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Selection of a fleet of vehicles for tasks based on the statistical characteristics of their operational parameters

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Highlights

- Statistical analysis was used to estimate the operational parameters of the vehicles.
- A multi-criteria method of selecting a fleet of vehicles for the tasks was developed.
- Reliability and cost of use evaluate the selection of a fleet for the tasks.
- A new decision model for selecting a fleet of vehicles for the tasks was presented.

Abstract

The article presents a method of selecting a fleet of vehicles with a homogeneous structure for tasks based on the statistical characteristics of their operational parameters. The selection of a vehicle fleet for tasks is one of the stages of vehicle fleet management in transport companies. The selection of a vehicle fleet for tasks has been defined as the allocation of a vehicle model to a given company, which is associated with the unification of the vehicle fleet to one specific type. The problem of selecting a fleet of vehicles has been presented in a multi-criteria approach. The operational parameters assessing the selection of vehicles for the tasks are mileage and the number of days to the first and subsequent failure, and vehicle maintenance costs. The developed method of selecting a fleet of vehicles for the tasks consists of two stages. In the first stage, the average operating parameter values are determined using statistical inference. In the second stage, using the MAJA method, a unified model of the fleet of vehicles operating in the enterprise is established.

Keywords

vehicle fleet management, vehicle selection for tasks, multi-criteria MAJA assessment method, statistical analysis of vehicle operating parameters.

1. Introduction

The selection of a fleet of vehicles for tasks is one of the stages in fleet management in transport companies. In the literature on the subject, there are many publications on the issues of supporting vehicle fleet management in terms of selecting a given vehicle for the implementation of commissioned tasks [19, 23]. Selecting a fleet of vehicles for tasks in transport companies is a complex decision-making process. On the one hand, customers' requirements covering a wide range of outsourced transport tasks should be taken into account. On the other hand, the technical potential of operators performing various transport processes and thus having a different fleet of vehicles should be considered. The selection of a fleet of vehicles for the tasks depends primarily on the business profile of a given company and current transport needs.

Considering the above, when selecting a fleet of vehicles for the tasks, special attention should be paid to their technical parameters, including cargo parameters and the efficiency and economy of the drive unit (unit engine power, fuel consumption). An essential functional feature is also their failure rate. The lower it is, the lower the maintenance costs of the fleet and the risk of failure to complete the task will be.

In classical literature and the literature relating to vehicle fleet management, selecting a vehicle fleet for tasks is understood as the allocation of a specific vehicle to a transport task or task. As a result of many studies [2, 34] the issue of assigning vehicles to tasks may be considered in terms of technical, economic, organizational and qualitative aspects. According to the literature, the classic allocation issue consists of assigning the available vehicles to the assigned tasks. The assignment assumes that each task, if possible, is assigned to precisely one vehicle and each vehicle completes only one task. The measures of a correctly generated allocation usually determine the minimum completion time for all tasks or the minimum cost of task completion. The issue is often modified by introducing various combinations of the number of assigned tasks to vehicles, e.g. an equal number of tasks and vehicles, more than vehicles, and fewer than vehicles.

Considering the current problems in the management of the vehicle fleet, the definition of the selection of the vehicle fleet for the tasks was modified and presented in a broader sense. The selection of the vehicle fleet for the tasks in the article was defined as the allocation

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of a vehicle model (brand) to a given company, which is associated with the unification of the vehicle fleet to one specific type. This approach is the current trend in vehicle fleet management and is recommended by transport companies. The benefits of standardizing the model (brand) of the car fleet in transport companies play an essential role in reducing servicing and repair costs compared to the diversified fleet [11]. The benefits of the standardization of the rolling stock are even more significant if the company's fleet is standardized to a model/brand of the manufacturer, which is currently characterized by the lowest failure rate concerning other brands of vehicles, operating costs or time of carrying out transport tasks.

The article aims to develop a method of selecting a fleet of vehicles with a homogeneous structure for transport tasks carried out in a given transport company, using descriptive statistics and procedures of statistical inference of selected operational parameters of vehicles. Statistical inference is related to the need to conduct measurements on a selected random sample, which covers a specific number of vehicles of a given model (brand). According to the assumption of the developed method, the average operating parameters of vehicles of a given model, determined based on a random sample, are verified using statistical hypotheses to the average values of parameters describing the entire population of vehicles operating in enterprises. For this purpose, the article uses tests to determine the mean value for the population. The problem of selecting a fleet of vehicles for transport tasks has been presented in a multi-criteria approach, so choosing a specific vehicle model was carried out using the multi-criteria assessment method for variants of MAJA solutions [22].

The article presents a decision-making model for selecting a vehicle brand to perform specific transport tasks. In the model, the operational parameters assessing a given vehicle make are mileage and the number of days to the first and subsequent failure and vehicle maintenance costs. The task of the developed method based on the decision model is to indicate such a vehicle brand, the operating parameters of which tend to the minimum values.

Bearing in mind the above, the article is divided into four parts. The first presents a research problem and an analysis of the literature on selecting vehicles for tasks and fleet management. The second part is developing a decision-making model for selecting a given vehicle brand for the tasks carried out in the company. The next part presents the method of assigning a given vehicle model to the fleet operating in the company. In contrast, the last part is verifying the proposed method based on actual data.

2. Literature analysis

The car fleet plays an essential role in the enterprise, especially in logistics, transport of goods, trade and mobile services. The selection of the appropriate fleet impacts the quality of services provided, timeliness, competitive advantage and cost optimization [29, 38]. Due to the variety of aspects that need to be taken into account, selecting a fleet of vehicles for tasks is a complex decision-making problem, often requiring the selection of compromise solutions. In this process, emphasis is placed not only on the optimization of transport costs related to the implementation of commissioned tasks but also on the aspect of safety and reliability of the rolling stock [31, 36] and the ecological part [25].

In the case of safety or reliability, one can mention, for example, the failure rate of vehicles in car fleets. For example, the authors of [16] indicate that the most significant repair costs are generated by damage to the suspension system and drive system and the engine, drive system, and brake system. Failure frequency of the mentioned systems is indicated in many works [24, 30].

The selection of the vehicle fleet for the tasks due to the availability and quality of the service network is presented in the paper [37]. The problem of selecting the fleet has been presented in a multi-criteria approach. Among the criteria, they distinguished groups of criteria: repair costs, quality of repairs, location of the service network and its equipment, and availability of parts. Using the hybrid DEMATEL multi-criteria decision support method, the authors solved the problem with a network analysis of processes.

Wang et al. [39] present a method of selecting a vehicle fleet for tasks based on the evolutionary algorithms of NSGA-III, SMS-EMOA, and DI-MOEA. In their work, they emphasize that with a fleet consisting of a large number of vehicles and operating over a large area (e.g. the entire country), when creating vehicle service schedules, many criteria should be taken into account, such as the distance to the service or various repair costs at multiple sites.

When selecting a fleet of vehicles for tasks, servicing damaged vehicles is essential. Jacyna and Semenov [20] raise the problem of ensuring the availability of significant parts in service stations. In their work, they proposed a proprietary optimization algorithm to minimize the risk associated with purchasing parts. The model is based on uncertain information related to various random situations, the risk of misdiagnosing a damaged vehicle associated with purchasing the wrong part, or the risk of selling the lousy part by the supplier.

The critical measure in selecting a fleet of vehicles is the cost of vehicle operation. These costs depend, among others, on repairs and maintenance and costs resulting from the purchase of consumables [4]. In classic models of selecting a vehicle fleet for tasks, assessing the allocation of vehicles to tasks is the cost or time of performing all tasks [15, 17].

In most cases, the problem of selecting a fleet of vehicles is presented in terms of multiple criteria. Therefore, multi-criteria assessment methods are often used to assign vehicles to tasks [8, 26]. The classic selection of vehicles for tasks is often described using the graph theory [44] and operations research [33, 43], which emphasizes the optimization aspect of the problem under study. Considering the complexity of the problem of selecting a fleet for tasks, this problem is often solved with heuristic algorithms, in particular with the genetic algorithm [7, 28] and with the help of linear programming [13] or the Tabu search algorithm [32].

The process of selecting vehicles for tasks is also related to the issue of determining the driver's work schedule (timetable) and thus assigning the driver to work shifts [27]. The problem of assigning drivers in fleet management is a complex issue, for example, because introducing a vehicle to a given route is associated with restrictions resulting from the driver's working and driving time.

The authors of the work [10] indicate that a typical scenario for the allocation of vehicles to tasks is to arrange a fleet of vehicles in such a way as to minimize, among others: the total cost of travel by vehicles with limited capacity to deliver the order to several customers [3], or the time of municipal waste collection [18]. Depending on the type of company managing a given fleet of vehicles, the allocation problem may be subject to certain modifications by introducing additional restrictions (e.g. time intervals for route implementation). However, the main task is to allocate the minimum number of available resources, e.g. vehicles, to designated routes. The issue of the allocation of vehicles to routes and schedules of driving routes in transport companies has been presented in many publications, among which one can indicate, among other things [9, 12].

An essential aspect of allocating a fleet of vehicles to transport tasks, which has been gaining in importance and popularity in recent years, is the environmental safety of the transport fleet. The authors present exciting analyses in the article [42], indicating the environmental benefits of using high-tonnage vehicles powered by LNG in cargo transport. The ecological safety of the transport fleet is determined by various factors, among which the authors of the work [2] mention vehicles in poor technical condition and emitting an increased amount of toxic compounds into the atmosphere [6], an adequately selected engine oil with low viscosity, which increases the efficiency of the engine and at the same time reduces fuel consumption[14], oil pollution with fuel [1]. The selection of vehicles for the tasks to reduce exhaust emissions to the environment is often taken into account when creating environmentally friendly transport systems [21, 41]. In the case of vehicle recycling systems, the selection of the fleet is of crucial importance in terms of environmental protection and minimizing the number of toxic compounds in the atmosphere [5].

Kazanç et al. [25] analyzed the problem of allocating the fleet, taking into account two aspects, i.e. profitability and the level of exhaust emissions. In the presented model, they used the two-criteria model of linear programming. Profit maximization and exhaust gas minimization for the heterogeneous fleet were analyzed. The transport fleet on long-distance routes was studied, taking into account various scenarios, the return with and without a load, and the fuel consumption was determined for each version.

In the summary of the literature analysis, it can be stated that selecting a fleet of vehicles for tasks is a complex optimization process and should be analyzed in a multi-criteria approach. In the article, the authors focused on two aspects: the reliability aspect of minimizing the mileage and days to the first and subsequent vehicle failures, and the economic aspect as the cost of vehicle maintenance. The literature analysis showed a research gap in selecting a vehicle model with a homogeneous structure for the fleet of a given company. In most publications, choosing a vehicle fleet is understood as assigning a specific vehicle to a task. The choice of vehicles is made from among vehicles with a heterogeneous structure. The method of selecting a fleet of vehicles for the tasks proposed by the authors determines one vehicle model, which is effective in terms of reliability and economy. It thus minimizes the risk of incorrect allocation of individual vehicles to tasks.

3. A decision model for selecting a vehicle fleet for tasks in the enterprise

3.1. General assumptions

The decision-making model for selecting a given type of vehicle model (brand) for the fleet applies to transport companies. Various transport tasks are carried out in various transport systems, e.g. transport systems, load transporters, or entire truckload transport [40, 35]. The decision model unifies the brand of the vehicle fleet and adjusts it to the nature of the tasks performed in a given enterprise. A given vehicle model should not only have a minimum failure rate (reliability) compared to other models but also a minimum maintenance cost. Therefore, the right choice of rolling stock in every transport company is crucial. Using the decision-making model, the vehicle type (brand) is selected for the company‘s fleet, taking into account a multi-criteria approach. The individual functions of the criteria refer to the cost of vehicle maintenance and reliability measures such as average mileage to the first failure (failure) of a given brand, average mileage to subsequent failures of a given brand, average number of days to the first failure for a given brand, the average number of days to subsequent losses, the average damage intensity of a given brand. Assumptions for the vehicle fleet selection model:

- The transport task in the enterprise is interpreted as a driving route between individual points of the transport network. Depending on the nature of the enterprise, vehicles may visit unique loading/unloading points by the prescribed delivery or collection schedule (collection or pickup systems) or follow the transport route from a collection point directly to the unloading point (full truckload systems).
- The routes of the transport assignments are known and defined by the mobility plan of each enterprise. A company’s mobility plan is interpreted as a schedule of tasks assigned to be performed by vehicles, which is adapted to customers’ needs for transport services.
- It is assumed that the vehicles once visit the loading and unloading points. Loading and unloading times were omitted.
- It was assumed that fleet maintenance costs include fuel consumption, repairs, and regular servicing to simplify the model.

3.2. Model input data

To develop a decision-making model for the selection of a fleet of vehicles for tasks, you should enter data on the transport network in which the vehicle mobility plan carries out transport tasks, define transport tasks in the form of vehicle driving routes based on which the cost of fuel consumption and task completion times for individual tasks will be determined. Vehicles, locate transport bases from which vehicles leave for tasks, locate customers/entities generating tasks for implementation, define technical parameters of the vehicle fleet, define points that are the beginning of transport tasks, i.e. points where cargo is collected from customers, define intermediate points and final shipping tasks. The necessary input data describing the decision model are presented in Tab. 1-Tab. 3.

Table 1. Elements of the transport network

Symbol	Meaning
P	a set of numbers of starting points of transport tasks
I	a set of intermediate point numbers
K	a set of numbers of endpoints of transport tasks
B	a set of numbers of transport bases
LPI	a set of connections between the starting point and an intermediate point
LIP	a set of connections between an intermediate point and a starting point
LII	a set of links between intermediate points
LIK	a set of connections between an intermediate point and an endpoint
LKI	a set of connections between an endpoint and an intermediate point
LBI	a set of connections between the base and an intermediate point
LIB	a set of connections between an intermediate point and a base
LBP	a set of connections between the base and the starting point
LKB	a set of connections between the endpoint and the base

Table 2. Characteristics of the elements of the transport network

Symbol	Meaning
Q1	customer demand on a given day of vehicle use (intermediate points of the transport task)
Q2	demand of recipients on a given day of vehicle use (endpoints of the transport task)
Q3	size of loads collected from senders (intermediate points of the transport task)
Q4	size of loads collected from senders (intermediate points of the transport task)
D1	a distance matrix between the starting point and the intermediate point
D2	a distance matrix between the intermediate point and the starting point
D3	a distance matrix between intermediate points
D4	a distance matrix between the intermediate point and the end point
D5	a distance matrix between end point and intermediate point
D6	a distance matrix between base and intermediate point
D7	a distance matrix between the intermediate point and the base
D8	a distance matrix between base and starting point
D9	a distance matrix between endpoint and base

D10	a distance matrix between intermediate points (without realization of the task)
T1	a driving time matrix between starting point and an intermediate point
T2	a driving time matrix between an intermediate point and a starting point
T3	a driving time matrix between intermediate points
T4	a driving time matrix between an intermediate point and an end point
T5	a driving time matrix between end point and an intermediate point
T6	a driving time matrix between base and waypoint
T7	a driving time matrix between an intermediate point and a base
T8	a driving time matrix between base and starting point
T9	a driving time matrix and between end point and base point
T10	a driving time matrix between intermediate points (without task completion)
R	set of relations between a given route start point *p* and end point *k*
ZAD	a set of all tasks carried out in the enterprise

Table 3. Characteristics of the vehicle fleet

Symbol	Meaning
M	a set of models (brands) of vehicles in the enterprise
***LP*(*m*)**	a set of vehicles of a given model
S	a matrix of average fuel consumption for individual vehicles
***U*(*lp*(*m*))**	a set of damage to vehicles of a given model
P	a mileage vector to the first vehicle damage
P1	a matrix of the course between successive failures
LD	a number of days until the first failure
LD1	a matrix of the number of days between successive failures
F	a matrix of vehicle damage intensity in a given period
KS	a vector of the average cost of servicing a vehicle of a given model
KN	a vector of the average repair costs of a given model vehicle
KU	a vector of the average fuel costs of a vehicle of a given model
ZP	a vector of the average fuel consumption of the vehicle of a given model
V	a vector of vehicle capacity of a given model

3.3. Model decision variables

The model distinguishes two types of decision variables with different interpretations, Tab. 4. The first type of decision variable concerning the performance of selecting the vehicle brand for the company's fleet is determined directly by the decision model supporting vehicle fleet management. The second type of variable about vehicle route interpretation is defined by the vehicle mobility plan and is not subject to the optimization process. Nevertheless, these variables are necessary to determine fuel consumption, which allows the cost of maintaining a given brand of vehicle to be calculated.

Table 4. Model decision variables

Symbol	Meaning
X	selecting the model (brand) of vehicles for the company's fleet
X1	a connection between the starting point and an intermediate point
X2	a connection between an intermediate point and a starting point
X3	a connection between intermediate points
X4	a connection between an intermediate point and an endpoint
X5	a connection between an end point and an intermediate point
X6	a connection between base and intermediate point
X7	a connection between an intermediate point and the base
X8	a connection between base and starting point
X9	a connection between the endpoint and the base
X10	a connection between intermediate points (without task execution)

3.4. Limits

The model's limitations are limited to the limitations resulting directly from selecting a vehicle model for the tasks and constraints resulting from the assumed vehicle mobility plans. The following limitations are defined:

– Selection of one vehicle model for the company's fleet:

$$\sum_{m \in \mathbf{M}} x(m) = 1 \tag{1}$$

– The working time of the vehicle on a given day of use should not exceed the permissible working time – T:

$$\forall lp(m) \in \mathbf{LP}(m), d \in \mathbf{D}, m \in \mathbf{M}$$
$$\forall (p,i) \in \mathbf{LPI}, (i,i') \in \mathbf{LII}, (i,k) \in \mathbf{LIK}$$
$$\sum_{(p,k)\in\mathbf{R}} \sum_{zad(p,k)\in\mathbf{ZAD}(p,k)} \Big(x1\big((p,i), zad(p,k), d, lp(m)\big) \cdot t1(p,i) + x3\big((i,i'), zad(p,k), d, lp(m)\big) \cdot t3(i,i') +$$
$$+ x4\big((i,k), zad(p,k), d, lp(m)\big) \cdot t4(i,k) +$$
$$+ \sum_{(i,p)\in\mathbf{LIP}} x2\big((i,p), d, lp(m)\big) \cdot t2(i,p) + \sum_{(k,i)\in\mathbf{LKI}} x5\big((k,i), d, lp(m)\big) \cdot t5(k,i) + \sum_{(b,i)\in\mathbf{LBI}} x6\big((b,i), d, lp(m)\big) \cdot t6(b,i) +$$
$$+ \sum_{(i,b)\in\mathbf{LIB}} x7\big((i,b), d, lp(m)\big) \cdot t7(i,b) + \sum_{(b,p)\in\mathbf{LBP}} x8\big((b,p), d, lp(m)\big) \cdot t8(b,p) + \sum_{(k,b)\in\mathbf{LKB}} x9\big((k,b), d, lp(m)\big) \cdot t9(k,b) +$$
$$+ \sum_{(i,i')\in\mathbf{LII}} x10\big((i,i'), d, lp(m)\big) \cdot t10(i,i') \le T \tag{2}$$

– Limited vehicle capacity in the transport system:

$$\forall lp(m) \in \mathbf{LP}(m), d \in \mathbf{D}, m \in \mathbf{M}$$
$$\forall (p,i) \in \mathbf{LPI}, (i,i') \in \mathbf{LII}, (i,k) \in \mathbf{LIK}, zad(p,k) \in \mathbf{ZAD}(p,k), (p,k) \in \mathbf{R}$$
$$x1\big((p,i), zad(p,k), d, lp(m)\big) \cdot q4(p,d) + x3\big((i,i'), zad(p,k), d, lp(m)\big) \cdot [q3(i,d) + q3(i',d)]$$
$$\le v\big(lp(m)\big) \tag{3}$$

– Restriction to meet the needs of customers (in the collector - (4), shuttle - (5), (6), full truck load - (7):

$$\forall lp(m) \in \mathbf{LP}(m), d \in \mathbf{D}, m \in \mathbf{M}$$

$$\forall (p,i) \in \mathbf{ÉPI}, (i,i') \in \mathbf{LII}, (i,k) \in \mathbf{LIK}, zad(p,k) \in \mathbf{ZAD}(p,k), (p,k) \in \mathbf{R}, k \in \mathbf{K}, i \in$$

$$x1((p,i), zad(p,k), d, lp(m)) \cdot q4(p,d) + x3((i,i'), zad(p,k), d, lp(m)) \cdot [q3(i,d) + q3(i',d)] \leq q2(k,d) \tag{4}$$

$$x1((p,i), zad(p,k), d, lp(m)) \cdot q4(p,d) \geq q1(i,d) \tag{5}$$

$$x1((p,i), zad(p,k), d, lp(m)) \cdot q4(p,d) \geq q2(k,d) \tag{6}$$

$$x1((p,i), zad(p,k), d, lp(m)) \cdot q4(p,d) = x4((i,k), zad(p,k), d, lp(m)) \cdot q2(k,d) \tag{7}$$

3.5. Evaluation criteria

The measures of assessing the selection of a vehicle brand for the company's fleet have been classified into two groups: reliability measures in the use of vehicles of a given brand and average vehicle maintenance costs of a given brand. Reliability measures take the form:

– average mileage to the first failure (failure) for a given vehicle model:

$$\sum_{m \in \mathbf{M}} \left(\frac{\sum_{lp(m) \in \mathbf{LP}(m)} p(lp(m))}{\overline{LP(m)}} \cdot x(m) \right) \longrightarrow \min \tag{8}$$

– average mileage between successive failures:

$$u(lp(m)), u(lp(m))' \in \mathbf{U}(lp(m))$$

$$\sum_{m \in \mathbf{M}} \left(\frac{\sum_{lp(m) \in \mathbf{LP}(m)} p1(lp(m), u(lp(m)), u(lp(m))')}{\overline{LP(m)}} \cdot x(m) \right) \longrightarrow \min \tag{9}$$

– average number of days to first failure:

$$\sum_{m \in \mathbf{M}} \left(\frac{\sum_{lp(m) \in \mathbf{LP}(m)} ld(lp(m))}{\overline{LP(m)}} \cdot x(m) \right) \longrightarrow \min \tag{10}$$

– average number of days between failures:

$$u(lp(m)), u(lp(m))' \in \mathbf{U}(lp(m))$$

$$\sum_{m \in \mathbf{M}} \left(\frac{\sum_{lp(m) \in \mathbf{LP}(m)} ld1(lp(m), u(lp(m)), u(lp(m))')}{\overline{LP(m)}} \cdot x(m) \right) \longrightarrow \min \tag{11}$$

– average damage intensity for a given vehicle model:

$$\sum_{m \in \mathbf{M}} \left(\frac{\sum_{lp(m) \in \mathbf{LP}(m)} f(lp(m))}{\overline{LP(m)}} \cdot x(m) \right) \longrightarrow \min \tag{12}$$

The average cost of maintaining a given vehicle brand in the enterprise includes only the costs related to fuel, service and repair. All fixed costs associated with vehicle insurance or depreciation were omitted. Service and repair costs are average values calculated from the period under examination (time interval) for a single vehicle.

The average cost of maintaining all vehicles in the enterprise for a given model is described as:

$$KU(X) = \sum_{m \in \mathbf{M}} \left(\frac{\sum_{lp(m) \in \mathbf{LP}(m)} ku(lp(m)) + \sum_{lp(m) \in \mathbf{LP}(m)} ks(lp(m)) + \sum_{lp(m) \in \mathbf{LP}(m)} kn(lp(m))}{\overline{LP(m)}} \cdot x(m) \right) \longrightarrow \min \tag{13}$$

where the average cost of fuel consumption is determined based on the cost of fuel consumption on a given day of vehicle use, which is determined by the formula (c- fuel cost):

$$\forall lp(m) \in \mathbf{LP}(m), d \in \mathbf{D}, m \in \mathbf{M},$$

$$\forall (p,i) \in \mathbf{LPI}, (i,i') \in \mathbf{LII}, (i,k) \in \mathbf{LIK}$$

$$\begin{aligned} dku(lp(m)) = & \Bigg(\sum_{(p,k) \in \mathbf{R}} \sum_{zad(p,k) \in \mathbf{ZAD}(p,k)} \big(x1((p,i), zad(p,k), d, lp(m)) \cdot d1(p,i) + x3((i,i'), zad(p,k), d, lp(m)) \cdot d3(i,i') + \\ & + x4((i,k), zad(p,k), d, lp(m)) \cdot d4(i,k) + \\ & + \sum_{(i,p) \in \mathbf{LIP}} x2((i,p), d, lp(m)) \cdot d2(i,p) + \sum_{(k,i) \in \mathbf{LKI}} x5((k,i), d, lp(m)) \cdot d5(k,i) + \sum_{(b,i) \in \mathbf{LBI}} x6((b,i), d, lp(m)) \cdot \\ & \cdot d6(b,i) + \\ & + \sum_{(i,b) \in \mathbf{LIB}} x7((i,b), d, lp(m)) \cdot d7(i,b) + \sum_{(b,p) \in \mathbf{LBP}} x8((b,p), d, lp(m)) \cdot d8(b,p) + \sum_{(k,b) \in \mathbf{LKB}} x9((k,b), d, lp(m)) \cdot \\ & \cdot d9(k,b) + \\ & + \sum_{(i,i') \in \mathbf{LII}} x10((i,i'), d, lp(m)) \cdot d10(i,i') \Bigg) \cdot \\ & \cdot zp(lp(m)) \cdot c \end{aligned} \tag{14}$$

4. The method of selecting a fleet of vehicles for tasks in the enterprise

4.1. Assumptions of the method

To assign a specific vehicle model (brand) to the tasks carried out by a given company, a method of selecting a fleet of vehicles for tasks has been developed, which bases its operation on the multi-criteria assessment of MAJA solutions [22]. As specified in the decision model, this method assigns a given vehicle model (brand) to the company, unifying the vehicle fleet to one specific brand. The proposed method selects the final solutions based on defined evaluation measures for various variants of the proposed solutions. The variants in the analyzed method are potential types of vehicles, one of which will be selected and put into use in the enterprise.

The proposed method consists of two stages. In the first stage, a statistical analysis of the measured and calculated parameters characterizing a given vehicle model, e.g. the cost of maintenance or the number of failures. This is related to the selection of a research sample within each model based on which tests and statistical analyzes will be carried out to verify the hypotheses about the distribution of the parameter under study or tests determining the mean value of a given parameter for the entire population (all vehicles of a given model in the enterprise). Essential descriptive characteristics are determined for each sample, e.g. sample mean value or variance.

First, the probability distribution of the parameter under examination should be examined within each sample, emphasising the indication of the normal distribution as the dominant distribution. The following tests will be used to verify the normality of the tested sample: the Kolmogorov-Smirnov (K-S) normality test with the Lilliefors test and the Shapiro-Wilk test.

The need to examine the distribution of the studied sample and the essential descriptive characteristics are required to carry out tests determining the mean values of the tested parameters for the entire population (all vehicles operating in the enterprise within a given model). In the second stage of the method, the multi-criteria MAJA assessment method will determine the final solution. The condition for implementing this method is to define the evaluation criteria, i.e. parameters that evaluate a given type of vehicle and determine the weights of these criteria. The evaluation criteria are the average values of the parameters specified in the first stage of the developed method (evaluation measures defined in the decision model).

The steps of the method can be described in the following steps:

- **Step 1.** The input of input data: vehicle models, measurements of selected parameters characterizing given vehicle brands.
- **Step** 2. Determination of mean values and variances for samples.
- **Step** 3. Examination of the probability distributions of the tested samples.
- **Step**. 4. Kolmogorov-Smirnov (K-S) normality test with the Lilliefors test and the Shapiro-Wilk test.
- **Step** 5. Choice of test statistic depending on the established distribution.
- **Step** 6. Conducting tests for mean values in the population.
- **Step** 7. MAJA multi-criteria assessment.

4.2. Tests to determine the mean value of the vehicle population

It should be emphasized that the method of selecting the vehicle fleet for the tasks is based on the average values of the parameters determined for the entire population (all vehicles in the enterprise), not on the average values within a given sample. To determine the mean value of the examined parameter for the entire population, tests examining a given type of random variable distribution are first carried out. Three tests were used to check whether a given variable has a normal distribution, i.e. the Kolmogorov-Smirnov (K-S) normality test with the Lilliefors test and the Shapiro-Wilk test. The Kolmogorov-Smirnov test is based on comparing the distribution in the sample with the theoretical normal distribution. For the Kolmogorov-Smirnov test, it is required to know the mean and standard deviation of the entire population. When we do not know it, and this is the case most often, we use the Kolmogorov-Smirnov test with the Lilliefors correction. The Shapiro-Wilk test is the most recommended for verifying normal distributions. In the case of a sample size of more than two thousand cases, it may give erroneous results. The Lilliefors test or the chi-square test is then used. Suppose it is found that the individual parameters characterizing a given vehicle model have a normal distribution. In that case, the t-Student statistics are used to determine the average values for all vehicles operating in the enterprise within a given model:

$$t = \frac{\bar{x} - \mu_0}{s}\sqrt{n} \tag{15}$$

where:

$\bar{x}$ – the mean value of the sample for the parameter under study;
s – standard deviation of the sample;
μ_0 – hypothetical mean value for the entire population;
n – the size of the research sample.

For any distribution, the test statistic is the Z statistic, which takes the form:

$$z = \frac{\bar{x} - \mu_0}{\sigma}\sqrt{n} \tag{16}$$

gdzie:

σ – standard deviation of the population.

5. Verification of the method of selecting a fleet of vehicles for the tasks

5.1. Input data and benchmarking

The verification of the method was carried out based on the transport company carrying out the tasks with six models (brands) of vehicles. For comparative studies, samples consisting of 6 brands of passenger vehicles of the same class were selected. All vehicles were used in similar operating conditions, in an even manner, which means that they received an approximate number and size of tasks to be performed. The research considered the approximate technical parameters of vehicles, i.e. permissible load and capacity, to avoid generating additional routes for particular types of vehicles. The analyzed vehicles reached the mileage in their useful life of not less than 90,000 km and not more than 125,000 km. The service life did not exceed 51 months. Vehicles with an engine powered by diesel fuel were tested. The sample size for each vehicle type (brand) was defined as follows: Kia Ceed - 261, Peugeot 308 - 156, Volkswagen Golf - 115, Hyundai - 108, Renault - 94, Opel Astra V - 49.

During the study, data was collected containing information related to the use of vehicles, such as: operating costs of each vehicle brand, failure costs, damage costs, the average decrease in the value of the vehicle over its lifetime; mileage to the first failure and between failures, days to the first failure and between failures.

A breakdown (damage) is assumed when the car was immobilized on the road or towed for service repair, and repairs lasted longer than 6 hours. The time and mileage to the first failure and subsequent failures in a given period and mileage were examined. The number of vehicles that had the first and subsequent failures in intervals of 10 thousand km. The study showed that the number of cars with breakdowns is decreasing. A significant decrease in the number of cars with a breakdown of the 3rd, 4th and 5th was noticed in Kia, Peugeot and Opel cars. The study's lowest number of cars with any breakdown

Table 5. Percentage share of cars with breakdowns

Brand / Model	% of cars to the first breakdown	% from the first to the second failure	% from the second to the third failure	% from the third to the fourth failure	% from the fourth to fifth failures
KIA Ceed	47,89	15,71	4,88	1,15	0,77
PEUGEOT 308	51,28	19,87	4,49	1,28	0,00
VOLKSWAGEN GOLF VII	78,26	40,00	17,39	9,57	2,61
HYUNDAI	79,63	44,44	23,15	9,26	1,85
RENAULT	76,60	38,30	19,15	8,51	4,26
OPEL Astra V	61,22	36,73	2,24	6,12	2,04

Table 6. Average mileage until the first failure and between successive failures

Vehicle model	Mileage to the first failure	Mileage from the first to the second failure	Mileage from the second to the third failure	Mileage from the third to the fourth failure	Mileage from the fourth to the fifth failure
KIA Ceed	60995,46	35685,44	15559,48	12489,96	5425,03
PEUGEOT 308	60551,62	34496,55	25492,81	15510,08	0
VOLKSWAGEN GOLF VII	70479,55	24539,71	24476,19	13445,98	6481,76
HYUNDAI	51441,85	27500,44	20489,05	18477,84	27478,33
RENAULT	58450,83	28460,93	25473,47	11487,18	7539,66
OPEL Astra V	59430,12	22473,27	28461,12	8502,81	20475,27

Table 7. Mean time to the first failure and between failures

Vehicle model	Days until the first failure	Days from the first to the second failure	Days from the second to the third failure	Days from the third to the fourth failure	Days from the fourth to the fifth failure
KIA Ceed	651,89	349,31	196,20	182,46	85,72
PEUGEOT 308	550,94	352,10	250,59	179,56	0
VOLKSWAGEN GOLF VII	647,40	251,00	250,78	197,74	126,54
HYUNDAI	550,65	256,29	248,50	162,12	250,71
RENAULT	547,09	250,92	247,74	160,10	78,27
OPEL Astra V	545,20	244,04	353,46	170,04	167,40

Table 8. Average failure rate

Vehicle model	Average cost of failure (PLN)	Average number of failures	Average mileage between failures (km)
KIA Ceed	237	0,71	60 370
PEUGEOT 308	745	0,77	57 382
VOLKS. GOLF VII	1 952	1,52	59 212
HYUNDAI	669	1,60	46 270
RENAULT	1 125	1,49	52 363
OPEL Astra V	1 349	1,27	47 787

Table 9. Average cost of damage

Vehicle model	Average cost of damage (PLN)	Average amount of damage	Average duration of damage repair (days)
KIA Ceed	6268	3,85	11,20
PEUGEOT 308	3589	1,38	9,30
VOLKS. GOLF VII	3799	2,43	4,76
HYUNDAI	5545	3,07	10,46
RENAULT	4174	1,15	8,90
OPEL Astra V	3214	1,49	9,61

Table 10. Average decrease in the value of the vehicle

Vehicle model	Average decrease in value during the term of the contract (PLN)	Average decrease in value %
KIA Ceed	20492	42,51
PEUGEOT 308	29855	45,42
VOLKS. GOLF VII	16352	29,50
HYUNDAI	17734	48,59
RENAULT	34241	63,56
OPEL Astra V	22750	42,52

concerned the Kia brand - 47.89%. The Hyundai brand had the largest share - 79.63%. (Tab. 5).

Tab. 6 summarises the fleet mileage to the first failure, while Tab.7 shows the average time to the first failure and between failures, calculated in days.

The average failure rate of the given models, the average cost of failure and the average mileage between failures are shown in Table 8. Based on the data from Table 8, it can be concluded that Kia cars in the entire period covered by the study were characterized by the most excellent mileage between successive failures compared to other brands, as well as the lowest ratio of the average number of failures and the average cost of failure. On the other hand, Hyundai cars had the lowest mileage between failures and the highest average number of failures.

Vehicle damage is vehicle damage that requires body repair (bodywork, paintwork or bodywork and paintwork). The repair cost is the cost of the parts used in the repair and the labour costs. The average price of damage for all models is presented in Table 9. Based on the results of the car loss ratio research, it can be noticed that the worst parameters occurred for the Kia Ceed model in all analyzed areas: average cost of damage (PLN 6,268), average amount of claims (3.85), average duration of repair (11.20 days) and the average time excluding the car from use (43.07 days). However, in the case of indicating the brands with the best parameters in the analyzed areas, the answer is not so clear because, in each of the analyzed areas, a different brand achieves the best results: average cost of damage - Opel Astra (PLN 3,214), the average amount of damages - Renault Clio (1, 15), average repair time - Volkswagen Golf (4.76 days), average downtime - Renault Clio (8,90).

The average decrease in the value of the vehicle for the contract is shown in Table 10.

Considering the multitude of assessment indicators for a given vehicle brand, which have different values, it is necessary to use a multi-criteria assessment supporting the selection of the final solution. Based on the performed measurements, the verification of the method, the unification of the vehicle model in the enterprise were carried out based on parameters that significantly affect the economic and reliability indicators describing a given vehicle, i.e. mileage to the first failure, mileage from the first to second failure, mileage from the second to third failure, mileage from the third to fourth failure, mileage from the fourth to fifth failure, number of days until the first failure, number of days from the first to the second failure, number of days from the second to the third failure, number of days from the third to fourth failure, number of days from the fourth to the fifth breakdowns, vehicle operation cost.

The characteristics of the studied sample for each model were described graphically using a box-whisker plot, which included the basic descriptive statistics: mean value in the sample, standard deviation, highest value, lowest value, median, lower and upper quartile. The greatest differentiation of the sample value is within 50% of the most typical units in the sample (lower quantile, upper quantile). The greater the width of the frame about the entire range, the greater the variation among typical units. The narrower the frame, the more similar the middle units are to each other. The length of the whiskers assesses the asymmetry in the whole distribution. If the upper whisker is longer than the lower whisker, the distribution of the variable is characterized by right-hand asymmetry. There is left-hand asymmetry if the lower whisker is larger than the upper one. The Kolmogorov-Smirnov confirmed normal distribution (K-S) tests, Lilliefors, and Shapiro-Wilk tests. At the adopted significance level α = 0.05, the condition α <p holds if there are no grounds for rejecting the null hypothesis of the normality of the distribution of the studied sample. All tested vehicle operation parameters were characterized by a normal distribution in the conducted tests. An exemplary presentation of the results for the Kia vehicle is shown in Fig. 1-2.

a)

b)

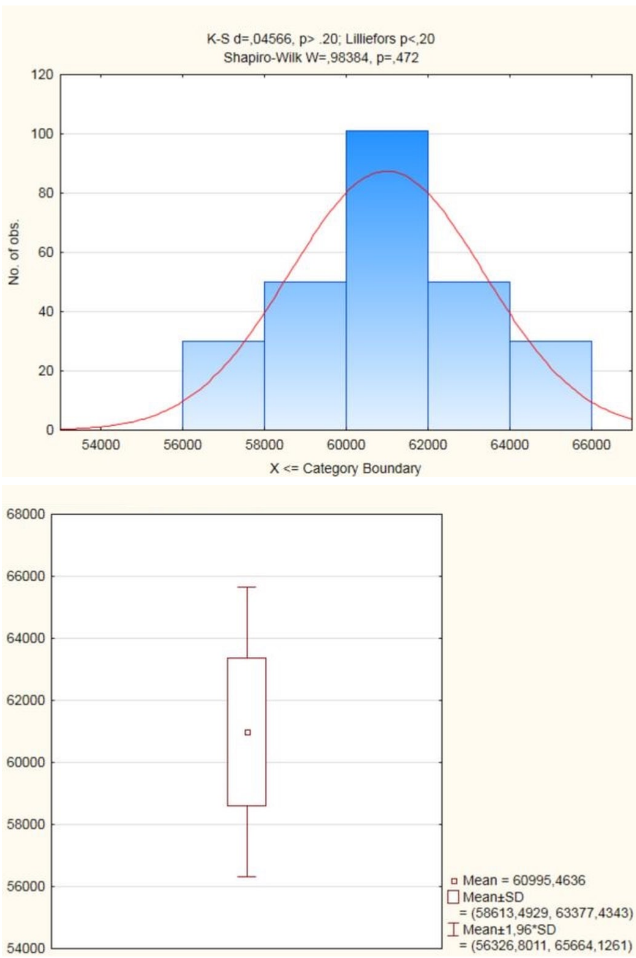

Fig. 1. Mileage to failure I for the KIA Ceed vehicle: a) box-whisker plot b) histogram

a)

b)

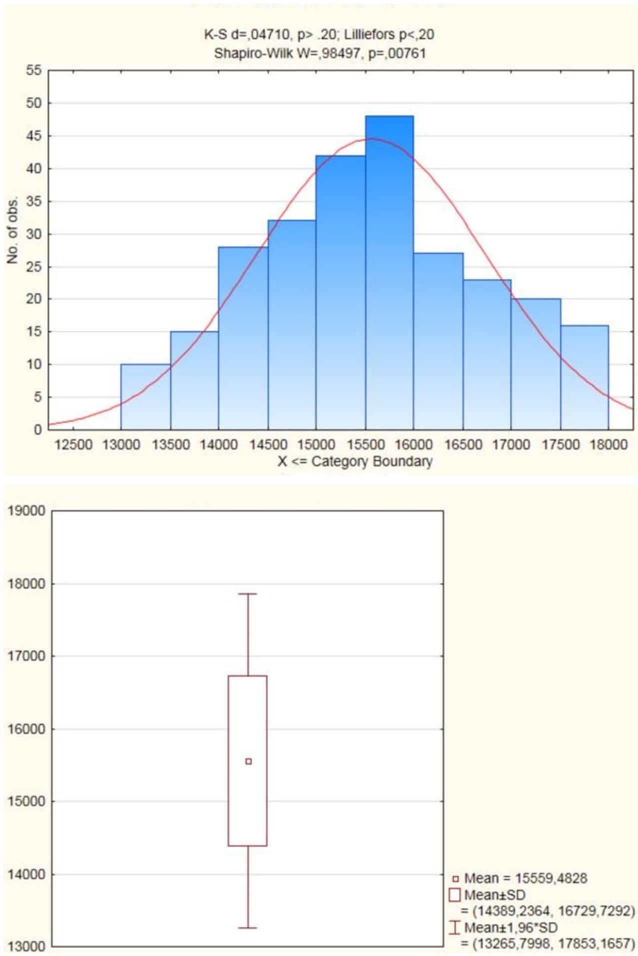

Fig. 2. Mileage from II to III of the failure for the KIA Ceed vehicle: a) box-whisker graph, b) histogram

The characteristics described by the box-whiskers diagram will be used to determine the average values of these parameters for the entire population of vehicles of a given model operating in the company.

5.2. Determination of the average values of parameters for individual groups of models

Bearing in mind that all examined parameters describing individual vehicle models have a normal distribution, the t-Student distribution with n-1 degrees of freedom was used to determine the mean value for each population (models). The tests were performed at the significance level of α = 0.05. The condition for accepting the null hypothesis that a given value is the mean value for the entire population occurs when the calculated probability level p is greater than the adopted significance level α. Tab. 11 - Tab. 16 presents the deduced mean values of the parameters for the entire population of vehicles within a given model operating in the enterprise.

In verifying the proposed method of managing a fleet of vehicles in a transport company, the key step is to determine the average values of parameters for the entire population of vehicles used in the company under a given model. Based on the results in Tab. 11 - Tab. 16, it can be concluded that there are significant differences in the mean values of the parameters from the samples about the mean parameters for the entire population. It should be emphasized that all mean values of the parameters were inferred at the significance level of α=0.05. Assuming a lower level of significance, e.g. α=0.01 the probability of making a mistake when rejecting null hypotheses would decrease. One consequence of this is the widening confidence interval responsible for the precision in parameter estimation. The tests adopted the confidence level recommended in statistical studies, taking the above into account.

Table 11. Mean values in the sample and population for the KIA Ceed vehicle

Parameter	Average for the sample	Average for the population (claimed value)	Probability level p
Mileage to I failure	60995,46	61150	0,26
from I to II	35685,44	35750	0,35
from II to III	15559,48	15800	0,25
from III to IV	12489,96	12600	0,11
from IV to V	5425,03	5570	0,35
Number of days until the first failure	651,89	730	0,43
from I to II	349,31	372	0,34
from II to III	196,20	222	0,27
from III to IV	182,46	172	0,32
from IV to V	190,41	218	0,23
Cost of use	2947,23	3210	0,45

Table 12. Mean values in the sample and population for the PEUGEOT 308 vehicle

Parameter	Average for the sample	Average for the population (claimed value)	Probability level p
Mileage to I failure	60551,62	60999	0,15
from I to II	34496,55	35020	0,28
from II to III	25492,81	25999	0,26
from III to IV	15510,08	16002	0,23
from IV to V	0	0	0
Number of days until the first failure	550,94	600	0,13
from I to II	352,10	399	0,34
from II to III	250,59	272	0,32
from III to IV	179,56	170	0,11
from IV to V	0	0	0
Cost of use	2649,42	2699	0,26

Table 13. Mean values in the sample and population for the GOLF VII vehicle

Parameter	Average for the sample	Average for the population (claimed value)	Probability level p
Mileage to I failure	70479,55	70823	0,34
from I to II	24539,71	24700	0,13
from II to III	24476,19	24600	0,22
from III to IV	13445,98	13600	0,14
from IV to V	6481,76	6670	0,06
Number of days until the first failure	647,40	660	0,21
from I to II	251,00	265	0,15
from II to III	250,78	265	0,14
from III to IV	197,74	181	0,15
from IV to V	126,54	135	0,12
Cost of use	3352,17	3399	0,09

Table 14. Mean values in the sample and population for the HYUNDAI vehicle

Parameter	Average for the sample	Average for the population (claimed value)	Probability level p
Mileage to I failure	51441,85	51300	0,18
from I to II	27500,44	27200	0,21
from II to III	20489,05	20720	0,18
from III to IV	18477,84	18702	0,14
from IV to V	27478,33	27601	0,26
Number of days until the first failure	550,65	565	0,36
from I to II	256,29	276	0,12
from II to III	248,50	235	0,06
from III to IV	162,12	185	0,23
from IV to V	250,71	240	0,11
Cost of use	2740,70	2689,00	0,08

Table 15. Mean values in the sample and population for the RENAULT vehicle

Parameter	Average for the sample	Average for the population (claimed value)	Probability level p
Mileage to I failure	58450,83	58000	0,14
from I to II	28460,93	28540	0,34
from II to III	25473,47	25030	0,15
from III to IV	11487,18	11540	0,30
from IV to V	7539,66	7600	0,23
Number of days until the first failure	547,09	560	0,25
from I to II	250,92	269	0,21
from II to III	247,74	237	0,12
from III to IV	160,10	170	0,34
from IV to V	78,27	85	0,32
Cost of use	3850,16	3723	0,11

Table 16. Mean values in the sample and population for the OPEL Astra V vehicle

Parameter	Average for the sample	Average for the population (claimed value)	Probability level p
Mileage to I failure	59430,12	59030	0,11
from I to II	22473,27	22273	0,23
from II do III	28461,12	28062	0,41
from III do IV	8502,81	8612	0,22
from IV do V	20475,27	20675	0,11
Number of days until the first failure	545,20	510	0,13
from I to II	244,04	230	0,09
from II to III	353,46	373	0,14
from III to IV	170,04	180	0,45
from IV to V	167,40	181	0,33
Cost of use	3254,34	3321	0,31

Considering the results presented in Tab. 11 - Tab. 16, it can be concluded that statistical inference is a crucial element of vehicle fleet management in an enterprise. In each of the tests performed on the means of the populations (groups of models), these means differed from the means of the sample. The minimum average of the parameter within the trials may have negative values if we consider it globally, about the entire population, e.g. in the parameter - a number of days from III to IV breakdowns for the Hyundai vehicle, the sample mean was the lowest compared to other brands and amounted to 162,12 days, which turned to the disadvantage as a result of determining the mean value for the entire population. This value turned out to be the highest of all tested models and amounted to 185 days.

5.3. MAJA multi-criteria assessment

In order to determine the most advantageous vehicle model, the weights of individual criteria were established. They are presented in Tab. 17. The list of variants and criteria is presented in Tab. 18.

The dominance matrix that generates the final solution is shown in Tab. 19. According to the method's algorithm, the vertex from which most arcs come out is the best solution. The model selected for a given company is the Peugeot 308 vehicle model.

The MAJA method's solution depends strictly on the weight values imposed for individual criteria. In the process of verification of the method, it was assumed that the most significant weight of the criterion concerns the minimization of vehicle operating costs. The comparative analysis of vehicles described in chapter 5.1 showed that the Peugeot 308 vehicles are characterized by a low average cost of damage - Tab. 9, which translates into a low average cost of using these vehicles and repairs. The average amount of damage during the use period is also at a low level compared to other models, contributing to the minimization of vehicle operating costs. The designated weights for the number of days to individual failures were set at a high level (from 4 to 6), which is also reflected in the selection of the Peugeot 308 brand because, in Tab. 7, the average time to the first failure and between failures is low. Considering the above, it can be concluded that the verification of the method was correct. The correctness of the generated result is justified by the comparative analysis of all models described in chapter 5.1.

6. Conclusions

Due to the growing needs of enterprises in vehicle availability, companies with a large fleet are looking for methods of proper fleet management, including the appropriate selection of a fleet of vehicles for the tasks. The selection of a fleet of vehicles for tasks in a transport company is a complex decision-making problem that requires advanced optimization methods. The proposed method of selecting a

Table 17. Weights of individual criteria

Mileage to I failure	Mileage from I II	Mileage from II to III	Mileage from III to IV	Mileage from IV to V	Cost of use
3	3	3	3	3	7
Days to I failure	Days from I II	Days from II to III	Days from III to IV	Days from IV to V	
6	5	4	4	4	

Table 18. List of partial criteria

Vehicle model	Mileage to I failure	Mileage from I to II	Mileage from II to III	Mileage from III to IV	Mileage from IV to V	Cost
KIA Ceed	61150	35750	15800	12600	5570	3210
PEUGEOT 308	60999	35020	25999	16002	0	2699
VOLKSWAGEN GOLF VII	70823	24700	24600	13600	6670	3399
HYUNDAI	51300	27200	20720	18702	27601	2689
RENAULT	58000	28540	25030	11540	7600	3723
OPEL Astra V	59030	22273	28062	8612	20675	3321
Vehicle model	Days to I failure	Days from I II	Days from II to III	Days from III to IV	Days from IV to V	
KIA Ceed	730	372	222	172	218	
PEUGEOT 308	600	399	272	170	0	
VOLKSWAGEN GOLF VII	660	265	265	181	135	
HYUNDAI	565	276	235	185	240	
RENAULT	560	269	237	170	85	
OPEL Astra V	510	230	373	180	181	

Table 19. The dominance matrix

	KIA Ceed	PEUGEOT	GOLF VII	HYUNDAI	RENAULT	Astra V
KIA Ceed	0	0	1	0	0	0
PEUGEOT 308	1	1	0	0	0	1
VOLKSWAGEN GOLF VII	0	0	0	0	0	0
HYUNDAI	0	0	0	0	0	0
RENAULT	0	0	0	0	0	0
OPEL Astra V	0	0	0	1	0	0

fleet with a homogeneous structure of vehicles operating in an enterprise is an effective tool for determining the allocation of vehicles to tasks. The approach to vehicle fleet management proposed in the article, which consists in unifying the car fleet brand in a given transport company, enables effective management of a large fleet of vehicles due to the reliability of vehicles and their maintenance cost. In the analyzed example, the Peugeot 308 model was an adequate model introduced for use in the company. It was characterized by the most favourable parameters for assessing vehicle efficiency, i.e. low average cost of service 2699 PLN or average cost of damage 3589 PLN. In the conducted tests, all vehicle operation parameters were characterized by a normal distribution.

The developed method can be used in companies dealing with vehicle rental and transport companies providing transport services for various transport tasks.

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