail.com
I. Tarandushka
Assistant*
E-mail: tarandushka@ukr.net
M. Rud
PhD, Associate Professor*
E-mail: hochspannung77@gmail.com
*Department of Vehicles and Technology of Their Operation
Cherkasy State Technological University
Shevchenka blvd., 460, Cherkasy, Ukraine, 18006

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1. Introduction

The economic growth of any country is accompanied by the development of the transportation sector, which ensures the proper functioning of other sectors and industries. Over that period, there is an increase in the fleets operated by legal entities, as well as in the overall level of motorization. Consequently, there is a growing demand for automobile services. All this leads to the emergence of new, as well as the further development of already existing, car service enterprises (CSEs). The competitiveness of car service enterprises directly depends on the completeness and quality of services proposed to vehicle owners.

The recent trend has been the implementation of quality management systems (QMS) at enterprises. Such systems should comprehensively take into consideration both the parameters of a CSE itself and the external factors affecting the quality of services rendered. In addition, some parameters cannot be accurately measured or calculated, so they are assigned a value of qualitative character. All this brings forth additional conditions during the design and practical implementation of this type of system. The automation of QMS requires comprehensive research into a CSE at the micro- and macro levels and is impossible without models that would provide enough accuracy in calculating the current and prospective levels of technological processes. The construction of methods and models for estimating the quality of technological processes would make it possible to control those parameters that influence the operational modes of enterprises and to timely manage them. That could lead to a higher quality level of services rendered and the development of car service systems in general.

Thus, it is a relevant scientific and technical task to devise a procedure for assessing the quality of technological processes at CSEs.

2. Literature review and problem statement

The authors of [1] built a functional model of the process "Service quality control" for CSE and derived a mathematical dependence to calculate the indicators of the current state of an enterprise, which is further recommended to use for determining the optimal development strategy. However, they considered neither the indicator corresponding to the CSE information support nor the external factors. To improve the quality of service rendered by CSE, it was proposed to use a strategy aimed at the reorganization of production, in particular, the rational choice of the form of production. However, the models and procedures for implementing the process of optimizing the CSE activities were not given. That is why work [2] considered the procedure for choosing the optimal form of an enterprise organization. However, there is an unresolved issue related to the software support for the service enterprise restructuring. So, paper [3] proposed the algorithms and computer implementation of the CSE optimization work.

The authors of study [4] believe that the quality of automobile services depends on staff training, the development of innovative services, the use of rules of communication with customers and includes testing a car operation, fault detection, and elimination without client's consent. However, the cited study does not account for the technical capacities of an enterprise, which is a very important factor affecting the quality of rendered services. Work [5] reports the results of studies that prove that the level of customer service quality at car service enterprises is an important characteristic, which influences the efficiency of the production process, that is, it increases profitability and improves customer loyalty. However, there are resolved issues related to the impact of technical support on the quality of services rendered. The reason could be the authors' tasks related only to consumer criteria. An option to overcome the difficulties associated with taking into consideration the entire spectrum of criteria affecting the quality is to compile a public document. This approach was used in paper [6]. The purpose of the cited paper was to make a "single-table" document open, which could guide future researchers in the field of maintenance and repair of automobiles. There, it was proposed to collectively combine research into the field of automobile services. The results of the paper showed that SERVQUAL remains the most popular method of assessing the quality of service and repair of vehicles. The author concluded that the model, based on a customer survey on the received service from a five-measurement perspective, is the basis for the evaluation of services. The list of measurements was defined: reliability, warranty, tangible values, sympathy, and the relevant reaction by manufacturers. However, the degree of influence of each measurement on the quality of services rendered was not determined. The reason could be the imperfection of a mathematical apparatus that solves multi-criteria problems. An option to address this issue was proposed in study [7]. Nine quality factors and their significance were defined there. It is believed that these results can facilitate control over automobile gasoline stations. In the cited study, significant factors are reliability (35.74 %), special features (6.490 %), responsiveness and sympathy (5.741 %), transparency (openness of work) (5.198 %), visual experience (4.402 %), comfort (4.012 %), trust and confidence (3.488 %), communication with customers (3.057 %), additional services (2.803 %). To determine the most influential factors on the quality of services from a customer's perspective, a factor analysis method was applied, as well as Cattell "Scree".

Paper [8] reports the results of studying the successful functioning of car service enterprises and determines that resolving a given issue necessitates the inclusion of after-sales services to the basic offer. They can be divided into three categories: after-sale economics, user requirements, and competitive advantage. However, this only affects the increase in the range of services and does not reflect the way to improve quality.

Work [9] does solve this task. The authors define the quality of performed operations as the base for the economic development of car service enterprises. This also applies to car services of the garage-type. In the cited work, the main opinion is the appropriateness of car service organization based on customer requirements. Quality control is the main factor for the successful production process of car service stations. Paper [10] also leads to the conclusion that customer satisfaction after selling cars is very important for companies to remain competitive in the market. Customer satisfaction is defined as the difference between the received and expected service. However, the evaluation procedure is based on a consumer survey, so the estimates could include errors that are not always within the permissible limits. That is why it is necessary to use the latest techniques for quality assessment. A solution to this task is proposed in work [11–13]. Owing to the development of new procedures and technologies, fuzzy control plays an increasingly important role in modern society. To describe the management processes, work [11] gives a review of the principles for constructing fuzzy sets, fuzzy rules, and fuzzy derivation systems. The authors investigated a series of fuzzy methods used in the design of a control system to manage the fuzzy and online fuzzy systems, as well as the fuzzy control system of the closed-loop, including a search table.

Paper [12] proposed a method based on the use of artificial neural networks in the process of evaluating the quality of transport services to deliver dairy products. A practical experiment proved the high efficiency of the proposed method in the estimation of transportation services (99 % convergence).

The evaluation of service quality often employs an expert method based on the assessment of a service using a specific scale. The 5-point and 7-point scales of the Likert type are used, as well as the semantic differential scales. A distortion of the results may be caused by the respondent's perception of the scale, as well as the cultural differences of respondents. That is why study [13] tackled the feasibility of using fuzzy logic in measuring consumer perception and experts and proposed the use of an unlimited n-dimensional scale to assess service quality. The study results established that people were able to put their estimates at high numerical precision, independently determining the scale size. The linguistic and numerical values can be used to determine the quality of services but the numerical values do not always provide an adequate assessment of the psychological uncertainty. A solution to this problem may be the use of fuzzy sets. This approach was applied in work [14]. Quality management system modeling is an important step for managing the production processes at an enterprise. Thus, work [14] proved that it is convenient, in order to reflect the multi-criteria quality management processes, to apply a mechanism for the construction of fuzzy set rules, which enables the visualization of influence of each criterion on the level of production quality. The cited work addresses the issue of priorities of corrective actions through fuzzy sets and related rules in order to avoid difficulties associated with ambiguous values of certain criteria. The fuzzy quality management approach has been applied to the main production processes at an enterprise producing motorboats. The authors of [15–18] also employ the principles of fuzzy set theory to model a quality management process.

Thus, the results of our analysis of the scientific literature allow us to argue about the lack of a comprehensive list of parameters that characterize the operational performance of CSEs and the absence of procedures that make it possible to assess and forecast the quality level of services rendered, which is important for the development of car service systems. Among the progressive methods of modern research in this field, the most widely applied methods are those based on the use of fuzzy logic.

3. The aim and objectives of the study

The purpose of this research is to determine the character of influence exerted by the car service system's parameters on the quality level of CSE technological processes aimed at its assessment. This would make it possible to investigate the sensitivity of the resultant characteristic of the system to changes in its input parameters and to apply the findings in the forecast process.

To accomplish the aim, the following tasks have been set:

– to perform morphological analysis of the car service system;

– to define a set of independent system parameters;

– to construct a model of the system in the form of a multiple linear regression equation;

– to build the system nonlinear models;

– to choose an adequate model for the quality assessment of technological processes.

4. Materials and methods to study the automobile service system

4. 1. Morphological analysis of the system

The morphological analysis method was applied to determine possible ways of improving the quality of technological processes at CSE. A given method makes it possible to systematize data that characterize the examined system and to analyze its possible configurations. For each of the 19 morphologic attributes of the system, the variants of their implementation have been defined. The morphological features of the automobile service system, the variants of attribute implementation, and their possible values are given in Tables 1, 2.

Table 1

Results of the morphological analysis of the automobile service system for the functional element "CSE"

1. CSE type	2. CSE capacity (number of posts)	3. Level of area availability	4. Level of technological equipment availability	5. Level of personnel availability	6. Level of material resources availability	7. Level of information support	8. Level of environmental safety	9. Production organization form
1. 1. AP 1	2. 1. 1-2 1	3. 1. Very low 0–0.4	4. 1. Low 0–0.6	5. 1. Very low 0–0.4	6. 1. Very low 0–0.4	7. 1. Very low 0–0.4	8. 1. Especially dangerous 0–0.2	9. 1. Post form with universal equipment 1
1. 2. Car repair shop 2	2. 2. 3-4 2			5. 2. Low 0.4–0.6			8. 2. Dangerous 0.2–0.37	
1. 3. AS 3	2. 3. 5-6 3	3. 2. Low 0.4–0.6	4. 2. Medium 0.6–0.8	5. 3. Medium 0.6–0.8	6. 2. Low 0.4–0.6	7. 2. Low 0.4–0.6	8. 3. Medium safe 0.37–0.63	9. 2. Post form with specialized equipment 2
1. 4. Authorized AS 4	2. 4. 7-8 4	3. 3. Medium 0.6–0.8	4. 3. High 0.8–1	5. 4. High 0.8–1	6. 3. Medium 0.6–0.8	7. 3. Medium 0.6–0.8	8. 4. Safe 0.63–0.8	
1. 5. Specialized 5	2. 5. 9-10 5							
1. 6. Complex 6	2. 6. 11-12 6	3. 4. High 0,8–1	4. 4. Excessive >1	5. 5. Excessive >1	6. 4. High 0.8–1	7. 4. High 0.8–1	8. 5. Completely safe 0.8–1	9. 3. Work shop-post 3
	2. 7. >12 7							9. 4. Individual 4

Table 2

Results of the morphological analysis of the automobile service system for the functional elements "Automobiles" and "Environment"

Automobiles			Environment						
10. Automobile full weight	11. Energy unit type	12. Automobile age	13. Location, thousand people	14. Population density, people/sq.km	15. Level of motorization, cars/1,000 people	16. Facility availability, number of stations/sq.km	17. Logistics potential level	18. Loyalty factor	19. Income level of Vs owners
10. 1. To 3.5 1	11. 1. Gasoline & diesel 1	12. 1. Up to 3 years 1	13. 1. Small <50	14. 1. Low <500	15. 1. Low <200	16. 1. Insufficient <5	17. 1. Low 0–0,4	18. 1. Low 0–0,4	19. 1. Low & medium 1
10. 2. To 7.5 2	11. 2 Gas cisterns 2	12. 2. Up to 15 years 2	13. 2. Medium 50–250	14. 2. Medium 500–1,000	15. 2. Medium 200–300	16. 2. Medium 5–10	17. 2. Medium 0.4–0.6	18. 2. Medium 0.4–0.6	19. 2. Medium 2
	11. 3 Electric & hybrid 3		13. 3. Large 250–500	14. 3. High 1,000–4,000			17. 3. High 0.6–0.8	18. 3. High 0.6–0.8	19. 3. Medium & high 3
10. 3 Regardless of weight 3	11. 4. ICE & electric & hybrid 4	12. 3. Regardless of age 3	13. 4. Significant (large) 500–1,000	14. 4. Very high >4,000	15. 3. High >300	16. 3. High >10	17. 4. Very high 0.8–1	18. 4. Very high 0.8–1	19. 4. High 4
			13. 5. Most important >1,000						19. 5. Low & medium & high 5

In Tables 1, 2, the following abbreviations are used: AP – autoservice point; AS – autoservice station; ICE – internal combustion engine.

The combination of different options x_{ij} for the implementation of morphological attributes X_j, where i is the number of an implementation option of the j-th attribute from Tables 1, 2, determine the possible states (structures) of the automobile service system.

The number of the possible states of the system is determined from the following formula:

$$N = \prod_{i=1}^{n} K_i, \qquad (1)$$

where K_i is the number of possible implementation variants of the i-th attribute; n is the number of attributes.

Thus, the number of potential states of the investigated system is

$$N=6\cdot 7\cdot 4\cdot 4\cdot 5\cdot 4\cdot 4\cdot 5\cdot 4\cdot 3\cdot 4\cdot 3\cdot 5\cdot 4\cdot 3\cdot 3\cdot 4\cdot 4\cdot 5=5.57384\cdot 10^{11}.$$

The considered method makes it possible to analyze the system configurations, which are promising for a specific CSE, in order to choose the best strategy for further development. However, it is inappropriate to consider the system states containing the incompatible attribute values. In addition, the analysis of the derived number of variants of the system is not reasonable in terms of time costs.

In the framework of this study, we examined 28 systems of car service typical for Ukraine. Tables 3, 4 give the quantitative indicators of the morphological characteristics of the main functional elements of these systems.

Table 3

Values of the morphological attributes of the investigated systems of car service for the functional element "CSE"

CSE No.	CSE title	CSE type	CSE capacity (number of posts)	Level of area availability	Level of technological equipment availability	Level of personnel availability	Level of material resources availability	Level of information support	Level of environmental safety	Production organization form	Level of technological processes quality
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	K_q
1	2	3	4	5	6	7	8	9	10	11	12
1	JWT Service, Cherkasy	2	2	0.62	1.5	2.42	0.8	0.3	0.4	4	0.92
2	ATL Autoservice, Cherkasy	3	4	0.59	0.97	1.44	0.7	0.8	0.5	1	0.8
3	TOV «Boyard and Co.», Cherkasy	3	1	0.35	0.76	0.4	0	0.2	0.1	4	0.42
4	Kolos-Avto, Cherkasy	6	3	0.85	0.93	1.9	0.52	0.8	0.7	3	0.83
5	TOV «Buros», Cherkasy	4	5	0.72	0.95	0.86	0.6	0.85	0.9	3	0.79
6	DP «CHARS-AVTO", Cherkasy	4	2	0.41	0.92	1.14	0.4	0.5	0.8	3	0.74

Continuation of Table 3

1	2	3	4	5	6	7	8	9	10	11	12
7	JSC CHERKASY-AUTO, Cherkasy	4	7	0.84	0.79	1.79	0.65	0.75	0.8	3	0.73
8	V12, Zolotonosha, Cherkasy region	3	2	0.21	0.69	0.67	0.4	0.35	0.3	1	0.38
9	«Avtoreyka», Cherkasy	5	4	0.65	0.98	0.61	0.7	0.75	0.5	2	0.68
10	Self-service car wash «Shampun», Cherkasy	1	3	0.68	1	1.21	1	0.65	0.3	2	0.93
11	OILER Demiyivka, Kyiv	6	5	0.72	0.97	0.92	0.74	0.8	0.7	3	0.72
12	TOV Dnipromotor, Dnipro	4	3	0.3	0.83	0.72	0.28	0.6	0.7	1	0.64
13	«STO-35 km», Boryspil	6	3	0.35	0.49	0.58	0.25	0.45	0.5	1	0.37
14	Mobile tyre service, Kyiv	1	1	0.17	0.9	0.63	0.53	0.35	0.3	4	0.81
15	PE «Garage», Cherkasy	2	1	0.1	0.43	0.51	0.53	0.1	0.2	4	0.2
16	«RIVIERA», Kostyantynivka, Cherkasy district, Cherkasy region	6	1	0.3	0.58	0.76	0.18	0.4	0.3	1	0.45
17	Tyre service (Chornovol, 10), Cherkasy	1	1	0.21	0.8	0.8	0.36	0.2	0.2	2	0.53
18	Garant Automobile Technic, Kyiv	4	6	0.82	0.98	1.7	0.72	1	0.9	3	0.91
19	PE «Olvia», Cherkasy	2	1	0.44	0.68	0.77	0.35	0.3	0.5	3	0.6
20	Car wash «NEPTUN», Cherkasy	1	3	0.7	0.9	0.85	0.8	0.55	0.5	2	0.76
21	Tyre service «Shipshina», Cherkasy	1	1	0.3	0.78	0.7	0.35	0.5	0.4	2	0.38
22	Tyre service «Tvoya shina», Cherkasy	1	2	0.55	0.8	0.82	0.68	0.6	0.5	2	0.71
23	«Inter Diesel», Khmelnytskyi	5	2	0.71	1.1	0.94	0.81	0.8	0.7	3	0.84
24	«Motor-Gas», Kyiv	5	5	0.78	0.99	1.05	0.75	0.7	0.7	3	0.89
25	VipGaz, Kyiv	5	7	0.72	1	1	0.81	0.9	0.8	3	0.91
26	Tesla Service, Kyiv	4	4	0.82	0.97	1.07	0.87	0.85	1	3	0.9
27	PE Gorobets, Ruska Poliana, Cherkasy district	2	1	0.32	0.4	0.5	0.2	0.1	0.1	4	0.57
28	PE Ovcharenko S. S., Lecky, Cherkasy district	2	2	0.34	0.63	0.55	0	0.2	0.5	1	0.7

Table 4

Values of the morphological attributes of the investigated systems of automobile service for the functional elements "Automobiles" and "Environment"

CSE No.	CSE title	Automobiles			Environment						
		Car full weight	Energy unit type	Car age	Location	Population density	Level of motorization	Facility density	Level of logistical potential	Loyalty factor	Income level of Vs owners
		X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
1	2	3	4	5	6	7	8	9	10	11	12
1	JWT Service, Cherkasy	1	1	2	3	4	2	3	0.67	0.75	4
2	ATL Autoservice, Cherkasy	2	4	3	3	4	2	3	0.7	0.8	3
3	TOV «Boyard and Co.», Cherkasy	1	1	3	3	4	2	3	0.38	0.6	1
4	Kolos-Avto, Cherkasy	2	4	1	3	4	2	3	0.66	0.7	3
5	TOV «Buros», Cherkasy	2	4	1	3	4	2	3	0.68	0.85	3
6	DP «CHARS-AVTO", Cherkasy	3	1	3	3	4	2	3	0.6	0.3	3
7	JSC CHERKASY-AUTO, Cherkasy	2	4	3	3	4	2	3	0.65	0.45	3
8	V12, Zolotonosha, Cherkasy region	2	1	3	1	3	1	1	0.62	0.5	1

Continuation of Table 4

1	2	3	4	5	6	7	8	9	10	11	12
9	«Avtoreyka», Cherkasy	2	4	3	3	4	2	3	0.66	0.7	3
10	Self-service car wash «Shampun», Cherkasy	3	4	3	3	4	2	3	0.7	0.9	1
11	OILER Demiyivka, Kyiv	2	4	2	5	3	3	3	0.68	0.72	3
12	TOV Dnipromotor, Dnipro	2	4	2	4	3	2	3	0.55	0.42	3
13	«STO-35 km», Boryspil	2	4	3	2	3	1	1	0.57	0.38	5
14	Mobile tyre service, Kyiv	2	4	3	5	3	3	3	0.72	0.81	3
15	PE «Garage», Cherkasy	2	1	3	3	4	2	3	0.4	0.25	1
16	«RIVIERA», Kostyantynivka, Cherkasy district, Cherkasy region	2	1	3	2	3	1	1	0.54	0.32	5
17	Tyre service (Chornovol, 10), Cherkasy	2	4	3	3	4	2	3	0.66	0.43	1
18	Garant Automobile Technic, Kyiv	2	4	2	5	3	3	3	0.81	0.9	4
19	PE «Olvia», Cherkasy	3	1	2	3	4	2	3	0.59	0.7	2
20	Car wash «NEPTUN», Cherkasy	2	4	3	3	4	2	3	0.65	0.82	3
21	Tyre service «Shipshina», Cherkasy	2	4	3	3	4	2	3	0.67	0.4	2
22	Tyre service «Tvoya shina», Cherkasy	2	4	3	3	4	2	3	0.74	0.7	3
23	«Inter Diesel», Khmelnytskyi	3	1	2	3	3	3	2	0.65	0.86	2
24	«Motor-Gas», Kyiv	2	2	2	5	3	3	3	0.62	0.82	1
25	VipGaz, Kyiv	2	2	2	5	3	3	3	0.7	0.84	1
26	Tesla Service, Kyiv	1	3	2	5	3	3	3	0.75	0.87	4
27	PE Gorobets, Ruska Poliana, Cherkasy district	1	1	3	1	1	3	1	0.43	0.6	1
28	PE Ovcharenko S. S., Lecky, Cherkasy district	2	1	2	1	2	2	1	0.34	0.8	3

An example of the morphological formula that specifies one of the possible states of the system is formula (2) obtained for the car repair shop JWT Service from the city of Cherkasy (Ukraine), which specializes on maintenance and repair of sports cars:

$$\begin{bmatrix} (x_{12};x_{22};x_{33};x_{44};x_{55};x_{64};x_{71};x_{83};x_{94})+ \\ +(x_{10\,1};x_{11\,1};x_{12\,2})+ \\ +(x_{13\,3};x_{14\,4};x_{15\,2};x_{16\,3};x_{17\,3};x_{18\,3};x_{19\,4}) \end{bmatrix}. \quad (2)$$

In order to study the character of the influence of the defined morphological attributes of the system, we shall construct a mathematical model of a given system. For this purpose, it is necessary to carry out the structural, as well as parametric, if possible, identification (specification) of model (3).

$$Y = F(X_1, X_2, \ldots, X_n), \quad (3)$$

where Y is the resulting model parameter; X_1, X_2, ..., X_n is the input parameters vector; n is the number of parameters.

The model parameters unambiguously correspond to the morphological attributes of the investigated system. The results of CSE and their environment surveys were used as initial information for the model (Tables 3, 4).

The quantitative parameters of the "CSE" functional element are integrated indicators whose structure was described by authors in work [20].

The structural components of the X_3 X_6 parameters are calculated as the ratio of the actual values to normative ones. The procedure of calculating the relevant normative values is outlined in [21].

The level of information support X_7 is an integrated indicator of the following characteristics:

– the availability of normative and technological documentation;

– the implementation of marketing activities (advertising, notifications of clients about campaigns, etc.);

– the availability of an automated control system;

– the availability of informational support to after-sales service (questionnaires, etc.);

– the availability of a web site.

Based on the quality of content completeness, the numeric value of each component is taken within 0–0.2.

X_8 is determined in line with the procedure of assessing the level of environmental safety, investigated in [22], based on ten criteria for assessing the harmful effects of an enterprise.

The system qualitative parameters X_1, X_2, X_9–X_{12}, X_{19} are defined based on a survey, which was carried out when examining a CSE; the X_{13}–X_{16} parameters – based on the statistical information provided by the oblasts' Statistical Services.

The sequence of estimating the logistics potential X_{17} is given in work [23]. The loyalty factor X_{18} is calculated as the share of favorable assessments by clients in the total number of services rendered.

The resulting parameter of a car service system is the quality level of CSE technological processes K_q. This parameter is an integrated indicator whose calculation is proposed to perform based on formulae (4) to (6):

$$K_q = \alpha K_{\text{TCD}} + (1-\alpha) K_{\text{C}}, \tag{4}$$

where α is the proportion of operations whose execution quality is assessed by a Technical Control Department (TCD).

$$K_{\text{TCD}} = \min\left(K_{\text{TCD}}^i\right), \tag{5}$$

$$K_{\text{C}} = \min\left(K_{\text{C}}^j\right), \tag{6}$$

where K_{TCD}^i is the indicator of a quality level of the i-th operation performed in accordance with the requirements of the normative-technical documentation, submitted to the TCD; K_{C}^j is the coefficient of favorable estimates by customers (consumers) of the j-th operation.

The calculation procedure of K_{TCD}^i and K_{C}^j is given in [24].

Dependence (3) can be both linear and nonlinear. To obtain the most adequate dependence, it is necessary to construct models for the first and second cases and to perform their comparative analysis.

4. 2. Defining a set of independent system parameters

One way to obtain a mathematical model of the system is to represent it in the form of linear multiple regression (7):

$$Y = a_0 + \sum_{i=1}^{n} a_i X_i, \tag{7}$$

where n is the number of parameters that will be considered; a_i are the unknown coefficients.

To obtain an adequate model, it is necessary to perform the preprocessing of a source data array – the results of studying the typical car service systems. The construction of models of type (7) is carried out using the least-squares method. The effective and adequate application of the least square method is associated with the use of independent parameters in model (7). To determine it, we shall use the Farrar-Glober algorithm [25, 26]. The specified algorithm makes it possible to identify three types of correlation relationships between system parameters based on the use of statistical criteria. In particular, it checks the presence of multicollinearity in the entire source data array and in each parameter with all, as well as the presence of linear dependence between each pair of parameters. Dependent variables are removed from further consideration. Note that the removal procedure is subjective with the only criterion of its effectiveness being the absence of multicollinearity in the new (reduced) set of input parameters. Here is a detailed description of the implementation of the algorithm's iteration I (steps 1–7).

Step 1. Normalize and center the parameter values based on formula (8):

$$x_{ik}^H = \frac{x_{ik} - \bar{x}_k}{\delta_k}, \quad 1 \le k \le 19.1 \le i \le 28, \tag{8}$$

where x_{ik}^H is the normalized value of the k-th parameter of the i-th CSE; x_{ik} is the initial value of the k-th parameter of the i-th CSE; $\bar{x}_k$ is the average value of the k-th parameter; δ_k is the k-th parameter variance.

Step 2. Find a sampling correlation matrix:

$$\hat{R} = \frac{1}{n}\left(X^H\right)^T X^H, \tag{9}$$

where n is the number of CSEs, n=28.

Step 3. Calculate the value of Pierson criterion χ^2:

$$\chi^2 = -\left(n - 1 - \frac{1}{6}(2m+5)\right)\ln\left|\hat{R}\right|, \tag{10}$$

where m is the number of input parameters; n is the number of observations.

We compare it with the tabular value at $\frac{1}{2}m(m-1) =$ $=171$ degrees of freedom and the significance level α. If $\chi^2 > \chi^2_{tabl}$, there is multicollinearity in the vector of input factors.

At m=19, n=28, α=0.05, the following criterion value was obtained:

$$\chi^2 = -\left(28 - 1 - \frac{1}{6}(2 \cdot 19 + 5)\right) \times$$
$$\times \ln\left(4 \cdot 10^{-10}\right) = 430.11.$$

Since

$$\chi^2 > \chi^2_{tabl}(171; 0.05) = 202.513,$$

the multicollinearity is present in the array of input variables.

Step 4. Determine the inverse matrix $D = \hat{R}^{-1}$.

Step 5. Compute the value of the Fisher F-criterion for the k-th parameter from formula (11):

$$F_k = \left|d_{kk} - 1\right| \frac{n-m}{m-1}, \tag{11}$$

where d_{kk} are the diagonal elements of matrix D, $1 \le k \le 19$; n is the number of CSEs, n=28; m is the number of input parameters of the system, m=19.

The calculated values of the F_k criterion (Table 5) are compared with tabular ones at $(n-m)$=9 and $(m-1)$= =18 degrees of freedom and the significance level α=0.05.

The tabular value $F_{tabl}(0.05;9;18)$=2.96. If, for the k-th parameter, $F_k > F_{tabl}$ (in Table 5, bold), a given parameter is considered to be multicollinear with others. It is obvious that the X_3, X_7–X_8, X_{13}–X_{16}, X_{18} parameters are multicollinear with others.

Step 6. Find the sample partial correlation coefficients:

$$\hat{P}_{kj} = \frac{-d_{kj}}{\sqrt{d_{kk} \cdot d_{jj}}}, \quad 1 \le k \le 19, \quad 1 \le j \le 19. \tag{12}$$

Table 5

The value of the Fisher criterion for the k-th parameter at the algorithm iteration I

F_k	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	F_{18}	F_{19}
Value	**4.6**	**3.3**	**6.5**	2.4	2.3	2.0	**10.4**	**5.9**	2.4	0.5	1.8	2.2	**5.6**	**10.5**	**10.4**	**14.8**	**3.6**	**4.7**	1.7

Step 7. Compute the value of the Student's *t*-criterion from formula (13):

$$t_{kj}=\frac{\hat{P}_{kj}\sqrt{n-m}}{\sqrt{1-\hat{P}_{kj}^{2}}}. \tag{13}$$

The results of computing t_{kj} are given in Table 6.

The calculated values of t_{kj} are compared with tabular ones at $(n–m)$=9 degrees of freedom and the significance level $\alpha=0.05$. If $|t_{kj}|>t_{tabl}(0.05;9)=1.833$, there is multicollinearity between X_k and X_j. In Table 6, the values whose modulo are greater than the tabular ones are marked in bold.

For each column in Table 6, find the sums S_j of the values of the Student's criteria t_{kj} whose modulo exceed the tabular values (Table 7):

$$S_j=\sum_{j=1}^{19}\left|t_{kj}\right|,\ \text{if}\ \left|t_{kj}\right|>t_{tabl},$$

$$k=\overline{1.19}. \tag{14}$$

The sums are in descending order.

Given the value F_k, $k=\overline{1.19}$ (Table 5), we exclude from further consideration the input parameters that correspond to the largest sum of S_j: X_8, X_{14}, X_{18}.

Next, one needs to check the new array of input data for multicollinearity: X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{15}, X_{16}, X_{17}, X_{19}.

Repeat steps 1 through 7 for the subsequent iterations of the algorithm. At iteration V, the value of the Pierson criterion equals

$$\chi^2=-\left(28-1-\frac{1}{6}(2\times7+5)\right)\times$$
$$\times\ln\left(3.06\times10^{-1}\right)=28.224.$$

$$\chi^2<\chi^2_{tabl}(21.0{,}05)=32.67$$

at

$$\frac{1}{2}\times m(m-1)=\frac{1}{2}\times7(7-1)=21$$

degrees of freedom and a significance level of 0.05. Therefore, we conclude about the absence of multicollinearity in the adjusted array of input variables, which consists of the following parameters: X_2, X_5, X_9, X_{10}, X_{11}, X_{12}, X_{19}. This completes the algorithm execution.

4. 3. Constructing a system model in the form of a multiple linear regression equation

To construct the linear model of a car service system, it is necessary to determine the coefficients in the multiple regression equation

$$K_q=a_0+a_2X_2+a_5X_5+a_9X_9+$$
$$+a_{10}X_{10}+a_{11}X_{11}+a_{12}X_{12}+a_{19}X_{19}. \tag{15}$$

Table 6

Values of the Student's *t*-criterion t_{kj} at iteration I

Xk \ Xj	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
X_1	0	0.47	1.49	1.36	–1.11	–0.70	**2.33**	–1.52	0.81	0.54	–0.38	–1.64	**1.91**	0.23	–0.23	–1.60	–1.12	**–3.05**	0.77
X_2	0.47	0	0.21	–0.43	1.31	0.35	0.52	1.77	0.66	–0.57	1.15	1.63	0.90	–0.80	–1.40	0.12	–1.00	0.88	**–2.07**
X_3	1.49	0.21	0	–0.99	1.72	1.04	0.20	0.99	–0.06	–0.83	0.25	0.67	–1.24	0.58	0.55	0.29	–0.33	**2.15**	–0.19
X_4	1.36	–0.43	–0.99	0	1.75	0.76	–0.58	0.57	–1.04	–0.91	–0.70	0.38	–0.56	0.39	0.47	0.67	0.69	1.72	–0.12
X_5	–1.11	1.31	1.72	1.75	0	–0.22	0.04	–1.56	0.27	0.62	–0.91	–1.57	–0.37	–0.44	–0.07	0.25	0.91	**–2.07**	1.59
X_6	–0.70	0.35	1.04	0.76	–0.22	0	0.32	–0.39	0.34	0.59	–0.23	0.26	0.60	0.19	0.03	–0.44	0.68	–0.28	–0.20
X_7	**2.33**	0.52	0.20	–0.58	0.04	0.32	0	1.19	–1.37	–0.07	0.44	0.51	–0.78	0.33	0.69	0.48	1.66	0.99	–0.36
X_8	–1.52	1.77	0.99	0.57	–1.56	–0.39	1.19	0	–0.38	0.91	–1.58	**–3.03**	–0.09	–0.04	0.63	0.06	0.40	**–2.34**	**2.72**
X_9	0.81	0.66	–0.06	–1.04	0.27	0.34	–1.37	–0.38	0	–1.01	–1.05	–0.68	–0.71	1.31	**2.69**	0.09	0.84	–0.08	0.56
X_{10}	0.54	–0.57	–0.83	–0.91	0.62	0.59	–0.07	0.91	–1.01	0	–0.11	0.25	–0.17	1.18	0.80	–0.48	0.04	0.52	–0.76
X_{11}	–0.38	1.15	0.25	–0.70	–0.91	–0.23	0.44	–1.58	–1.05	–0.11	0	–0.09	–0.05	–0.02	0.02	0.05	0.11	–0.04	0.17
X_{12}	–1.64	1.63	0.67	0.38	–1.57	0.26	0.51	**–3.03**	–0.68	0.25	–0.09	0	0.03	0.66	1.06	–0.60	0.38	**–2.67**	1.78
X_{13}	**1.91**	0.90	–1.24	–0.56	–0.37	0.60	–0.78	–0.09	–0.71	–0.17	–0.05	0.03	0	–0.52	0.77	**2.47**	1.68	0.70	1.03
X_{14}	0.23	–0.80	0.58	0.39	–0.44	0.19	0.33	–0.04	1.31	1.18	–0.02	0.66	–0.52	0	**–4.07**	**3.56**	0.41	0.20	–0.11
X_{15}	–0.23	–1.40	0.55	0.47	–0.07	0.03	0.69	0.63	**2.69**	0.80	0.02	1.06	0.77	**–4.07**	0	1.32	–0.38	0.55	–1.05
X_{16}	–1.60	0.12	0.29	0.67	0.25	–0.44	0.48	0.06	0.09	–0.48	0.05	–0.60	**2.47**	**3.56**	1.32	0	–1.37	–0.95	–0.54
X_{17}	–1.12	–1.00	–0.33	0.69	0.91	0.68	1.66	0.40	0.84	0.04	0.11	0.38	1.68	0.41	–0.38	–1.37	0	–0.12	–0.50
X_{18}	**–3.05**	0.88	**2.15**	1.72	**–2.07**	–0.28	0.99	**–2.34**	–0.08	0.52	–0.04	**–2.67**	0.70	0.20	0.55	–0.95	–0.12	0	1.19
X_{19}	0.77	**–2.07**	–0.19	–0.12	1.59	–0.20	–0.36	**2.72**	0.56	–0.76	0.17	1.78	1.03	–0.11	–1.05	–0.54	–0.50	1.19	0

Table 7

The sums of absolute values for the *t*-criterion S_j exceeding t_{tabl} at iteration I

Parameter	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
Sj	7.29	2.07	2.15	0	2.07	0	2.33	8.10	2.69	0	0	5.70	4.39	7.63	6.76	6.04	0	12.28	4.79

The coefficients of model (15) are determined from the following formula [25, 26]:

$$A=\left(a_0,a_2,a_5,a_9,a_{10},a_{11},a_{12},a_{19}\right)= =\left(X^T\times X\right)^{-1}\times X^T\times K_q, \quad (16)$$

where X is the matrix consisting of vectors-columns of independent parameters determined at the last iteration of the Farrar-Glober algorithm; K_q is the vector-column of quality levels of the rendered services at each CSE (Table 3).

Thus, we obtain the following model:

$$K_q=0.3935+0.0308\cdot X_2+0.1554\cdot X_5+ +0.0288\cdot X_9+0.05691\cdot X_{10}+ +0.0128\cdot X_{11}-0.071\cdot X_{12}+0.0009\cdot X_{19}. \quad (17)$$

The RMS deviation of the model values from tabular ones is calculated from the following formula

$$\bar{\sigma}=\frac{1}{n}\sum_{i=1}^{n}\left(K^i_{q\,tabl}-K^i_{q\,model}\right)^2, \quad (18)$$

where n is the number of CSEs in a sample; i is the CSE index in the source data array; $K^i_{q\,tabl}$, $K^i_{q\,model}$ are the tabular and model values of the quality factor of technological processes at the i-th CSE, respectively.

To calculate the relative RMS deviation, we used the following formula

$$\bar{S}_r=\frac{1}{n}\sum_{i=1}^{n}\frac{\left(K^i_{q\,tabl}-K^i_{q\,model}\right)^2}{\left(K^i_{q\,tabl}\right)^2}\cdot 100\ \%. \quad (19)$$

When implementing the model on the initial sample, $\bar{\sigma}=0{,}0172$, $\bar{S}_r=13{,}6\ \%$. The visualization of simulation results is shown in Fig. 1, 2.

The resulting model yields a large error and cannot be used for small car repair shops of the garage type.

According to the general provisions for the experiment theory, the source data are typically divided into the training and reference samples. The algorithms that implement the models built on a training sample are more adequate to actual tasks than those built on a larger set of data. The training sample is 75–80 % of the initial one. We shall use the algorithm according to which the results of observations with the higher value of a sampling variance are included in the training sequence; a given approach is most common [25]. The stages of the algorithm implementation are as follows.

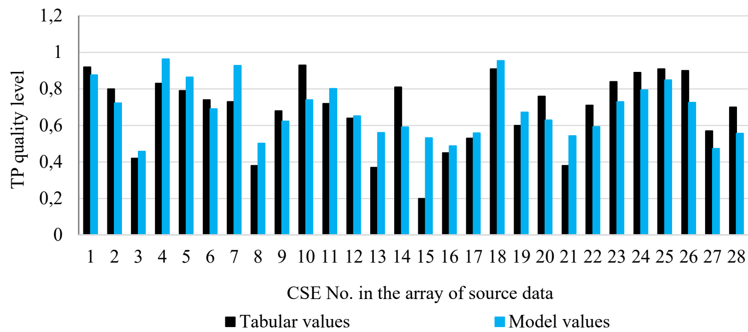

Fig. 1. Comparison of the tabular and model values of the quality level of technological processes (TP) in the construction of a linear model

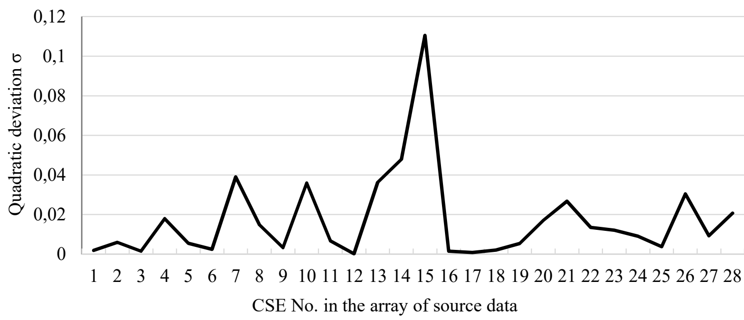

Fig. 2. The error of the linear model built on the initial sample

Step 1. Take the ratio between the number of CSEs in the training and reference samples equal to 80/20. Accordingly, the training sample includes 22 enterprises, reference – 6.

Step 2. For each vector X_j, calculate the average value of its elements (Table 8) from the following formula:

$$\bar{x}_j=\frac{1}{28}\sum_{i=1}^{28}x_{ij},\quad j=\overline{1.7}. \quad (20)$$

Table 8

The results of splitting the initial sample

i	CSE title	X_2	X_5	X_9	X_{10}	X_{11}	X_{12}	X_{19}	Sampling variance, D_i
1	2	3	4	5	6	7	8	9	10
1	JWT Service	2	2.42	4	1	1	2	4	1.90778
2	ATL Autoservice	4	1.44	1	2	4	3	3	0.95307
3	TOV «Boyard and Co.»	1	0.4	4	1	1	3	1	2.16274
4	Kolos-Avto	3	1.9	3	2	4	1	3	0.8453
5	TOV «Buros»	5	0.86	3	2	4	1	3	1.41931
6	DP «CHARS-AVTO»	2	1.14	3	3	1	3	3	0.93351
7	JSC CHERKASY-AUTO	7	1.79	3	2	4	3	3	3.24198
8	V12	2	0.67	1	2	1	3	1	1.51597
9	«Avtoreyka»	4	0.61	2	2	4	3	3	0.5941
10	Self-service car wash «Shampun»	3	1.21	2	3	4	3	1	0.93817

Continuation of Table 8

1	2	3	4	5	6	7	8	9	10
11	OILER Demiyivka	5	0.92	3	2	4	2	3	1.08427
12	TOV Dnipromotor	3	0.72	1	2	4	2	3	0.73748
13	«STO-35 km»	3	0.58	1	2	4	3	5	1.70505
14	«Mobile tyre service»	1	0.63	4	2	4	3	3	1.32983
15	PE «Garage»	1	0.51	4	2	1	3	1	1.97699
16	«RIVIERA»	1	0.76	1	2	1	3	5	2.55577
17	Tyre service (Chornovol, 10)	1	0.8	2	2	4	3	1	1.3865
18	Garant Automobile Technic	6	1.7	3	2	4	2	4	2.33794
19	PE «Olvia»	1	0.77	3	3	1	2	2	1.43603
20	Car wash «NEPTUN»	3	0.85	2	2	4	3	3	0.384
21	Tyre service «Shipshina»	1	0.7	2	2	4	3	2	1.03687
22	Tyre service «Tvoya shina»	2	0.82	2	2	4	3	3	0.52826
23	«Inter Diesel»	2	0.94	3	3	1	2	2	0.95301
24	«Motor-Gas»	5	1.05	3	2	2	2	1	1.29897
25	VipGaz	7	1	3	2	2	2	1	3.34576
26	Tesla Service	4	1.07	3	1	3	2	4	0.78763
27	PE Gorobets	1	0.5	4	1	1	3	1	2.14523
28	PE Ovcharenko S. S.	2	0.55	1	2	1	2	3	1.14963
$\bar{x}_j$		2.929	0.975	2.536	2	2.75	2.5	2.571	

Step 3. Determine the sampling variances for the *i*-th CSE (Table 8):

$$D_i = \frac{1}{n-1}\sum_{j=1}^{n}\left(x_{ij}-\bar{x}_j\right)^2 = \frac{1}{6}\sum_{j=1}^{7}\left(x_{ij}-\bar{x}_j\right)^2, \quad i=\overline{1,28}. \qquad (21)$$

Step 4. Arrange Table 8 in the descending order of the sampling variance values.

Step 5. Split the array of initial data. The following CSEs from the initial sample have the smallest values of a sampling variance: "KOLOS-AVTO" (Cherkasy), specialized CSE "Avtoreyka" (Cherkasy), TOV "Dnipromotor" (Dnipro), car wash "NEPTUN" (Cherkasy), tire service "Tvoya shina" (Cherkasy), and "Tesla Service" (Kyiv). The specified CSEs make up the reference sample (in Table 8, they are highlighted with a different color), all others – the training sample.

The following model was obtained from the training sample:

$$K_q = 0.50551 + 0.0137\cdot X_2 + 0.2263\cdot X_5 + \\ +0.0216\cdot X_9 + 0.0796\cdot X_{10} + \\ +0.0152\cdot X_{11} - 0.123\cdot X_{12} - 0.0189\cdot X_{19}. \qquad (22)$$

The derived model is slightly different from model (17). For six CSEs from the reference sample, the RMS error σ_{linear}= =0.032254. The relative RMS deviation is $S_r^{linear} = 5.1\ \%$.

4. 4. Building the nonlinear system models based on a fuzzy sets theory

Another method of model identification (3) has been considered. Since one part of the factors is quantitative and another part is of qualitative character, these tasks are termed weakly structured. To solve them, it is advisable to use an apparatus from the theory of fuzzy sets. An expert in the visual domain sets the parameters for the membership functions of the input factors and the resultant characteristics. Then a model of the desired dependence is the system of fuzzy production rules built on the training sample, and the forecasted values of the output parameter for the enterprises that make up the reference sample are determined based on one of the algorithms of fuzzy logic derivation.

To construct this type of a model, we applied the MATLAB suite and its module to manage fuzzy sets, Fuzzy Logic Toolbox, which implies using two o derivation algorithms: by Mamdani and by Sugeno [27].

In order to build a system of fuzzy rules in line with the first algorithm, it is necessary to split the domains of the input and output parameters into intervals, terms, and to build, for each of them, the membership function μ. The split is based on the results of the preliminary morphological analysis (Tables 1, 2). Given that within the framework of our study the model contains 22 fuzzy rules and 7 factors, then it is rational to select the trapezoidal membership functions. Otherwise, there is a high probability that the adequate application of the Mamdani derivation could prove impossible due to the operation of finding a minimum of the membership function and its zero value.

A trapezoidal membership function is defined by five elements: *a*, *b*, *c*, *d*, and *h*. The height *h*=1. Other parameters are set in the Membership Function Editor in the Fuzzy Logic Toolbox module according to Fig. 3.

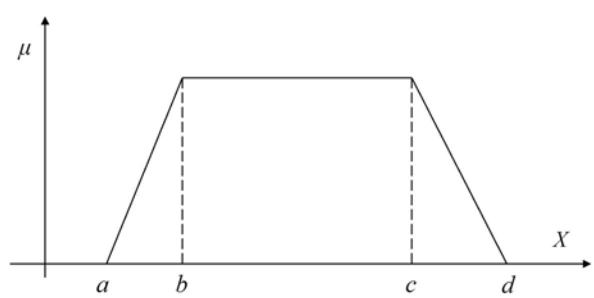

Fig. 3. A general form of the trapezoidal membership function

Table 9 gives the parameters of the membership functions for the individual terms A_i^j ($i \in \{2, 5, 9, 10, 11, 12, 19\}$, $j=\overline{1,k^i}$), which were determined by engaging the experts, CSE employees; k^i is the number of terms in the i-th factor. The term A_i^j uniquely corresponds to the j-th variant of the i-th morphological attribute x_{ij}.

Table 9

Parameters of TMF terms for the system input factors

Factor X_i	Term A_i^j	Membership function μ parameters			
		a	b	c	d
X_2	A_2^1	0	0.5	1.5	8
	A_2^2	0	1.5	2.5	8
	A_2^3	0	2.5	3.5	8
	A_2^4	0	3.5	4.5	8
	A_2^5	0	4.5	5.5	8
	A_2^6	0	5.5	6.5	8
	A_2^7	0	6.5	7.5	8
X_5	A_5^1	0	0.1	0.4	2.5
	A_5^2	0	0.41	0.6	2.5
	A_5^3	0	0.61	0.8	2.5
	A_5^4	0	0.81	1	2.5
	A_5^5	0	1.01	2.49	2.5
X_9	A_9^1	0	0.5	1.5	5
	A_9^2	0	1.5	2.5	5
	A_9^3	0	2.5	3.5	5
	A_9^4	0	3.5	4.5	5
X_{10}	A_{10}^1	0	0.5	1.5	4
	A_{10}^2	0	1.5	2.5	4
	A_{10}^3	0	2.5	3.5	4
X_{11}	A_{11}^1	0	0.5	1.5	5
	A_{11}^2	0	1.5	2.5	5
	A_{11}^3	0	2.5	3.5	5
	A_{11}^4	0	3.5	4.5	5
X_{12}	A_{12}^1	0	0.5	1.5	4
	A_{12}^2	0	1.5	2.5	4
	A_{12}^3	0	2.5	3.5	4
X_{19}	A_{19}^1	0	0.5	1.5	6
	A_{19}^2	0	1.5	2.5	6
	A_{19}^3	0	2.5	3.5	6
	A_{19}^4	0	3.5	4.5	6
	A_{19}^5	0	4.5	5.5	6

Similarly, we determined and constructed, for the quality coefficient of rendered services K_q, the membership functions for five terms $B^s\left(s=\overline{1.5}\right)$: very low, low, medium, high, and very high (Fig. 4).

At the next step, in accordance with the output data (Tables 3, 4) and the parameters for the terms of the input factors (Table 9), we built a rule base, which, in a general form, is matched with the following expression:

$$\vee_{p=1}^{22}\left(\text{If} \wedge_{i=1}^{7} X_i \in A_{ip}^j, \text{then } K_q \in B_p^s\right), \quad (23)$$

where X_i is the i-th parameter of a car service system; A_{ip}^j is the j-th term, which includes a value for the i-th parameter of the system, for a CSE with the index p in the input data array; K_q is the quality factor of the execution of technological processes; B_p^s is the s-th term, which includes a value of K_q for a CSE with the index p.

We have built the fuzzy logic rules for a system of the Mamdani type, which, in their combination with model (3), are shown in Fig. 5.

In Fig. 5, mf_j is the membership function corresponding to the term A_i^j of the X_i parameter.

The rules are accepted as equivalent, so the weight of each rule W_p=1, $p=\overline{1.22}$.

When constructing a system for the logical derivation by Sugeno, the input variables of the model were divided into the term-sets and the parameters for membership functions of the system of the Mamdani type. The output parameter is given by a set of constants that correspond to the values of K_q in the training sample, arranged in ascending order (Fig. 6).

Model (3) in the form of a rule base for the system of logical derivation by Sugeno is built on the following principle:

$$\vee_{p=1}^{22}\left(\text{If} \wedge_{i=1}^{7} X_i \in A_{ip}^j, \text{then } K_q = K_{q\,tabl}\right), \quad (24)$$

where $K_{q\,tabl}$ is the value of a quality factor of technological processes at a corresponding CSE from the training sample.

The weight coefficients of the rules are equal to unity. The constructed fuzzy logic rules of the Sugeno-type system are shown in Fig. 7.

The implementation of the rules for the system of logical derivation in a Sugeno-type system is similar to the implementation in the Mamdani system. The visualization of the logical derivation, using one enterprise from the reference sample as an example, is shown in Fig. 8.

By substituting the current values for the input parameters in a fuzzy rule scheme viewer with prospective ones (Fig. 8), analysts can forecast the development of a specific car service system.

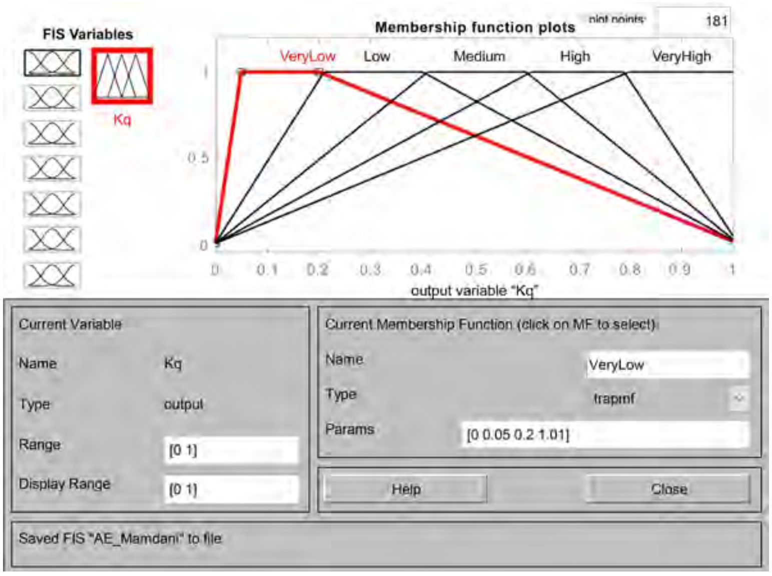

Fig. 4. Membership functions to derive a model of the Mamdani type

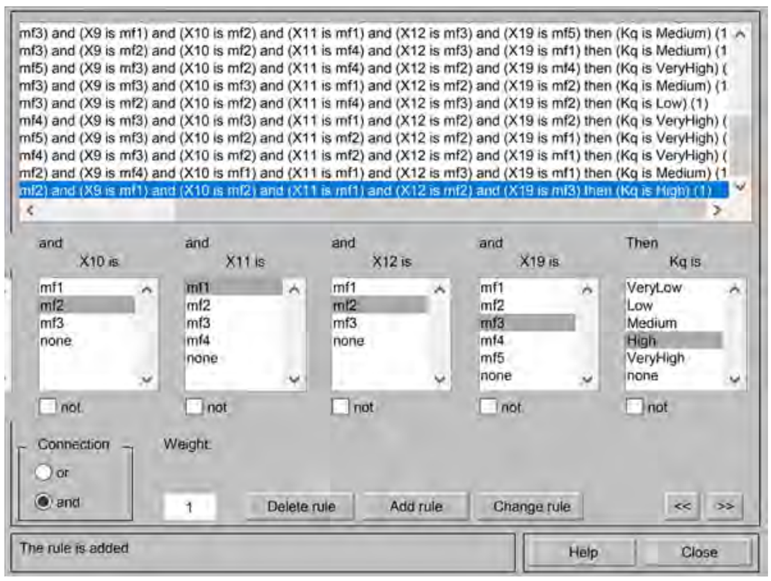

Fig. 5. Fuzzy rules to derive a model of the Mamdani type

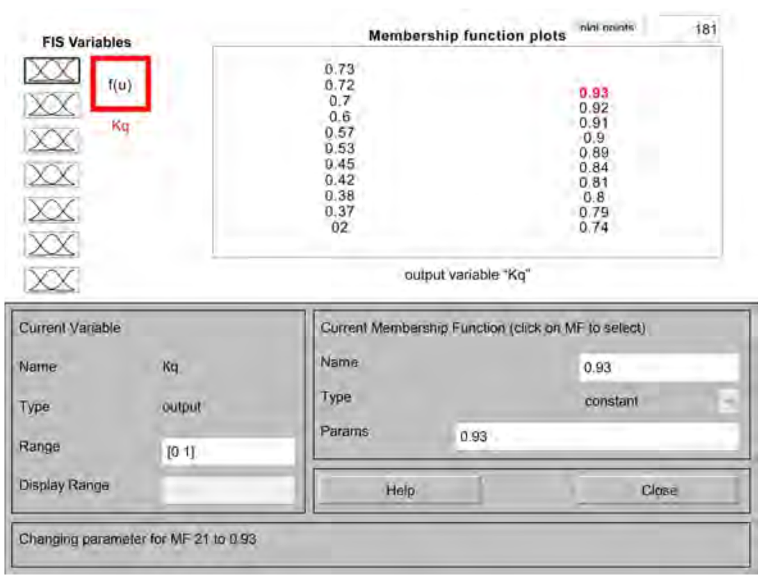

Fig. 6. Parameters for the output variable of the Sugeno-type model

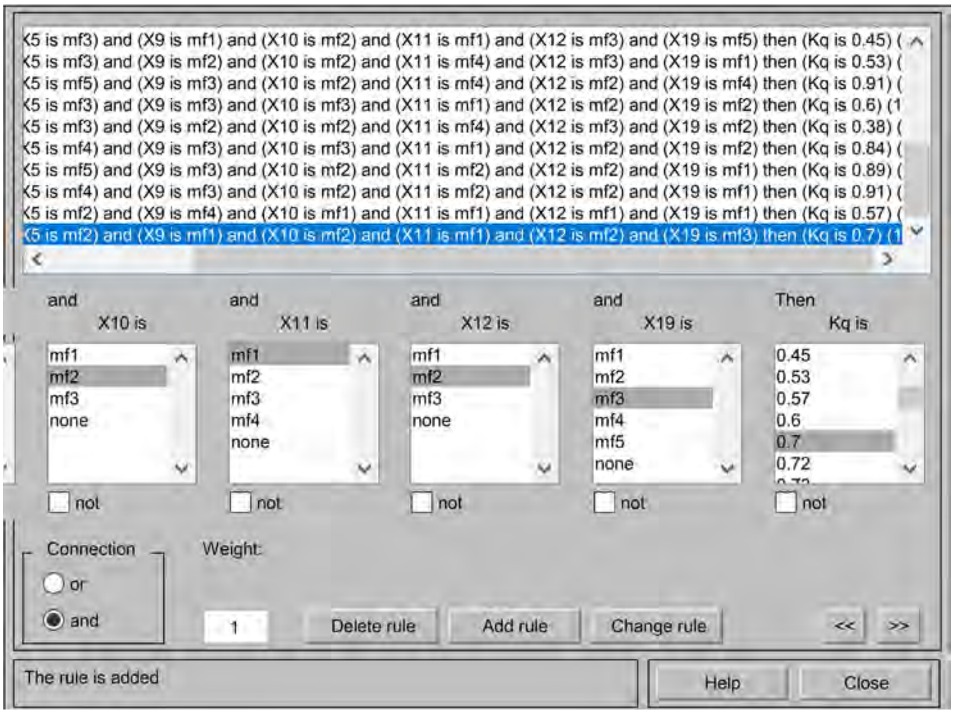

Fig. 7. A rule base for the logical derivation of the Sugeno-type model

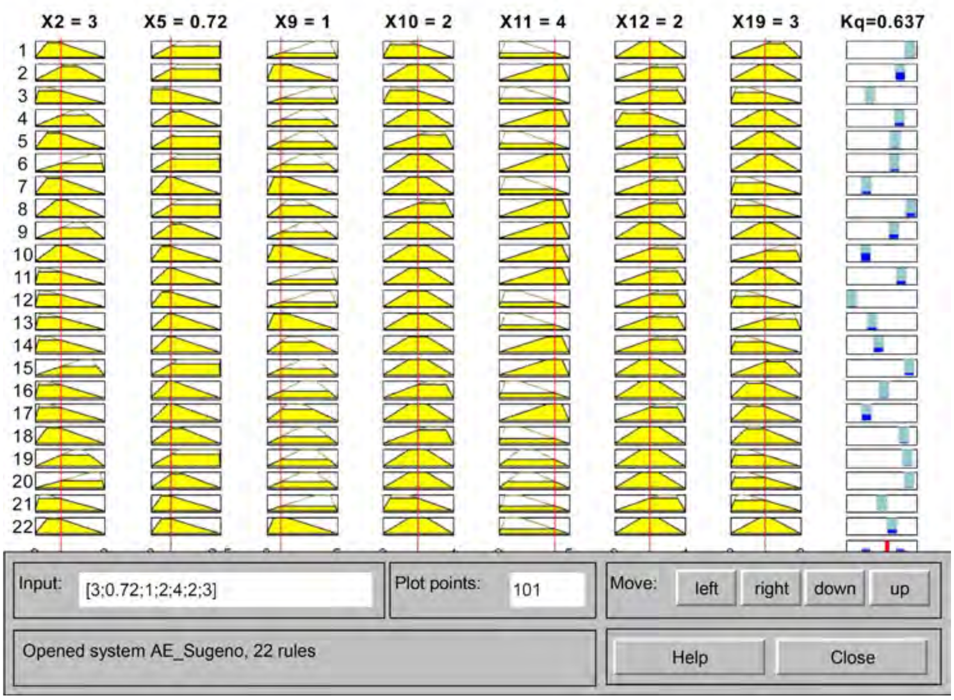

Fig. 8. Deriving a value of K_q for TOV Dnipromotor

5. Choosing an adequate model to assess the quality of technological processes

Fitting the values of the morphological attributes of the reference sample's enterprises to each derived model in the form of parameters makes it possible to estimate the accuracy of these models. The value of RMS deviation and the relative quadratic deviation is determined from formulae (18), (19).

In order to choose a more adequate model when implementing the nonlinear models based on the Mamdani algorithm, the following defuzzification methods were applied [28]: bisector, centroid, the largest of maximums, the smallest of maximums, the mean of maximums. The derivation based on the algorithms for the first four methods produced an error that exceeded that yielded by the algorithm that implements the method of the mean of maximums. For a Sugeno-type system, we used such defuzzification methods as the weighted average and the weighted sum. The highest precision was achieved when using the first method. A comparative analysis of the linear and nonlinear models is given in Table 10.

For six points from the reference sample, the lowest rms error is 0.007298, the relative rms error is 1.07 %. The highest accuracy of modeling was achieved when using the system of the fuzzy logical derivation of the Sugeno type.

For an arbitrary CSE, one can investigate the dynamics of changes in the resultant characteristic dependent on the two selected system parameters at the fixed values for other parameters. Visually, a given dependence is surface $K_q=F(X_i, X_j)$. Since the most influential among all the parameters is the level of personnel availability, it is advisable to choose X_5 as one of the arguments of the surface. Fig. 9, 10 show the dependence of the Mamdani and Sugeno models derivation on, accordingly, the level of personnel availability and the average age of cars being serviced, for the same CSE.

The graphic representation of the results of the Mamdani-type system modeling is more visual. Although the Sugeno-type surface, as noted, is more adequate to the original.

Also of interest is an analysis of the character of the impact exerted on the quality of technological processes execution by those parameters the decision on the adjustment and correction of which can be directly taken by the owners of a CSE. Fig. 13 shows the dependence of the Mamdani-type system derivation on the capacity of a CSE and the form of production organization.

Based on the analysis of the surface, it can be concluded that for a given CSE the highest level of quality is achieved under the conditions of the work shop-post or individual forms of the organization of production and at the number of posts of 7 or more.

Table 10

Comparison of the accuracy of system modeling results

i	CSE title	Quadratic deviation			Relative quadratic deviation		
		σ_{linear}	$\sigma_{Mamdani}$	σ_{Sugeno}	S_r^{linear}	$S_r^{Mamdani}$	S_r^{Sugeno}
4	Kolos-Avto, Cherkasy	0.06354	0.0121	0.00314	0.09223	0.01756	0,0046
9	«Avtoreyka», Cherkasy	0.02060	0.03063	0.00116	0.04456	0.06623	0,0025
12	TOV Dnipromotor, Dnipro	0.00008	0.00003	0.00001	0.00019	0.00006	0,00002
20	Car wash «NEPTUN», Cherkasy	0.03347	0.00723	0.01124	0.05795	0.01251	0,0195
22	Tyre service «Tvoya shina», Cherkasy	0.02355	0.00203	0.0036	0.04672	0.00402	0,0071
26	Tesla Service, Kyiv	0.05228	0.03803	0.02465	0.06455	0.04694	0,0304
Mean value		0,03225	0.01500	0.0073	0.05103	0.02455	0.01068

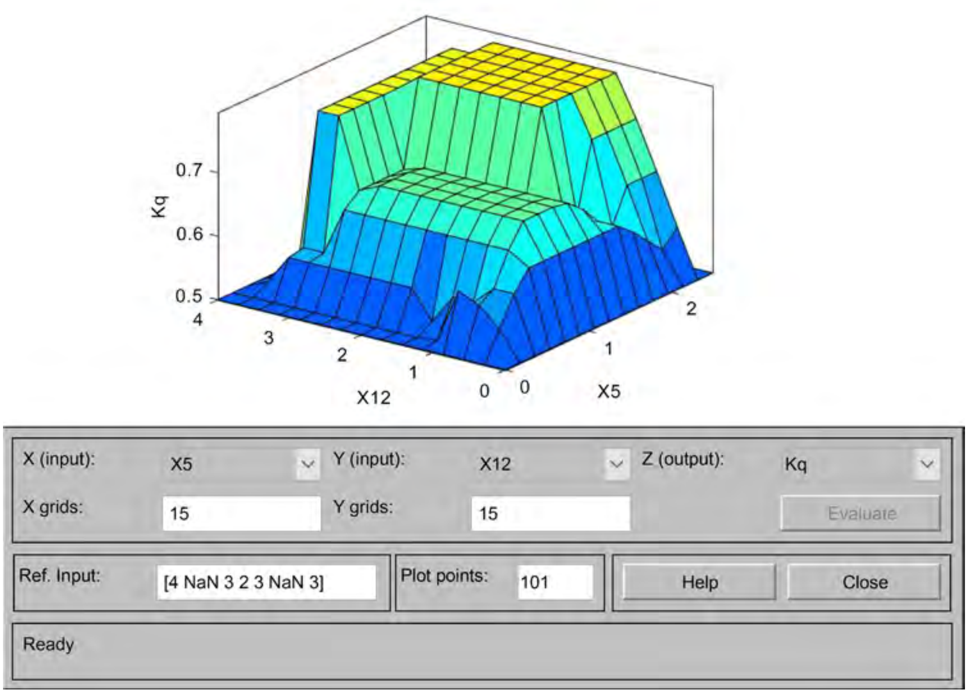

Fig. 9. Dependence of K_q on the level of personnel availability and the average age of vehicles in the Mamdani-type system

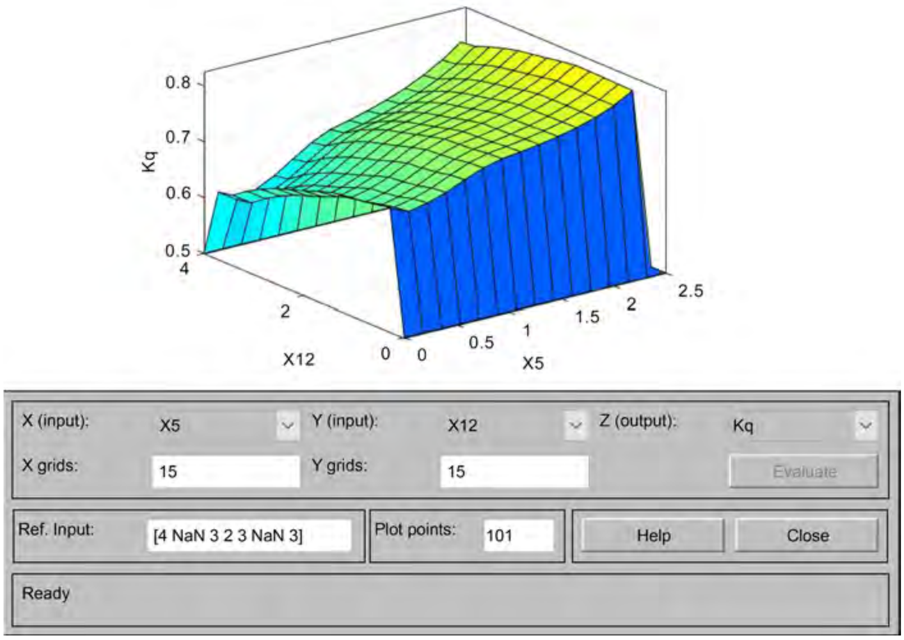

Fig. 10. Dependence of K_q on the level of personnel availability and the average age of vehicles in the Sugeno-type system

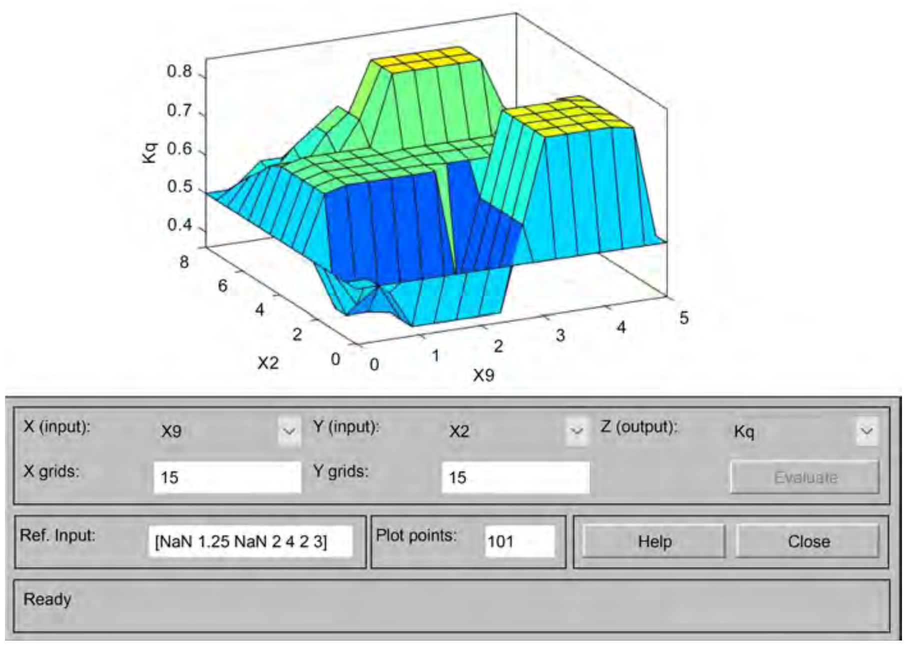

Fig. 11. Dependence of K_q on the number of posts at CSE and the form of production organization

6. Discussion of results of studying the car service systems

At the stage of morphological analysis, 19 morphological attributes of a car service system were defined, which influence the quality of technological processes execution at CSE. The selection of attributes is based on the results of the survey carried out at the examined CSEs involving experts, the employees of these enterprises. We selected from the list provided by experts, for the functional element of the system "CSE", those attributes that are directly influenced by the top management and owners of CSEs. We chose, for the functional elements "Automobiles" and "Environment", those morphological attributes, which, according to experts, affect the quality of technological processes execution at CSEs and whose significance can be determined based on the actual statistical information within Ukraine's information space. When selecting attributes that are of quantitative character, the possibility to examine their structure and obtain the calculation algorithms was taken into consideration. The attributes of the elements "Automobiles" and "Environment" are unmanageable within the CSEs but they should be taken into consideration in the process of finding the strategies to improve the quality of technological processes. The number of possible configurations of a car service system was calculated, which is $5.57{\cdot}10^{11}$. A significant number of configurations is explained by the presence of different implementation variants of each morphological attribute.

The need to construct a uniform model of the car service system is predetermined by the inability to investigate all its configurations. However, the results of the morphological analysis have made it possible to determine the parameters of a mathematical model of the system, which unambiguously match the morphological attributes of its functional elements. The application of the Farrar-Glober algorithm allowed us to preprocess the initial data array and to identify, among the 19 system parameters, seven independent ones. The selection of the independent parameters is based on the results of statistical estimates that were computed at each iteration of the specified algorithm. The presence of the dependence between the parameters in the initial data array is due to the interconnectedness of individual morphological attributes, which was not explicit at the stage of the morphological analysis. Determining the independent parameters contributed to the construction of adequate models and reduced the complexity of further calculations.

We have obtained a model of the car service system in the form of a multiple linear regression, which makes it possible to quantify the impact of each of the specified parameters on the functioning of CSE. The values of coefficients in the regression equation (22) indicate that the highest weight is inherent in the level of personnel availability and the age of cars being serviced at a given enterprise. The relative rms error of this model is 5.1 %. However, the model produces high single accuracy only for typical medium and large CSEs (Fig. 1, 2). This is due to the inaccurate information provided by the heads of CSEs of the garage type. The specified CSEs do not have Internet sites, which makes it impossible to verify the values of their parameters.

In the process of solving the fourth problem for an automobile service system, we constructed the nonlinear models in the form of the systems of fuzzy logical derivation. The higher accuracy of modeling, in this case, improved owing to the use of a fuzzy set apparatus, which can handle inaccurate, approximate data.

The accuracy of a fuzzy logical derivation system is also influenced by the type and parameters of the selected membership functions for the system inputs and outputs. The results of the computer experiment proved the expediency of using the trapezoidal membership functions with the parameters given in Table 9. In the process of testing the Mamdani and Sugeno logical derivation systems, we determined, on the CSEs from the reference sample, the most adequate model and found that the defuzzification method also influences the accuracy of the result. A mathematical model of the Sugeno type is more adequate to the actual car service systems, in which we implemented such a defuzzification method as the weighted average. The relative rms deviation of the output of this model is two times less than that of the Mamdani-type model and is five times less compared with the linear model. The higher accuracy of the Sugeno-type model is explained by that the value of the output characteristic in the specified model was set quantitatively. The Mamdani-type model is appropriate to use when there is no possibility to quantify the level of quality of the performed technological processes at CSE. One of the advantages of using the systems of fuzzy logical derivation is the possibility to visualize the results of research into an arbitrary CSE. The resulting model of the car service system could be used to control the current level and forecast the prospective quality levels of the technological processes execution, as well as to analyze various options for optimizing the strategy of CSE operation.

Previous papers did not include a systematic study of the CSE functioning, which would take into consideration the morphological attributes, the characteristics of vehicles, and patterns of the functioning environment.

We have implemented this approach by using a morphological analysis method and by synthesizing the possible structures of car service enterprises and the procedure of evaluating the quality of technological processes taking into consideration the changes in the parameters of the morphological attributes of main functional elements.

The advantage of a given approach is that it makes it possible to analyze the efficiency of functioning of not only the actual CSE but also to estimate a large number of possible system structures and to predict the quality of technological processes at any CSE structures. It should be noted that determining and excluding the dependent parameters of the car service system from consideration would in the future make it possible to significantly reduce the cost of time to collect statistical information about arbitrary CSEs whose optimization might be necessary.

The application of a fuzzy set apparatus, which takes into consideration the possibility of error in the input parameters of the system, indicates the robustness of the output model characteristic to the changes in the input parameters under the influence of unaccounted external factors. The errors of the Sugeno-type system derivation (Table 10), obtained in the process of testing the systems from the reference sample, confirm the reproducibility of the resultant characteristic of the car service system. Restrictions on the use of our study results are imposed by the ranges of possible values for the morphological attributes of the system functional elements.

The disadvantage of this study is observing the car service systems only at the micro-level, that is, within the functioning of a single enterprise. Further research should tackle the construction of models and procedures of quality assessment of the automobile services rendered, proposed by a CSE network at the regional and state levels.

7. Conclusions

1. To estimate the quality level of technological processes at CSEs, we have proposed the morphological structure of a typical car service system, which contains three functional elements: CSE, automobiles, environment. The essential morphological attributes of the functional elements and the variants of their implementation have been determined. The system analysis has made it possible to set the intervals within which the parameters of the examined system model are measured, as well as split these intervals into terms. Based on the results of our morphological analysis, the statistical study of 28 typical CSEs in Ukraine was conducted and an array of initial data was built for further calculations.

2. To eliminate the multicollinearity of the input model parameters, we have preprocessed the CSE survey results, due to which the volume of the output data array was reduced from 19 to 7 independent parameters. Thus, the quality of technological processes execution is significantly

influenced by the following factors: the capacity of a CSE (the number of posts), the level of personnel availability, the form of production organization, the age, and category of vehicles having a greater share of appeals to a CSE is in their total number, the type of their energy setup, as well as the customer income level.

3. The possibilities of the structural and parametric identification of the system linear model have been examined, the result being the established character of the influence of input parameters on the model derivation. It has been found that the greatest weight in terms of quality assessment belongs to the level of personnel availability, which defines the strategy of personnel training as one of the top priorities among other optimization strategies for CSE operation.

4. We have built the nonlinear models of the system in the form of the systems of fuzzy logical derivation by Mamdani and Sugeno. The fuzzy logical rules describe the nonlinear dependence up to 2.45 % and 1.07 %, respectively. They make it possible to take into consideration qualitative factors along with quantitative ones and can be integrated into the system of managerial decision-making in order to determine the optimal operating regimes and improve the stability of CSE functioning.

5. An analysis of the obtained linear and nonlinear models has been carried out; the result has revealed that the most adequate model to actual conditions in the field of CSE operation is a Sugeno-type model that employs a defuzzification algorithm based on the weighted average method. The relative error of the model output is 1.07 %.

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