Multicriteria optimization in the study of active vehicle safety.

A.I. Markovnina, V.S. Makarov, V.V. Belyakov

Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Minin st., 24, 603950, Nizhny Novgorod, Russia

E-mail: alinomalino@yandex.ru

Abstract. Ensuring road safety is a paramount task to be solved by specialists in the field of automobile transport. It affects all aspects of the Driver-Car-Road-Environment system and is aimed at increasing the degree of protection of road users from traffic accidents, at reducing the degree of road traffic injuries and reducing the risk of mortality. Similar functions for ensuring road safety are performed by the active safety systems of the car, including intelligent driver assistance systems and assistants. With all the variety of possibilities of equipping automobiles with complex systems, there is a need to assess the feasibility and profitability of installing a particular complex of systems. For this, it is proposed to apply multi-criteria assessment methods. At the same time, the possibility of multi-parameter optimization according to two or more criteria is considered, respectively, several approaches to solving the problem are described. As a result, a concept is developed that is close to universal, in assessing the active safety systems of a car and intelligent systems.

With all the variety of possibilities of equipping cars with complexes of systems, there is a need to assess the feasibility and profitability of installing a package. In this case, it is necessary to turn to multicriteria assessment methods.

The task is to determine the best of the options for complexes of active safety systems installed on a car. At the beginning, you must select one or more criteria by which the comparison and selection of options will take place. The variety of criteria is not limited to the list given in this article. For example, this can be the degree of prevention of road accidents as such, the degree of reduction in mortality, the degree of reduction in road traffic injuries, the degree of coverage of the variety of traffic situations leading to road accidents, the cost of equipping a car with a system, the cost of repair and maintenance of systems. At this stage, a list is formed: the system and performance indicators.

At this stage of the multicriteria assessment, a general indicator of the complex is formed, based on the assumption that there is a certain probability that at the onset of a pre-emergency situation at least one of the systems will work and prevent an accident / have time to reduce the speed of the car / will allow a safe maneuver.

After defining the criteria for comparison, it is necessary to choose a methodology for assessing, as well as a method for determining and assigning weighting coefficients for each criterion, if necessary. When considering two comparison criteria, the Edgeworth-Pareto set is constructed for clarity. The problem of extracting the Edgeworth-Pareto set is usually considered as a preliminary one. It is followed by the most significant stage of decision making [2]. An example of the distribution of alternatives when compared according to two criteria by the Edgeworth-Pareto method is presented in Fig. 1.
Figure 1. An example of the distribution of alternatives by the Edgeworth-Pareto method.

For a larger number of criteria, it is proposed to use the construction of scales of criteria [3]. In Fig. 2. presents a comparison of three models, evaluated by four indicators.

Figure 2. An example of constructing models according to criteria scales.

The cost of active safety systems is taken from authorized car dealers. If there are several prices for the same system, you can use different calculation options: maximum indicator, minimum or average. It is more expedient to take the maximum indicator when considering the multicriteria assessment problem in the long term, the average indicator in the short term, and the minimum when calculating at a given time.

When using some methods, the presence of weight coefficients is necessary, which can be determined in the following way.

The simplest method for determining the weighting coefficients is the method of direct assessment by one expert who selects the most important criterion, in his opinion, and gives him an assessment $C_i=1$, and for other criteria $C_i<1$ depending on the importance of each criterion. The disadvantage of this assessment is too subjective, because it depends on the opinion of one person. In this regard, often
use a group of experts whose opinions are averaged, so the assessment is more subjective. Suppose there are m experts and n criteria, the rating set by the i-th expert to the j-th criterion is denoted by $c_{ij}$, where $i = 1, 2, ..., m$, $j = 1, 2, ..., n$. It is necessary to find the values of $a_i$ based on expert estimates $c_{ij}$. If experts use the same scales in their assessments, then the values of $a_i$ are calculated by simple averaging - dividing the sum of the estimates by the number of experts [4]. If different experts use different scales, then these estimates need to be normalized first. This is necessary in order to bring the rating scales used by different experts to one scale, in which all ratings are in the range from zero to one. Then the normalized expert estimates $a_{ij}$ are calculated by the formula:

$$a_{ij} = \frac{c_{ij}}{\sum_{k=1}^{m} c_{ij}}$$

- scaling condition.

The final values of the weight coefficients $a_i$ are obtained by averaging the normalized estimates of all m experts for each particular criterion.

$$a_i = \frac{\sum_{j=1}^{m} a_{ij}}{m}$$

The determination of weights is not limited to the proposed method.

The following describes the approximate calculation procedure using the example of the criterion “Probability of accident prevention”.

Let us designate the type of accident “collision” - event 1, “collision” - 2, “rollover” - 3. The complex of AXn systems will prevent event 1 with probability $AY_n$, the complex BXn - event 2 with probability $BY_n$, the complex CXn - event 3 with probability $CY_n$, where n is the serial number of the considered system or complex of systems.

If one system is considered, then there are no problems with it and the likelihood of accident prevention is simple and understandable. If the complex is considered, it is necessary to calculate the probability that at least one system will work in the pre-emergency or during an emergency.

Suppose $P(A)$ is the degree of accident prevention by a complex of systems, $P(A_n)$ is the reduction in the probability of accidents when using one system, $P(\bar{A}_n)$ is the probability that the system n will not work properly.

$$P(\bar{A}_n) = 1 - P(A_n)$$

$$P(A) = 1 - P(A_1) \times P(A_2) \times ... \times P(A_n)$$

After calculating the probabilities, we choose the best options AX, BX and CX. To do this, we choose the comparison criteria and methods of multi-criteria evaluation. In the example, we consider the choice according to two criteria: the degree of accident prevention, calculated earlier, and the cost of installing complexes on the car.

Assign: the complex AXn prevents accidents with probability $P(A) = AY_n$ and costs $S_{AXn}$, the systems BXn have $P(A) = BY_n$ and cost $S_{BXn}$, respectively CXn - $P(A) = CY_n$, $S_{CXn}$.

In this case, according to two criteria, one can construct the Edgeworth-Pareto set. Also, by assigning weight criteria to the method of expert evaluations, the following calculation can be done.

Suppose the weight of the cost criterion for installing WS systems, the weight of the security criterion $W_Y$. Then, for each option, we calculate the utility function $F$ by the formula:

$$F = S \times W_S + P(A) \times W_Y$$

Based on the results of calculations and graphing, the final complexes of systems AX, BX, CX of the corresponding cost are selected. The composition of the complexes determines the set of systems X, which is optimal and appropriate for installation on a car and to ensure road safety.

After determining the AX, BX, CX complexes, based on the statistics of accidents with victims during the January 3rd to February 26th period, one can calculate how many accidents could theoretically have been avoided if all the vehicles involved in the accident were equipped with active safety systems. This requires the total number of accidents by type.
Figure 3. The distribution of the number of accidents for the period by type.

Table 1. The number of accidents of each type for the period.

| Type            | Number |
|-----------------|--------|
| collisions      | 139    |
| arrivals        | 107    |
| tipping over    | 13     |
| other           | 11     |

In the presence of AX systems in event 1 (accident - collisions):

\[ N'_1 = A_Y \times N_1 \]

- \( N'_1 \) – number of collisions prevented;
- \( A_Y \) – probability of accident prevention by the AX system complex;
- \( N_1 \) – the number of accident type "collision".

With BX systems in event 2:

\[ N'_2 = B_Y \times N_2 \]

- \( N'_2 \) – the number of accidents prevented such as a “collision”;
- \( B_Y \) – probability of accident prevention by a complex of BX systems;
- \( N_2 \) – number of traffic accidents of the “collision” type.

With CX systems in event 3:

\[ N'_3 = C_Y \times N_3 \]

- \( N'_3 \) – number of collisions prevented;
- \( C_Y \) – probability of accident prevention by a complex of CX systems;
- \( N_3 \) – the number of accident type “collision”.

Further, the proportion of all types of accidental accidents prevented is considered \( K \).

\[ K = \frac{\sum N'}{\sum N} \]

- \( \sum N' \) – the number of theoretically prevented accidents of all types;
- \( \sum N \) – the number of all accidents for the January 3rd to February 26th period.

Next, we examine the economic feasibility of installing the selected complex of X systems. For this, the cost of installation or the cost of installing and repairing intelligent systems is compared. It is worth mentioning the urgent problem of assessing the cost of human life and the cost of injuries.

The problem of determining the cost of human life is one of the most controversial in the field of automobile transport. The cost of human life, or the cost of the average life, is a conditional estimated economic value, since human life is not a market commodity.

There are objective and subjective approaches to assessing the value of human life.
Objective assessment methods are called methods that rely on the following performance indicators:

- Per capita lifetime income of a person, or total lifetime income;
- Average GDP per capita;
- Total lifelong income and average per capita GDP, adjusted for the likelihood of death at a particular age;
- Social costs of human reproduction;
- The balance of material goods and services consumed and accumulated by a person.

The above approaches take into account economic losses only after a person dies. But there are cases when a person survives, but loses the ability to work in general or only to certain types of work. Considering the area of road transport and the cost of accidents, it is more convenient to use the methodology by which insurance payments are computed. In turn, insurance companies are subject to the Federal Law "On Compulsory Third Party Liability Insurance of Vehicle Owners" N 40-FL.

To do this, two indicators are compared: the cost of injuries of all victims of road accidents during the January 3rd to February 26th period and the cost of installing systems on all cars involved in these accidents. Here you can evaluate both the current situation and the situation in the future, given the life of the car, the cost of periodic maintenance of the systems and the number of accidents that can occur. Ideally, the cost of injuries should be higher than the cost of equipping a passenger car with systems. But in the accident reports on the website of the State Traffic Safety Inspectorate for the Nizhny Novgorod Region, accident details are only described for the dead and wounded, and road accidents with material damage are only numerically mentioned, which gives reason to conclude that if the conditions for the economic feasibility of installing the systems described above are not met, it is impossible to conclude that this action is completely inappropriate.

The multicriteria optimization method gives clear conclusions, but does not guarantee one clear solution, the best in all respects at once.
References

[1] Automatic and intelligent vehicle systems. Cars and tractors, multi-purpose wheeled and tracked vehicles, ground transportation and technological complexes, mobile robots and planet rovers: a textbook / under the general Ed. Professors V. Belyakov and L. Palkovich; Nizhny Novgorod State Technical University R.E. Alekseeva. - N. Novgorod, 2012. -- 475 p.

[2] Larichev O. I. Theory and decision-making methods, as well as the Chronicle of events in the Magic Countries: Textbook. - M.: Logos, 2000. 229 s: silt

[3] Lomakin V.V. et al. Vehicle safety. Textbook for high schools. - M.: MSTU "MAMI", 2011. - 299 p.

[4] Chernorutsky I. G. Methods of decision making. - SPb.: BHV Petersburg, 2005. -- 416 s: silt.