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INFORMATION SYSTEM OF VEHICLE RELIABILITY ANALYSIS BASED ON DATA FROM CAR MAINTAINANCE SERVICES

In Europe and the United States, the popularity of independent organizations engaged in testing, inspections and consultations related to the condition or value of the car is growing. They provide breakdown statistics, test results, help estimate the vehicle or the cost of damage. Car manufacturers, insurance companies and car owners use their services. In Ukraine, such services are not yet provided and everyone pays attention to statistics from other countries, which is not very relevant. We decided to develop our own system for analyzing the car reliability.

The paper describes the information system of vehicle reliability analysis. The reliability assessment analysis of cars includes the use of methods of statistical modeling and analysis.

The purpose of the research is to develop an information system for analyzing the reliability of a car according to information from car services, storing statistics on car maintenance, the formation of annual ratings of car reliability. Information system for car reliability analysis implements the functionality needed to generate a ranking of car reliability for different age categories: 2-3 y. o., 4-5, 6-7, 8-9 and 10-11 y. o. Reliability rankings can be updated once a month, a quarter or a year. The implemented system is based on the car service reservation system.

The subject of research is algorithms and methods of implementing the system of vehicle reliability analysis. The essence of this approach is to analyze the information about orders from car service salons in Ukraine. The software product uses the analysis to form car reliability ratings and reports on the average cost of service.

For implementation of the system such tools were used: HTML5 markup language; CSS3 style sheet language; SCSS preprocessor scripting language; PHP programming language; Laravel framework; MySQL database management system; OpenServer Panel platform; Visual Studio Code editor; Digital Ocean Web hosting.

The results show that this approach can be useful for drivers, official dealers, car manufacturers or insurance companies.

Keywords: ranking system, car maintenance service, car failure, reliability of a car.

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ІНФОРМАЦІЙНА СИСТЕМА АНАЛІЗУ НАДІЙНОСТІ АВТОМОБІЛЯ ЗА ДАНИМИ АВТОСЕРВІСІВ

В країнах Європи та США зростає популярність незалежних організацій, які займаються перевірками, тестуванням, інспекціями та консультаціями, пов'язані зі станом або цінністю автомобіля. Вони надають статистику поломок, результати тестувань, допомагають оцінити транспортний засіб або вартість збитків. Їх послугами користуються як автовиробники, так і страхові компанії та власники авто. В Україні подібних послуг поки що не надається, всі звертають увагу на статистику з інших країн, яка є не зовсім актуальною, тому було вирішено розробити власну систему з аналізу надійності автомобіля.

У статті описується інформаційна система аналізу надійності транспортних засобів. Аналіз оцінки надійності автомобілів включає застосування методів статистичного моделювання і аналізу.

Метою роботи є розробка інформаційної системи аналізу надійності автомобіля за даними автомобільних сервісів, збереження статистичних даних щодо обслуговування автомобілів, формування щорічних рейтингів надійності автомобілів. Інформаційна система аналізу надійності автомобіля – реалізує функціонал необхідний для формування рейтингу надійності автомобілів за різними віковими категоріями: 2-3 роки, 4-5, 6-7, 8-9 та 10-11 років. Рейтинги надійності можуть обновлятися раз на місяць, квартал або рік. Система реалізована на основі системи бронювання послуг автосервісу.

Предметом дослідження є алгоритми та методи реалізації системи аналізу надійності автомобіля. Суть даного підходу полягає в аналізі замовлених послуг в автомобільних сервісах на території України. Аналіз застосовується в програмному продукті, де формуються рейтинги надійності автомобіля та звіти середньої вартості послуг обслуговування.

Для реалізації було використано: мову розмітки гіпертекстових документів HTML5; каскадні таблиці стилів CSS3; препроцесор SCSS; мову програмування PHP; фреймворк Laravel; середовище керування базами даних MySQL; пакет OpenServer; редактор коду Visual Studio Code; хостинг DigitalOcean.

Результати показують, що цей підхід може бути корисний для користувачів, офіційних дилерів, виробників автомобілів чи страхових компаній.

Ключові слова: рейтинг, автосервіс, відмова, надійність, автомобіль.

Introduction

According to LMC Automotive forecasting company, 32 million new passenger cars and light commercial vehicles (LCVs) were sold in the first half of 2020, which is 27% less than in the same period of 2019. According to the UkrAutoprom Association, sales of new cars in Ukraine in 2020 amounted to 85 500, which is 3.4% less than in 2019.

The extremely low-income consumer behavior in the new car market is the main reason for the drop of the sales. It prevailed even before the COVID-19 pandemic, caused both by a fall of population purchasing power on

the segment of inexpensive cars, and by the policy of liberalizing imports of used cars, which radically changed the structure of demand in the Ukrainian car market.

In 2019, statistics showed that Ukrainians bought and registered 408.1 thousand used cars, which is 5 times more than the number of purchases of new cars. Compared to 2018, this number increased 3.5 times. The increase in the purchasing power of used cars led to a demand to reliability assessment of these cars.

Reliability (dependability) - a property of a car to perform transport function, maintaining technical and operational indicators in time or in mileage, which is important for used cars.

In Europe and the United States, there is a growing popularity of independent organizations engaged in inspections, testing and consultations related to the condition or value of the car. They provide statistics of breakdowns, test results, help estimate the vehicle or the cost of damage. Car manufacturers, insurance companies and car owners use their services.

In Ukraine, there is no yet companies, which provide such a service. As a rule, statistical data are taken from other countries and such information is not always relevant.

Analysis of the sources and problem statement for the research

In scientific literature, the number of works directly devoted to the assessment of vehicle reliability is very limited. General theoretical and methodological provisions for determining the reliability assessment are set out in the works of such scientists as Franz J. Brunner [0], Chong Chen, Ying Liu, Xianfang Sun, Carla Di Cairano-Gilfedder, Scott Titmus [0] and Y Zhang, Q Liu [0].

In [0] Dr. Ajith Tom James gives an overview of the latest developments in car reliability, affordability and maintainability. Studies by A. Abdullah, M. Yusoff, K. Wahab, Z. Ripin [0] present a methodology for determining the maintainability index based on assembly criteria. The research [0] presents a brief introduction and selective relevant links related to reliability of cars.

Paper [0] illustrates techniques that have been applied to use warranty claim information to assess the relative reliability and incident rates for diagnostic trouble codes occurrences.

The goal and tasks of the research

The goal of the research is to develop a web-oriented system for analyzing the car reliability.

The goal determines the following tasks:

- Analysis of the vehicle evaluation process;
- Automation of vehicle evaluation according to certain criteria;
- Software implementation of the vehicle evaluation system;
- Implementation of the information module of the vehicle evaluation system.

Vehicle reliability assessment

To assess the reliability of vehicles the division into several parts is used [0, 0]. The first, main part is the body, designed for passengers and cargo transportation. In Ukraine, cars with anti-corrosion protection, such as galvanized or aluminum bodies, are mostly preferred.

The second part is the engine. In general, when choosing a car, the main factor is fuel consumption. In addition, many other factors can also lead to high maintenance costs.

The third one is the running gear, where the condition of the roads must be taken into account.

The fourth part is the transmission, and most of the attention must be paid to the gearbox.

The reliability of a car contains a set of properties such as stability, longevity, maintainability and life expectancy.

An indicator of stability and longevity is the car resource - maximum service life from the beginning of vehicle operation or after repair to complete failure.

Mathematical methods for determining the vehicle reliability

Statistical information on the reliability (failures) of any element or object includes a set of quantitative and qualitative indicators, which can be provided in the form of a number of numerical values.

We can characterize any failure by the probability of occurrence. Assume that a failure is an accidental event that may or may not occur at any time with some probability. In this case, we apply the theorem of addition probabilities of incompatible events.

To determine the extreme and average parameters of indicators change, it is advisable to use variation series $(x_{\min}\, x_{\min+1} \ldots x_{\max-1}\, x_{\max})$, which make it possible to determine the distribution of population units on a particular quantitative characteristic.

To check the homogeneity of the variation series, we use the Grabbs's test, where we check the affiliation of the extreme elements of the series to the general set (formula 1, 2).

$$r_{\max} = \frac{x_{\max} - \bar{x}}{\sigma} \le r_{tabl}(\approx 3) \tag{1}$$

$$r_{\min} = \frac{x_{\min} - \bar{x}}{\sigma} \le r_{tabl}(\approx 3) \tag{2}$$

where $\bar{x}$ is the mean value of the parameter, and σ is the standard deviation. We discard elements that have not passed the test. Based on these variation series, we form an interval series of 5-12 intervals.

Processing an interval series is more effective by computer calculations. Next, we determine the mean value of the parameter (formula 3), the standard deviation (formula 4) and the coefficient of variation (formula 5).

$$\bar{x} = \frac{\sum x_j \times m_i}{\sum m_i} \tag{3}$$

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2 \times m_i}{m_i}} \tag{4}$$

$$v = \frac{\sigma}{\bar{x}} \tag{5}$$

For better visualization, we present the result in the form of a histogram (Fig. 1).

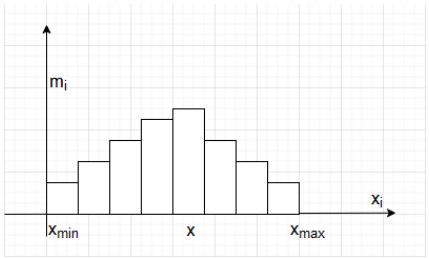


Fig. 1. Histogram of the failure rate distribution

To assess reliability seven laws are most often used.

Normal Gaussian law (formula 6) - describes the wear of working surfaces under normal operating conditions, the life of parts and car as a whole (Fig. 2).

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{\frac{(x-\bar{x})}{2\sigma^2}} \tag{6}$$

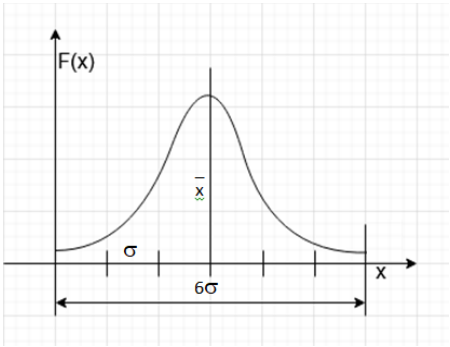


Fig. 2. Gaussian distribution function

Weibull-Gnedenko distribution (formula 7) - is considered to be the fundamental law of reliability. It describes the efficiency of elements, such as operating time before and between failures, repair resource (Fig. 3).

$$f(x) = \frac{a}{b}\left(\frac{x}{a}\right)^{b-1} e^{-\left(\frac{x}{a}\right)^b} \tag{7}$$

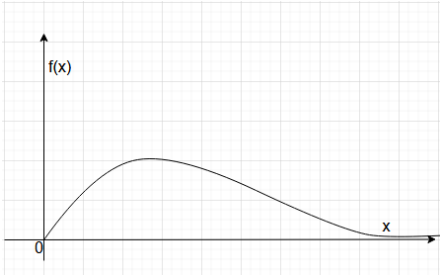


Fig. 3. Weibull-Gnedenko distribution function

Newton's binomial theorem (formula 8), based on expanding the polynomial $(p+q)^n$ into a series:

$$(p+q)^n = p^n + np^{n-1}q + \frac{n(n-1)}{2!}p^{n-2}q^2 + \ldots + q^n$$

$$f(x) = C_m^n p^x q^{(n-x)} \; f(x) = C_m^n p^x q^{(n-x)} \tag{8}$$

where C_m^n is the number of m-combinations from the set of n elements, q and p are the probabilities of failure occurrence or absence (Fig. 4).

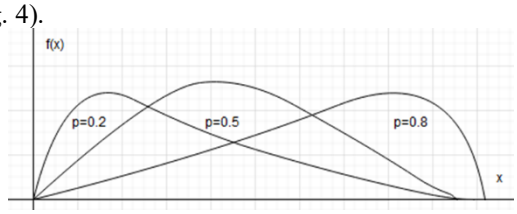


Fig. 4. Binomial theorem distribution functions for different probabilities of the faultless operation p

This law describes the multiple repetitions of failures quite well.

Poisson distribution (formula 9) - describes the reliability of independent elements (Fig. 5).

$$f(x) = \frac{ax}{x!} \cdot e^{-a} \tag{9}$$

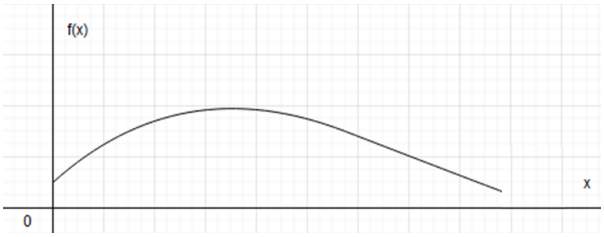


Fig. 5. Poisson distribution function

Rayleigh distribution (formula 10) - used in the theory of queuing and describes the operating time for failure (Fig. 6).

$$f(x) = \frac{2}{a} \cdot \left(\frac{x}{a}\right) e^{-\left(\frac{x}{a}\right)^2} \tag{10}$$

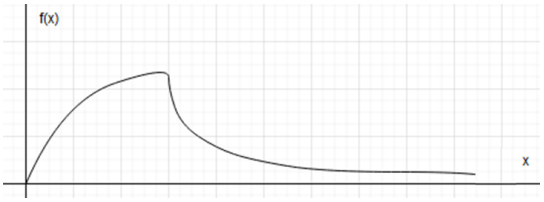


Fig. 6. Rayleigh distribution function

We also use an exponential distribution that describes well the occurrence of rare failures. The Gamma distribution, Fisher, Student, Pearson laws, etc. are used to assess the accuracy of theoretical and empirical distributions.

The agreement between the empirical and theoretical distributions should be checked by least squares method.

Therefore, having analyzed the models and methods of assessing the car reliability, we identified the main aspects to be used in the implementation of the information system.

Sources and methods of collecting information to assess reliability

The best source of information for the assessment of the vehicle cost are manufacturers or dealers. The manufacturer can find out any information about a particular vehicle, the total cost, the cost of additional options, the weight of the unit and more.

Reference books, technical docs, cost catalog, price lists are valuable sources of information. Car appraisal experts need to keep a record of recovery prices to have accurate information and work more efficiently.

The assessment of the vehicle cost also includes an assessment of its reliability. To assess the reliability of a car a lot of information can be obtained from operational tests. However, such tests do not show the full real car reliability because it depends on many other factors. Therefore, complete failure becomes an accidental event and service life may vary, depending on operating conditions.

The assessment of the car reliability is carried out to determine compliance with the requirements, by comparing the indicators of longevity, stability, maintainability and shelf life of a particular car with the same indicators of others.

The main reliable source of information is controlled car operation or testing in conditions as close as possible to real. This is the operation of a certain number of cars, with monitoring of the technical condition of each machine by specially trained personnel.

To solve problems, we must correctly structure data. From the data collection, we need to get data about the object, operating conditions, failures and their elimination.

Basic information can be received from the technical passport: manufacturer's brand, body number, year of manufacture, category.

Conditions are set by definition of a geographical zone of operation and also a character of district, climatic and soil conditions, system of maintenance.

Each failure should be characterized by the time of the element to failure, the date of detection, nature and appearance, the probable cause, method and time spent on elimination. Everything must be recorded in accounting documents.

In general, several types of accounting forms are already provided:

– Primary forms of accounting for information on operation;
– Forms for information storage;
– Forms for recording the results of reliability analysis.

The main methods used to collect information on the reliability of cars in operation are:

– Instrumental method;
– Timing method;
– Method of periodic observations;
– Method of data analysis of maintenance and repair documentation.

To improve the results and to get more information in less time, it is advisable to use a combination of these methods. Information is collected from different sources and combined using the methods of mathematical statistics [0, 0].

Technologies of analytical analysis of car reliability indicators

The car reliability depends on the mode of operation, quality of service, operating time, year of manufacture of a car and the environmental conditions [0].

When buying a new car, a client believes that maintenance costs will be minimal, only for fuel and oil. However, the statistics of one of the largest providers of car service and spare parts YourMechanic from the United States say otherwise. The experts analyzed all their data and determined the cost of servicing new cars for 10 years. According to them, the cost of servicing a car like Toyota Prius in the US is $ 4,300. Moreover, this is the lowest cost. Ukrainian local police began to use this factor. An owner of Toyota Camry, considered a more prestigious car and at the same time inexpensive to use, will spend $ 5,200 in 10 years. Comparing these two cars, the cost of the second is not very large enough, considering their difference in class. However, these statistics are not entirely suitable for the regions of Ukraine.

An overall reliability assessment can be viewed on the TUV (European Technical Inspection Organization) website.

In the 2014 report, in the range from 2 to 3 years old, Toyota Prius is ranked 42nd in the reliability rating, the average mileage is 42,000 kilometers, faults were recorded in 7.7% of cars.

In the 2013 report, in the range from 2 to 3 years old, Toyota Prius ranks 7th, mileage is 43,000 kilometers, and the percentage of failures is 3.5%.

In the 2016 report, in the range of 4 to 5 years old, the Toyota Prius ranked 21st with a mileage of 65,000 and recorded 8.9% of malfunctions. We clarify that the same cars as in the 2014 report took part in the 2016 report. Thus, in 2 years the number of breakdowns increased from 7.7% to 8.9%, i.e. in 3 years the number of breakdowns increased by 7.7%, and in 5 years it increased by only 1.2%.

Let us explore why the indicators in the 2013 report are so different from the indicators in 2014, though the difference between them is only 1 year. It is possible to assume that the 2013 report includes cars of an average 2009 year of production. The 2014 report includes cars of 2010 year of production accordingly. Having made a review, we noticed that the new models of Toyota Prius were have been produced from 2009 to 2016. That is possible to assume that the old models of 2004-2009 year of production have a higher reliability rating than the cars of 2009-2016 years of production.

To confirm these assumptions, let's make a review of the 2012 rating. The average year of production is 2008, first place, the mileage of 39 thousand kilometers and malfunctions of 1.9%.

Consider another car, for instance the Volkswagen Passat. In the category of 2-3 years the 2011 model ranks 106th, with 10.8% of malfunctions. The same model in the category of 4-5 years takes 99th place and 12.3% of malfunctions. This fact suggests that most breakdowns occur in the first years of operation.

The same model but 2004 year of production and in the category of 2-3 years takes 64th place with 4.9% of breakdowns. Category 4-5 years - 61 place with 9.7% of breakdowns. 6-7 years - 42 place and 15.4% of breakdowns

accordingly. As we can see, the dependence of breakdowns on age is almost the same, in 2 years the number of breakdowns increases by 5%.

This model confirms that the car reliability depends more on the car resource than age. The research showed that over seven years, the failure indicators increases smoothly. In the ranking, this model increased by 22 places in 7 years. The best position in the ranking is 36 in the 2016 report among cars aged 10-11.

Thus, we can conclude that the hypothesis of new cars is not confirmed. In addition, it is not obvious that old cars break down too often, as in the case of the Passat, where as it is found the percentage of breakdowns changes with age by nearly the same value. The other fact in favor of old cars is that today specialists in the old car selection are in great demand. This means that buying these cars is profitable.

We should also take into consideration the case with the Prius. The difference in reliability between the old model and the new one can be great, so it should not to rely too much on the reliability of the previous model.

In general, the condition of a particular car can be determined quite accurately, but the percentage of breakdowns is a very vague term. For accurate analysis, you need to understand at least car modules or elements in which there were breakdowns. This will play a big role in choosing a car for different operating conditions. For example, if there are many breakdowns in chassis, then this car should not be purchased, given that the roads in Ukraine are much worse than in Europe and there will be even more breakdowns.

Taking into account the cost of repairing breakdowns in our system is very important, because there are car models with quite high reliability rating, but the cost of spare parts is higher than in others, sometimes even several times.

Mathematical statistics proves that with multiple repetition of random events, the accuracy of estimation of statistic parameters of the research data increases. Thus, it is possible to receive rather small error with a sufficiently large number of random events.

Results of the research and design of the information system

The analysis of functional requirements revealed the following database entities, which will provide realization of a software complex of system.

Fig. 7 shows a class diagram of the system.

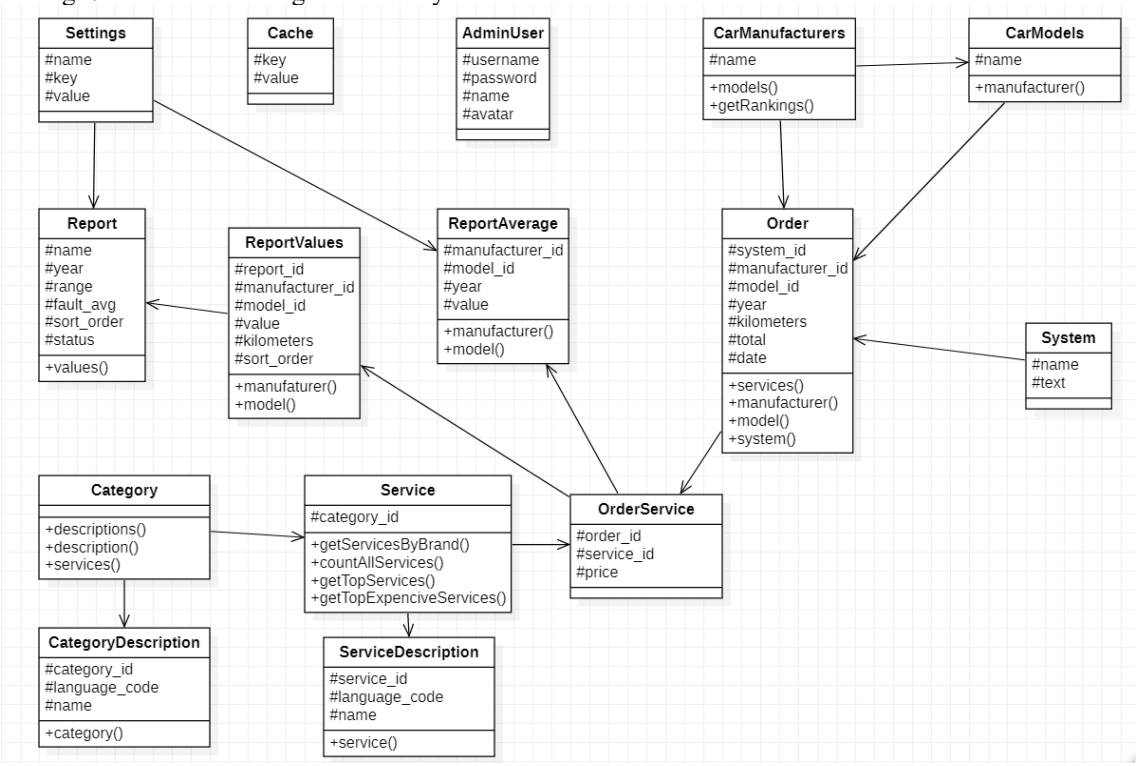


Fig. 7. Class diagram

For the convenience of analysis and display of results, we made interval grouping of data by time parameter as follows: 2-3, 4-5, 6-7, 8-9 and 10-11 years old for each rating. The functionality for creating reliability ratings is accessed to administrator of the system.

Since the number of services in the database is unlimited and can reach millions, the ratings will be stored in separate tables of the database. Reliability indicators do not change cardinally every day and the information does not need frequent updating, it is enough to update the data every month or quarter.

The algorithm processes the information for each car, taking into account the parameters of the minimum number of services and the maximum number of cars in the rating. Then it selects services that fit the criteria of the rating, calculates the percentage of breakdowns, average mileage, sorts by percentage of breakdowns and saves the

results into the database. The old data, if available, are deleted. Administrator receives a notification about the successful rating generation and then after verification the rating is opened for public access (Fig. 8).

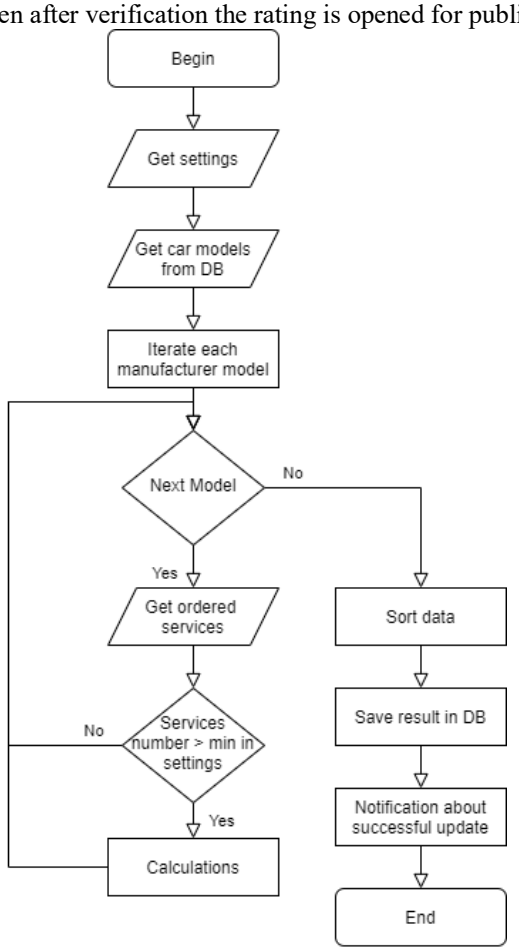


Fig. 8. Flowchart of the rating algorithm

The system can update ratings, either individually or all together within the year.

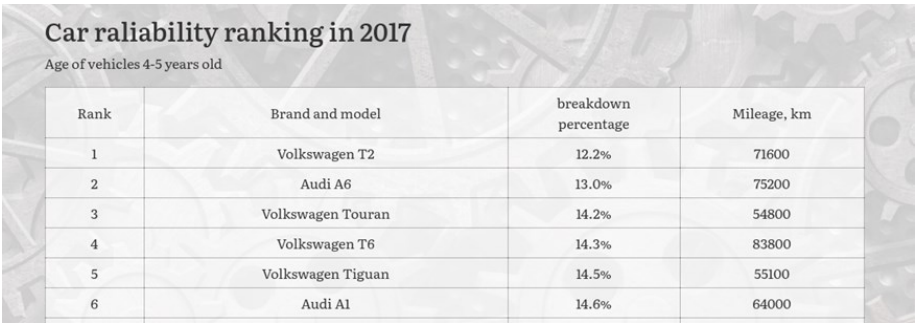
The reports of an average service cost work the same as ratings. The system generates them automatically, stores them separately in the database, and notifies the administrator about updates through the session.

For the user convenience, the system can compare cars by the reliability rating and the cost of services. Such comparisons are based on already formed and calculated data.

The structure of the user interface. A rating is formed by 5 age categories every year: 2-3, 4-5, 6-7, 8-9 and 10-11 years old. This gradation allows us to analyze in detail each car model of different years of production, body models, restyling, etc. (Fig. 9).

Fig. 9. List of reliability ratings

By selecting the reliability rating, the user gets the rating page of the selected year, which provides a list of cars sorted by reliability rating. In addition, the list provides information on the % of breakdowns and average mileage of the certain car model, which also plays an important role in the assessment and significantly affects the reliability of the car, as well as helps to assess for example whether this car is popular among taxis (Fig. 10).



Car raliability ranking in 2017

Age of vehicles 4-5 years old

Rank	Brand and model	breakdown percentage	Mileage, km
1	Volkswagen T2	12.2%	71600
2	Audi A6	13.0%	75200
3	Volkswagen Touran	14.2%	54800
4	Volkswagen T6	14.3%	83800
5	Volkswagen Tiguan	14.5%	55100
6	Audi A1	14.6%	64000

Fig. 10. Reliability rating page

By selecting a specific car, the user gets the page with information about the car where the schedule is provided. User can select years of release of this model and compare them on the schedule.

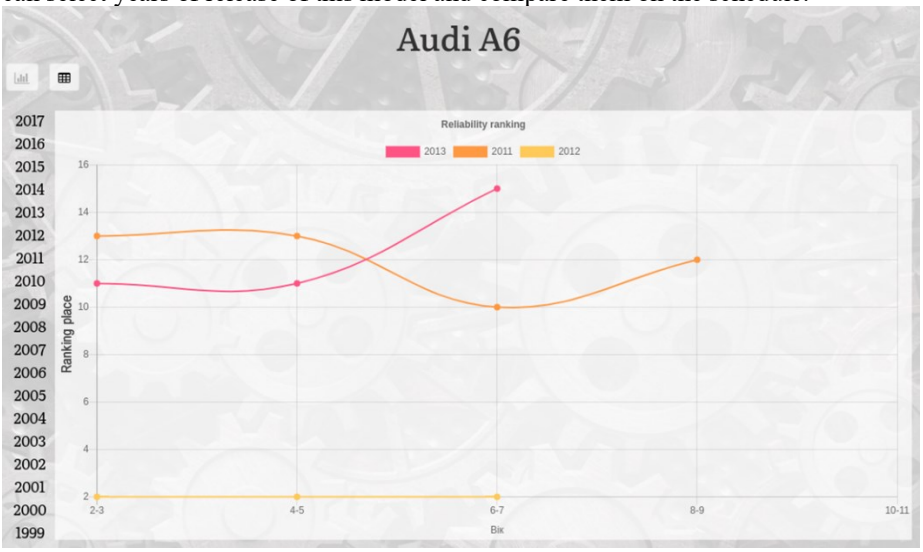
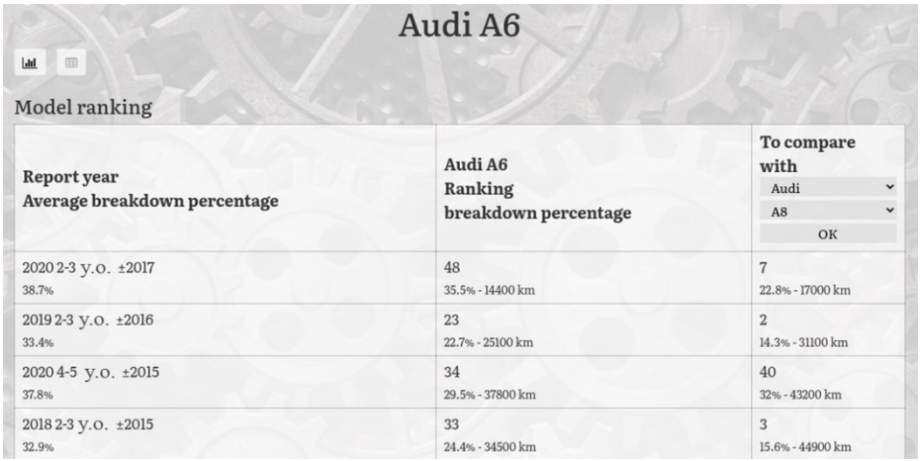


Fig. 11. Reliability comparison graph of different year of production

On the graph (Fig. 11), we can analyze in detail the dynamics of change of the ranking position depending on car age. For instance, the model of 2013 year proved to be quite worthy in terms of reliability and for 6-7 years is consistently ranked 11th in the ranking. The 2011 model initially took 13th place, but eventually rose to 10th place, then dropped to 13th again, which is also a good result. However, the car of 2012 year of production maintains the same position for 6-7 years. Moreover, it ranks 2nd place. Therefore, we can say that this model is the most reliable car, which definitely makes it the best option for purchase.

Considering other years of production, we assume some factors made the newer model the most reliable. Among them are the model range of cars change, the model restyling, technical changes and refinements of the 2011 model.

Another type of comparison is grid view, where the user can compare the selected car model with another (Fig. 12).



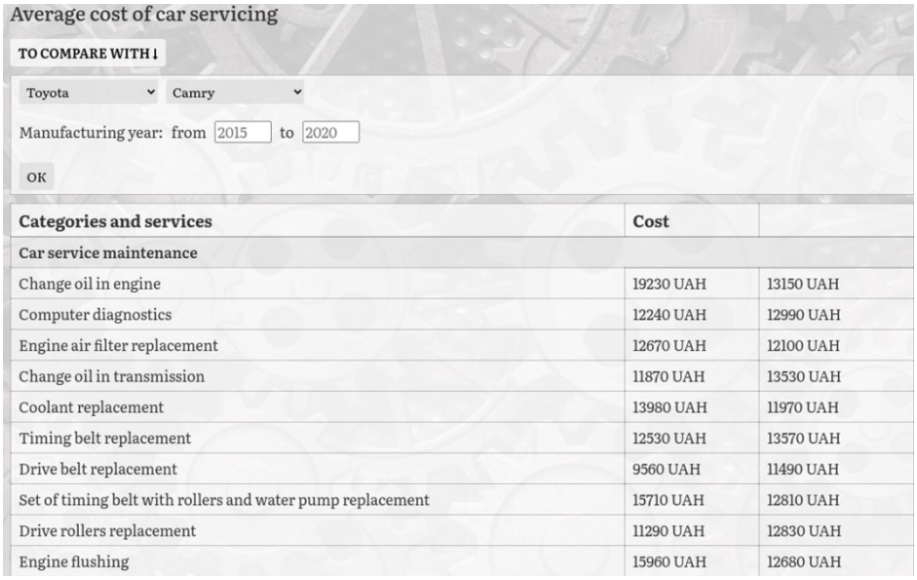
Audi A6

Model ranking

Report year Average breakdown percentage	Audi A6 Ranking breakdown percentage	To compare with Audi A8 OK
2020 2-3 y.o. ±2017 38.7%	48 35.5% - 14400 km	7 22.8% - 17000 km
2019 2-3 y.o. ±2016 33.4%	23 22.7% - 25100 km	2 14.3% - 31100 km
2020 4-5 y.o. ±2015 37.8%	34 29.5% - 37800 km	40 32% - 43200 km
2018 2-3 y.o. ±2015 32.9%	33 24.4% - 34500 km	3 15.6% - 44900 km

Fig. 12. Comparison of Audi A6 and Audi A8 models

A comparison of models Audi A6 and Toyota Camry of 2015-2020 years of production is presented in Figure 13.



Categories and services	Cost	
Car service maintenance		
Change oil in engine	19230 UAH	13150 UAH
Computer diagnostics	12240 UAH	12990 UAH
Engine air filter replacement	12670 UAH	12100 UAH
Change oil in transmission	11870 UAH	13530 UAH
Coolant replacement	13980 UAH	11970 UAH
Timing belt replacement	12530 UAH	13570 UAH
Drive belt replacement	9560 UAH	11490 UAH
Set of timing belt with rollers and water pump replacement	15710 UAH	12810 UAH
Drive rollers replacement	11290 UAH	12830 UAH
Engine flushing	15960 UAH	12680 UAH

Fig. 13. Price comparison for Audi A6 and Toyota Camry models

Comparing service prices, there is no obvious advantage. This makes these cars very close competitors. We assume that the only difference is that the average mileage of the Toyota Camry is slightly higher than the one of the Audi A6 and therefore reliability rating is a slightly lower.

The general statistics block is placed on the main page (Fig. 14). It displays the overall rating of breakdowns by car manufacturers, the most popular services, the most expensive services and the most often serviced car brands.

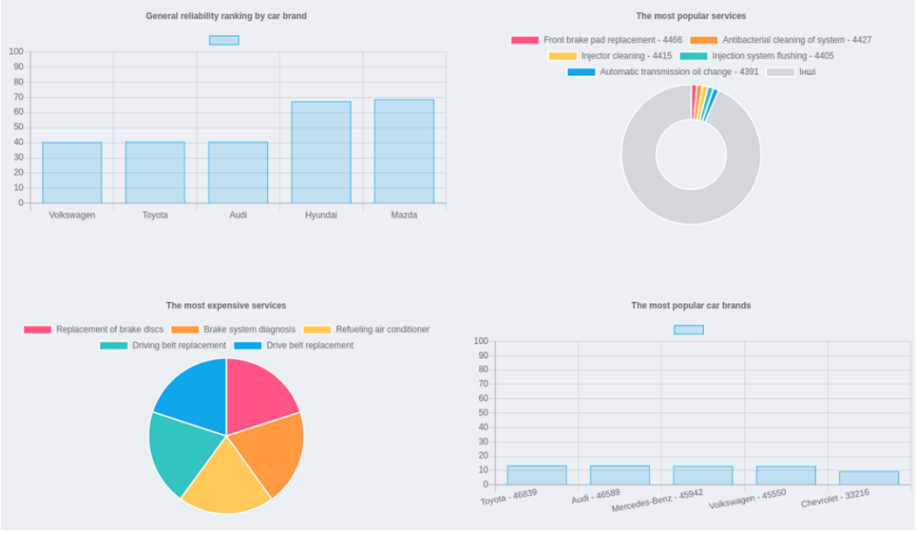


Fig. 14. General statistics on the main page of the admin panel

The updates of the ratings are made in the background. Once the rating is updated, an admin receives the corresponding notification displayed on any page of the panel.

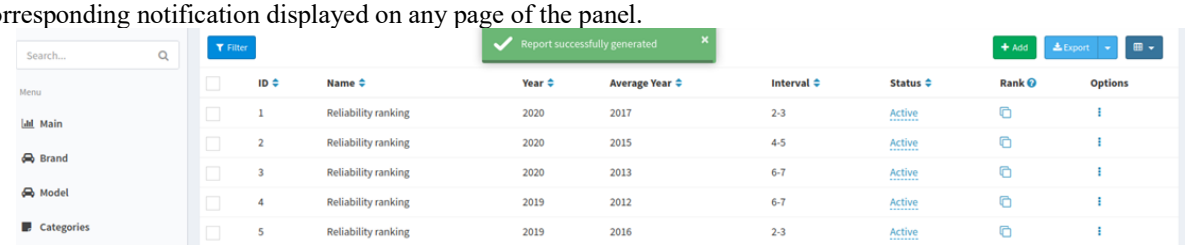


Fig. 15. Notification of successful rating update in the admin panel

The rating of the average cost of services works on the same principle in the background, but there all models of cars are updated at once.

Conclusions

This paper proposes a modified approach for choosing a reliable car. The approach consider analyzing the ordered services in car service shops in Ukraine. Data analysis is used in the software product, where car reliability ratings and reports on the average cost of services are formed.

A system of car reliability analysis is designed within Ukrainian market segment. The report system of information in grid views and graphs is implemented. The system will help any user, official dealer, car manufacturer or insurance company to assess a particular car, its faults, cost and maintenance problems in conditions of Ukrainian segment.

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