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EVALUATION THE STRUCTURE EFFICIENCY OF TESTING EQUIPMENT FOR MANUFACTURE OF AUTOMOBILES

АВТОМОБИЛЬДЕРДІ ӨНДІРУГЕ АРНАЛҒАН СЫНАҚ ЖАБДЫҚТАРЫНЫҢ ҚҰРЫЛЫМЫНЫҢ ТИІМДІЛІГІН БАҒАЛАУ

ОЦЕНКА ЭФФЕКТИВНОСТИ СТРУКТУРЫ ИСПЫТАТЕЛЬНОГО ОБОРУДОВАНИЯ ДЛЯ ПРОИЗВОДСТВА АВТОМОБИЛЕЙ

***Abstract**. Nowadays, the automotive industry plays a significant role in the structure of domestic mechanical engineering. There are a large number of enterprises engaged in the production and assembly of cars and trucks of various well-known brands on the territory of our country. A necessary stage in the production line of automobiles is testing (diagnostics). To diagnose the flow of produced cars, various options for placing technological equipment can be used. In this article, the authors have conducted a study of several layouts of diagnostic equipment for testing vehicles according to the criterion of the highest throughput using the method of mathematical modeling. As the research results have shown the most efficient equipment layout corresponds to the organization of the technological process with a six-post two-beam line. This variant of the organization of the technological process makes it possible to increase the efficiency of the diagnostic line by almost 2 times. The results of the investigations can be applied to the effective organization of the process of testing automobiles at the enterprises for the production of transport equipment.*
***Keywords:** automotive industry; diagnostics; equipment, throughput, performance, modeling.*

***Аннотация.** На сегодняшний день автомобильная промышленность играет значительную роль в структуре отечественного машиностроения. На территории нашей страны функционирует большое количество предприятий, занимающихся производством и сборкой легковых и грузовых автомобилей разных известных марок. Необходимым звеном производственной линии автомобилей является испытание (диагностика). Для диагностирования потока производимых автомобилей могут применяться различные варианты размещения технологического оборудования. В данной статье авторами с применением метода математического моделирования проведено исследование нескольких схем расположения диагностического оборудования для проведения испытаний автомобилей по критерию наибольшей пропускной способности. Как показали результаты исследований, наиболее эффективная схема размещения оборудования соответствует организации технологического процесса с шестипостовой двухлучевой линией. Данный вариант организации технологического процесса позволяет повысить эффективность диагностической линии почти в 2 раза. Результаты исследований могут быть применены для эффективной организации процесса испытания автомобилей на предприятиях по производству транспортной техники.*
***Ключевые слова:** автомобильная промышленность; диагностика; оборудование, пропускная*

способность, производительность, моделирование.

***Аңдатпа**. Бүгінгі таңда отандық машина жасау құрылымында автомобиль өнеркәсібі маңызды рөл атқарады. Біздің еліміздің аумағында әртүрлі танымал маркалы жеңіл және жүк көліктерін шығарумен және құрастырумен айналысатын көптеген кәсіпорындар бар. Автомобильдерді өндіру желісіндегі қажетті буын тестілеу (диагностика) болып табылады. Өндірілген автомобильдердің ағынын диагностикалау үшін технологиялық жабдықты орналастырудың әртүрлі нұсқаларын қолдануға болады. Бұл мақалада авторлар математикалық модельдеу әдісін қолдана отырып, ең жоғары өткізу қабілеттілігі критерийі бойынша көлік құралдарын сынауға арналған диагностикалық жабдықтың бірнеше схемаларын зерттеуді жүргізді. Зерттеу нәтижелері көрсеткендей, жабдықтың ең тиімді схемасы технологиялық процесті алты бағаналы екі сәулелі желімен ұйымдастыруға сәйкес келеді. Технологиялық процесті ұйымдастырудың бұл нұсқасы диагностикалық желінің тиімділігін 2 есеге жуық арттыруға мүмкіндік береді. Зерттеу нәтижелерін көлік құралдарын шығаратын кәсіпорындарда автомобильдерді сынау процесін тиімді ұйымдастыруға қолдануға болады.*

***Түйін сөздер:** автомобиль өнеркәсібі; диагностика; жабдық, өткізу қабілеті, өнімділігі, модельдеу.*

Introduction. The automotive industry is one of the main drivers for the development of the mechanical engineering industry in Kazakhstan. A significant number of factories for the production and assembly of automobiles operate on the territory of our country which are Saryarka AvtoProm (Kostanay), SemAZ (Semey), Hyundai Trans Kazakhstan (Almaty), KAMAZ-Engineering (Kokshetau) and others. The most popular automobile brands produced in Kazakhstan are Hyundai, Chevrolet, GAZ, UAZ, KAMAZ, etc.

The process of creating an automobile consists of the following stages which are substantiation of the need to create a new automobile, scientific and technical research, development of a design project, manufacturing, testing and fine-tuning of prototypes [1]. Justification and analysis of the need to create a automobile is carried out on the basis of methods of scientific forecasting of technical problems. Scientific forecasting is a probabilistic judgment about the future with a high level of certainty and is based on an objective assessment of the possible. At the second stage of the creation of the automobile scientific research is carried out on the technical provisions that will be used in the design of the automobile. The list of issues to be studied at this stage depends on the type, purpose and operating conditions of the machine, on the specific features of its design, the degree of their study. In some cases, research is carried out in the direction of finding a rational principle of the machine, the direction of improving performance, the possibilities of using products or materials manufactured by industry in the design of a future machine are being studied, the suitability of certain inventions for a given design is checked. Manufacturing, testing and fine-tuning are the final stage in the creation of a new automobile. Practice shows the inexpediency of manufacturing a large number of automobiles according to new design documentation that has not passed production verification. The design project passes such a check during the manufacture and testing of the first prototype of the automobile. At this stage of the creation of the automobile the engineering concepts and design solutions included in the project during development are evaluated. Therefore, the final stage is a support for designers-developers helping them to visually reveal and analyze their mistakes conducted in the development of the automobile and directs their activities to eliminate these mistakes.

One of the key stages of automobile production is testing. Diagnostic procedures are carried out using test lines consisting of a set of diagnostic equipment [2-6]. Taking into account the fact that the testing time of vehicles is an indicator of performance the actual issue is the implementation of measures to optimize the time of diagnosing vehicles on the test line.

The importance of the test phase in vehicle production should also be emphasized. Among the most common consequences of poor quality vehicle testing are traffic accidents and environmental degradation. According to the official statistics 8307 road accidents were registered in the country for 8 months of the past year [7]. In the accidents 12205 people were injured. The increase in road traffic accidents amounted to 10.2% compared to the previous year. And the number of victims increased by 11.2% compared to the same period last year. In addition to the increase in accidents and the number of victims of them there is another global negative consequence which are emissions of exhaust gases into the atmosphere. In a number of regions, the share of emissions from vehicle exhaust gases is about half of all sources of harmful emissions. In addition to the direct negative impact on nature and humans of harmful substances contained in the exhaust there is also the impact of carbon dioxide on the atmosphere which is expressed in an increase in the greenhouse effect and climate change. Reducing CO_2 emissions is the most important goal of international climate policy [8]. During the 21st United Nations Framework Convention on Climate Change a decision to reduce CO_2 emissions in order to prevent global warming was made [8]. Since road transport makes a significant contribution to the growth of global emissions, the introduction of new technologies for saving fuel and the application of organizational measures with strict control over emissions is extremely important. Although technologies are already known in the field of automobile design that allow the elimination of internal combustion engines, however, the widespread use of electric vehicles does not yet occur.

In connection with the need to reduce the harmful effects of vehicles and reduce accidents on the roads in all civilized countries (including the Republic of Kazakhstan) a number of legislative acts have been adopted to normalize the environmental situation and ensure road safety. In particular, the Decree of the Government of the Republic of Kazakhstan No. 523 dated May 17, 2011 was adopted [9-11]. This document regulates the organization of mandatory technical inspection of motor vehicles and trailers for them, the frequency of its passage by motor vehicles. In accordance with the rules for conducting technical inspection, it is envisaged to control the parameters of the technical condition of vehicles on stationary and mobile lines. The increase in the flow of automobiles produced in the Republic of Kazakhstan makes it necessary to improve the work of diagnostic lines at the enterprises of the automotive industry. There is also a need to choose the structure of technological equipment and methods of organizing labor, improve and simplify the technological process in order to achieve the high results of economic efficiency.

The complexity of automobiles and their diversity in terms of designs requires the use of a large number of methods for testing systems and assemblies, the use of a variety of diagnostic stands and devices. For example, the number of parameters subject to mandatory registration and assessment for compliance with regulatory data when passing a mandatory technical inspection varies between 32-39 items for various types of rolling stock, and the number of main diagnostic stands and devices varies within 12-14. In addition, the characteristics of the equipment itself vary widely in terms of cost, degree of versatility, reliability, degree of mechanization and automation, the presence and absence of an interface for transmitting data to the diagnostic control line. When switching to modern information technologies, automatic registration and processing of controlled parameters is used, which in turn leads to a change in the technological process, a decrease in time losses during data entry and processing, and an increase in requirements for the level of organization of the technological process.

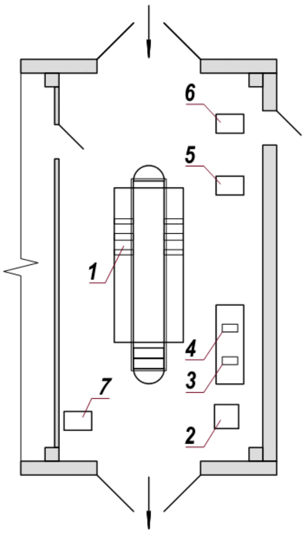
In this article, the authors has been considered four options for the location of test equipment on the diagnostic line for testing automobiles which are

1) One-station single-beam line (Figure 1, a). With this organization of labor, car maintenance is carried out at one post (n=1) as a result of which the employment of posts is maximum. At the same time, this option has minimal costs and insignificant economic efficiency.

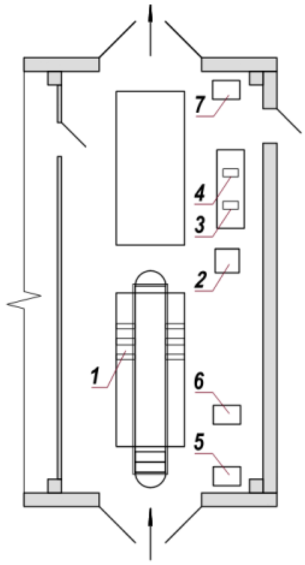
2) Two-post single-beam line (Figure 1, b). In this case, the labor intensity for performing operations is distributed evenly between two posts (n=2) which will lead to a comparative in-

crease in throughput. The cost of the equipment complex remains constant, the number of operators increases to 3.

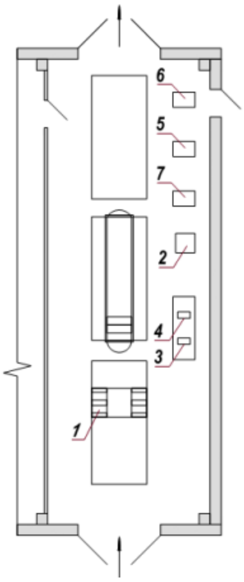
3) Three-post single-beam line (Figure 1, c). The diagnostic process is divided into three posts (n=3). The cost of the equipment complex remains constant, the number of operators increases to 4.



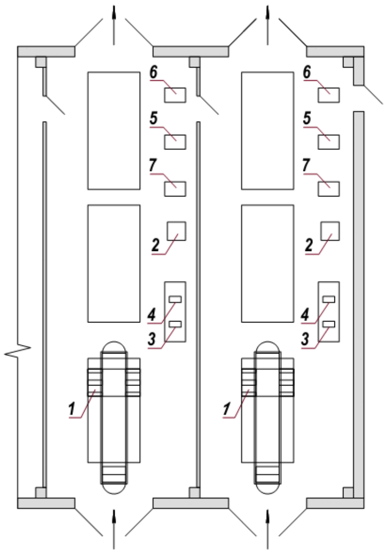
a) One-station single-beam line



b) Two-post single-beam line



c) Three-post single-beam line



d) Six-post two-beam line

Figure 1. The options of technological process organization: 1 – Stand for testing brake systems; 2 – Computer; 3 – A device for checking the full backlash of the steering; 4 – Leak detector; 5 – Smoke meter; 6 – Gas analyzer; 7 – A device for testing external lighting devices

4) Six-post two-beam line (Figure 1, d). This option involves the simultaneous maintenance of cars and trucks. The cost calculation takes into account the cost of diagnostic equipment for

trucks.

The purpose of this article is to select the optimal structure of the test equipment.

Materials and methods. The initial data for solving the problem are the average values of the number of tested cars in a certain interval obtained in the course of the statistical analysis. The data has been based on the data obtained from the D. Serikbayev EKTU Center of Competence in the field of automotive transport. Data was collected throughout the year by month, week, day by vehicle category. The quantitative information presented in Table 1 shows the frequency of the arrival of the number of vehicles in the test area during each hour of the working day (from 9:00 to 18:00). According to numerous studies, the statistical distribution corresponds to the Poisson law [12-15].

$$p(X) = e^{-\lambda X} \frac{(\lambda X)^{n_k}}{n_k!}, \quad (1)$$

In Eq.(1), X is the interval number; n_k is the number of vehicles in the test area at the appropriate interval.

Table 1. Average values of the number of cars by intervals

X	1 (9:00-10:00)	2 (10:00-11:00)	3 (11:00-12:00)	4 (12:00-13:00)	5 (14:00-15:00)	6 (15:00-16:00)	7 (16:00-17:00)	8 (17:00-18:00)
n_k	3,8	4,5	5,9	4,4	2,4	2,2	3,7	2,8

A graphical interpretation of the probability distribution is shown in Figure 2.

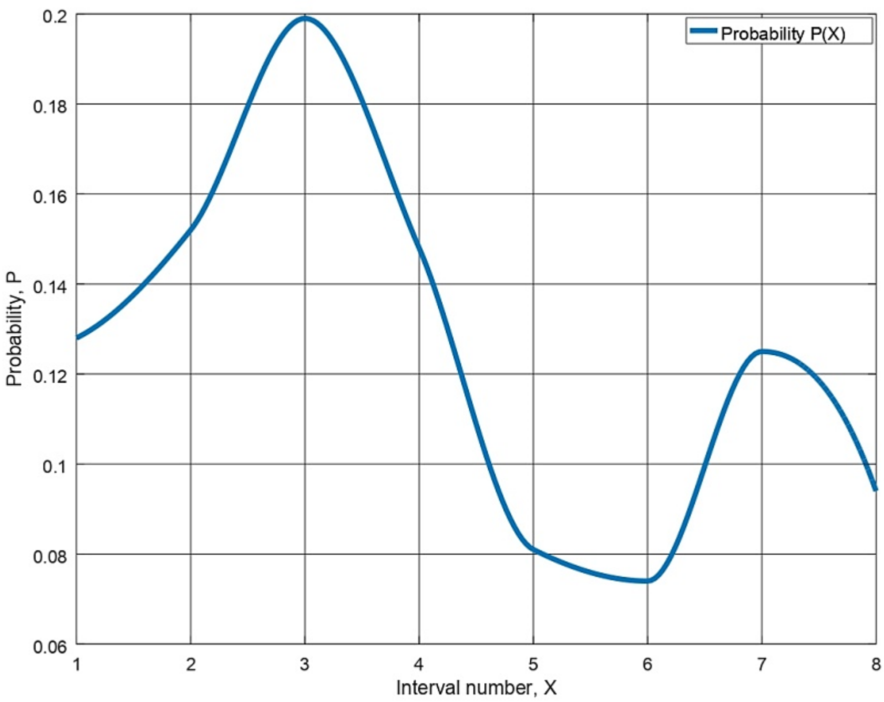


Figure 2. Probability distribution curve according to Poisson's law for cars

The algorithm for solving the problem includes determining the value of the mathematical expectation.

$$\lambda(n_k) = \sum_{i=1}^{n} n_k \cdot p \tag{2}$$

numerically equivalent to the intensity of car visits in the Center of Competence.

According to Eq. (2):

$\lambda(n_k) = 3{,}691$ (trucks per hour)

The average values of the number of trucks by intervals are presented in Table 2.

Table 2. Average values of the number of trucks by intervals

X	1 (9:00-10:00)	2 (10:00-11:00)	3 (11:00-12:00)	4 (12:00-13:00)	5 (14:00-15:00)	6 (15:00-16:00)	7 (16:00-17:00)	8 (17:00-18:00)
n_k	1,4	3,1	3,8	4,2	3,3	2,05	1,7	1,2

According to formula (2), the mathematical expectation of the system:

$\lambda(n_k) = 2{,}349$ (cars per hour)

A graphical interpretation of the probability distribution is shown in Figure 3.

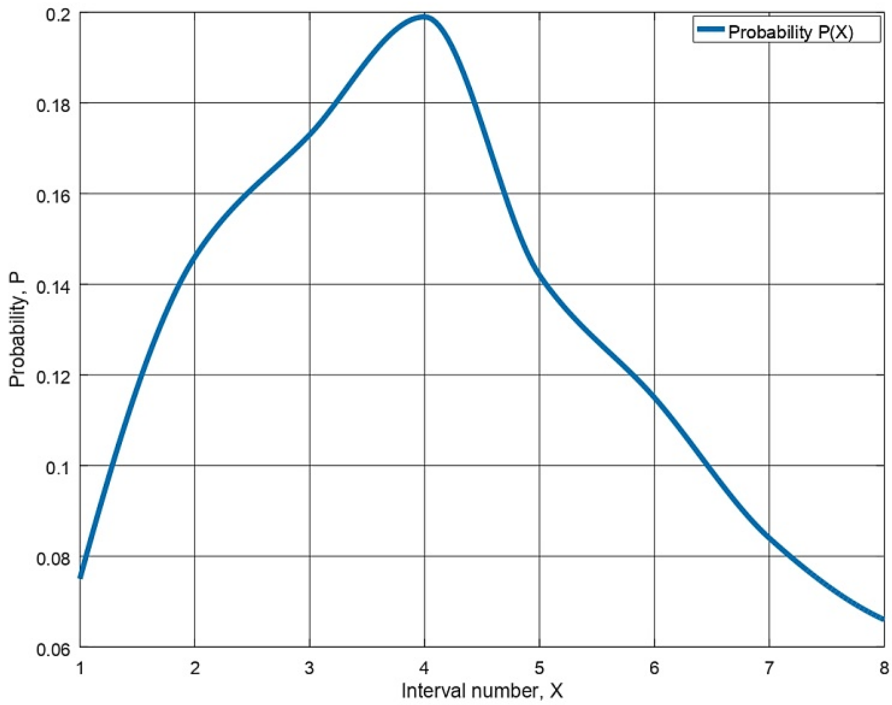


Figure 3. Probability distribution curve according to Poisson's law for trucks

A further research procedure is to consider a system consisting of several states S_0, S_1, S_k $\ldots S_n$: S_0 – there is no application in the system (all posts are free); S_1 – there is one application in the system (one post is occupied, the rest are free); S_k - there are k applications in the system (k posts are occupied, the rest are free); S_n – there are n applications in the system (all n posts are occupied) which is the limit state.

Each state has probabilities p_0, $p_1 \ldots p_k$, p_n representing some series. Expressing the probabilities in terms of p_0 and taking into account the normalization condition [12-15]

$$p_0 + p_1 + p_2 + \ldots + p_n = 1 \tag{3}$$

let us determine the probabilities using the Taylor series [12-15]:

$$p_0 = \left(1 + \rho + \frac{\rho^2}{2!} + \ldots \frac{\rho^k}{k!} + \ldots + \frac{\rho^n}{n!}\right)^{-1} = \frac{1}{e^n}, \tag{4}$$

$$p_1 = \rho p_0,\ p_2 = \frac{\rho^2}{2!} p_0, \ldots, p_k = \frac{\rho^k}{k!} p_0, \ldots, p_n = \frac{\rho^n}{n!} p_0, \tag{5}$$

In Eqs. (4) and (5), ρ is the reduced intensity of the flow of applications, i.e. the average number of cars arriving for the average service time of one car [12-15]:

$$\rho = \frac{\lambda}{\mu} \tag{6}$$

In Eqs. (6), λ is traffic intensity equal to the mathematical expectation of the system, μ is the complexity of servicing one car.

Based on the found probabilities, the characteristics of the efficiency of the process organization system are calculated, in particular, the probability of failure P_f, i.e. the probability that the arriving car will be refused (will not be serviced). To do this, all n posts must be occupied:

$$P_f = p_n = \frac{\rho^n}{n!} p_0 = \frac{\rho^n}{n!} \cdot \frac{1}{e^n} \tag{7}$$

relative throughput of the line , i.e. the probability that the application will be served:

$$Q = 1 - P_f = 1 - \frac{\rho^n}{n!} \cdot \frac{1}{e^n} \tag{8}$$

absolute throughput

$$A = \lambda Q = \lambda\left(1 - \frac{\rho^n}{n!} \cdot p_0\right) \tag{9}$$

Numerical results illustrated in Table 3 were obtained for the studied layout options.

Table 3. Automobile throughput depending on various options for organizing the technological process

Options for organizing the technological process	μ	$\rho = \frac{\lambda}{\mu}$	P_{OTK}	Q	A, aut./hour
Single station single beam line ($n = 1$)	2	1,845	0,291	0,709	2,615
Two-post single-beam line ($n = 2$)	1,8	2,051	0,271	0,729	2,693

Three-post single-beam line ($n = 3$)	1,6	2,307	0,204	0,796	2,939
Six-post two-beam line ($n = 6$)	1,4	2,212	0,197	0,803	4,841

Results and discussion. Thus, analyzing the results presented in the Table 3, it can be concluded that the values of the absolute vehicle throughput for single station single beam line and two-post single-beam line are almost the same, A=2.615 and A=2.693, respectively. With a three-post single-beam line, the efficiency of the diagnostic line is increased by 11% compared to the organization of the technological process corresponding to single station single beam line and two-post single-beam line. The most efficient option is the layout of diagnostic equipment corresponding to six-post two-beam line (absolute throughput value of A=4.841). With this organization of the technological process, the productivity of the diagnostic line increases by 46%.

Conclusion. The automotive industry is an integral part of modern engineering in our country. A large number of cars of different brands are produced at automobile plants in Kazakhstan.

Among the existing stages of the production cycle of the automotive industry, one of the main stages is the testing of cars. One of the key criteria for improving the efficiency of a diagnostic line is productivity (line capacity). As a rule, the performance of the line depends on the structure of the test equipment. In this article, the authors carried out theoretical studies of various options for the location of diagnostic equipment. To conduct research, a mathematical model based on the theory of queuing has been developed.

As the results of theoretical studies have shown, the most effective option is the location of the equipment corresponding to the six-post two-beam line. As a result of applying this option, the line productivity increases almost 2 times.

Thus, the results of these studies can be applied to car manufacturing enterprises. Using the mathematical model presented in the article, it is possible to choose the optimal structure of diagnostic equipment, which will increase the productivity of the line, and hence the economic efficiency of the production process.

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