The choice of rational complex of active safety systems for smart cars

A I Markovnina, N D Tsyganov, A V Papunin, V S Makarov and V V Belyakov

Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Nizhny Novgorod, Russia

E-mail: alinomalino@yandex.ru

Abstract. The problem of ensuring road safety affects all elements of the Driver-Car-Road-Environment system. Smart cars equipped with enough traffic assistants can significantly improve road safety. Active vehicle safety systems, including intelligent driver assistance systems and assistants, perform similar road safety functions. With all the variety of possibilities for equipping cars with systems complexes, the need arises to assess the feasibility and profitability of installing a particular complex of systems. For this, it is proposed to apply the methods of multi-criteria assessment. As a result of calculations, the best options for the sets of systems that most widely cover the road situation have been identified.

1. Introduction

The problem of providing road safety affects all system elements Driver-Car-Road-Environment. The “Development of Transport Infrastructure in 2010-2020” federal target program is implemented in Russia today [1]. Within the program, ministries and departments of the Russian Federation conduct a set of measures aimed at improving the regulatory and actual provision of road safety.

Active car safety systems are aimed at preventing road accidents, which are currently developing very rapidly. Manufacturers are ready to offer all systems for installation, but the end user, who is not an expert in the field of automotive and safety, has a problem and a question: “What exactly to install?”

The problem of assessing the feasibility of installing one or another complex of active safety systems requires an integrated approach. The question was raised, which set of systems could be equipped on the car, so that it is not expensive and as efficient as possible in the field of safety. The task comes down to determining the best of the options for complexes of active safety systems installed on a car.

2. Results

Due to the insufficient number of studies, it is currently impossible to perform a calculation using all of the proposed criteria. In this regard, the comparison criteria were selected: the efficiency of the system (data from open sources): reduction in speed, braking distance, probability of skidding or roll, coverage of traffic situations (the calculation of this parameter is given below), cost of a system or a set of systems (information is being searched from official websites of dealers and on offers of car dealerships).

A criterion was defined to cover the traffic situations in which the system could operate. It does not mean that it is 100% effective in this situation, but only considers the fact that it would not be useless. The values of the comparison criteria are presented in Table 1.

System complexes prices:
Audi: Assistance systems complex "Travel" 81 700 rubles…168 454 rubles. Includes: adaptive cruise control; traffic recognition camera, adaptive driver assistance system, including emergency stop assistant; left turn assistant; emergency steering system [2]. Night vision system with pedestrian recognition function 150 818 rubles. Lane assist system with emergency stop assistant 24 552 rubles.

Chevrolet 495 $ (at 1 $ = 73 rubles - 36135 rubles): automatic parking system, collision warning system, lane assist system. $ 2095 (at $ 1 = 73 rubles - 152 935 rubles): lane assist system, adaptive cruise control, electromechanical parking brake, collision warning systems, automatic parking system, lane change assistance system, intersection assist, pedestrian detection system.

| Table 1. Values of comparison criteria [3], [4], [5]. |
|-----------------------------------------------------|
| **System or assistant** | **Installation cost** | **The maximum efficiency declared by manufacturer, %** | **The share of coverage of causes of road accidents, %** |
|-------------------------|------------------------|--------------------------------------------------------|--------------------------------------------------------|
| ABS, Anti-lock braking system | 25000…100000 calculated 25 000 | 30…63 calculated 45 | 100 |
| Collision warning system | 23811…28059 calculated 25 935 | 30 | 92,74 |
| ESP, Electronic Stability Programme (including ASR, EDB, BAS, EDS, EPB, DSR, ROP, FBS) | 11900…29000…55000 calculated 33 450 | 78 | 92,74 |
| PDS, Pedestrian Detection System | 15600 | 20…100 calculated 60 | 34,68 |
| All-round visibility | 36000…155000 calculated 36 000 | Informing, 20 | 34,68 |
| Downhill Assist Control, Hill Start Assist | ESP function +5000 | 15 | 19,35 |
| Cruise control | 23000 | 10 | 34,68 |
| Adaptive Cruise Control | 26400…29900…31616 calculated 29 900 | 42 | 68,15 |
| Traffic jam assistant | ACC function +5000 | 40 | 41,52 |
| Active Steering System | 40000 | 5 | 50,27 |
| Lane assist system | 10500…22600…69700 calculated 22 600 | 28 | 26,21 |
| Lane change Assistance System | 63133 | 28 | 8,46 |
| Intersection assist | By analogy with lane assist 55000 | 28 | 33,46 |
| Night vision system | 55000…112 400 calculated 55 000 | Informing, 20 | 33,06 |
| Traffic Sign Recognition System | 42000 | Informing, 20 | 4,44 |
| Driver tiredness monitoring system | Volvo and Mercedes from 60-80 km/h 5600…8000 | Informing, 20 | 100 |
| Emergency Steering System, ESA from VW | 15000 | 65 | 67,73 |
| Brake drying system (Bremsscheibenwischer, BMW) | Works from 80 km/h Not considered | 43 | 67,74 |
| Emergency Steer Assist ESA and improved assistant Lane Assist | 209 000 Considered as a package of systems | 45 | 26,21 |
| AEB, Autonomous Emergency Braking | 12100…15600 calculated 13 850 | 25…40…80 (New) calculated 60 | 67,73 |
| Parking assistance system | 20000 | Informing, 20 | 100 |
| Automatic parking system | 29800…42089…54617…77584 calculated 42 089 | 35 | 100 |
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.

Using the Edgeworth-Pareto method, two schemes are drawn up: the first is a comparison of cost and efficiency, the second is efficiency and coverage (Figure 1).

Figure 1. Distribution of systems by the Edgeworth-Pareto method.

According to the method of expert assessments using a questionnaire, the weights of the criteria were obtained. The survey was conducted among people aged 19 to 51 year old, mainly with a technical education. Most of them have the driver's license and a car.

As a result, it was found that most of the respondents consider the criterion of system efficiency to be the most important of those considered. The next in importance is the criterion of the cost of repair and maintenance; for the full functioning of the system, it is necessary that all the components are in a satisfactory condition.

The last two considered criteria are approximately the same in value; the cost of retrofitting turned out to be slightly more important than the cost of installation on a new car. It should be noted that the process of installing additional equipment on a car that was not initially prepared for this is more time consuming and expensive.

As previously planned, the values of the criteria are expressed in points. In terms of accident prevention and coverage of situations, the higher the actual value, the higher the score, while the cost is the opposite: the cheaper, the better.

Survey results:
- the importance of the efficiency criterion - 33.5%;
- the importance of the cost criterion - 42.33%;
- the importance of the coverage criterion is 24.17%.

Total 100%.

The following comparison complexes are assigned.
The very first and simplest complex is standard: ABS, ESP, adaptive cruise control. An approximate cost is 79,935 rubles. ABS is included in ESP, only ESP efficiency takes into account.

Second: Lane assist system, adaptive cruise control, electromechanical parking brake, collision warning system, automatic parking system, lane change assistance system, intersection assist, pedestrian detection system. An offer from Chevrolet, an approximate cost of 152,935 rubles.

Third: adaptive cruise control; traffic recognition camera, adaptive driver assistance including autonomous emergency braking (AEB); left turn assistant; emergency steering system. Offer from Audi, price from 81,700 rubles.

Fourth: ESP with hill start assist, hill start assist, PDS, AEB, parking sensors, driver tiredness monitoring system. An approximate cost is 95,900 rubles.

Fifth: PDS, adaptive cruise control with traffic jam assist, intersection assist, driver tiredness monitoring system, AEB, automatic parking system. An approximate cost is 161,439 rubles.

Sixth: ESP only with downhill assist control, hill start assist. An approximate cost is 38,450 rubles.

Seventh: ESP with hill start assist, hill start assist, all-round visibility, active steering system, lane assist system, AEB, parking assistance system. An approximate cost is 170,900 rubles.

Eighth: ESP, AEB, adaptive cruise control, collision warning system. An approximate cost is 103,135 rubles.

Ninth: ESP, adaptive cruise control, collision warning system, automatic parking system and traffic sign recognition system. An approximate cost is 173,374 rubles.

Tenth: ESP, adaptive cruise control with traffic jam assist, collision warning system, lane assist system. An approximate cost is 111,885 rubles.

For each complex, it is necessary to calculate the overall efficiency and the proportion of coverage of the causes of possible accidents.

The coverage is determined according to Table 1. Next calculate the efficiency parameter

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

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

\[
P(A) = 1 - P(A1) \times P(A2) \times ... \times P(An)
\]

The calculation results are presented in Table 2.

| Number | Efficiency, % | Coverage, % |
|--------|---------------|-------------|
| 1      | 87,2          | 93,14       |
| 2      | 94,5          | 93,14       |
| 3      | 83,3          | 93,15       |
| 4      | 98,1          | 94,75       |
| 5      | 97,9          | 91,94       |
| 6      | 81,3          | 94,35       |
| 7      | 96,7          | 93,14       |
| 8      | 96,4          | 92,74       |
| 9      | 95,4          | 97,18       |
| 10     | 96,1          | 92,74       |

Next, we calculate the utility function for each complex using the weighting factors. Due to the fact that efficiency and coverage have similar values, expressing these criteria on a 10-point scale reduces the accuracy of the calculations, so a 100-point scale will be used. The recalculation was only necessary for the cost criterion, since efficiency and coverage are expressed as percentages.
\[ F = \frac{S \times W_S + Y \times W_Y + I \times W_I}{100} \]  

(3)

where \( F \) is the utility function;
- \( S \) – the value of the cost criterion;
- \( Y \) – the value of the efficiency criterion;
- \( I \) – the value of the coverage criterion;
- \( W_S \) – the weight of the cost criterion;
- \( W_Y \) – the weight of the efficiency criterion;
- \( W_I \) – the weight of the coverage criterion.

\[
\begin{align*}
F_1 &= \frac{54 \times 33.5 + 87.2 \times 42.33 + 93.14 \times 24.17}{100} = 77.51 \\
F_2 &= \frac{6 \times 33.5 + 94.5 \times 42.33 + 93.14 \times 24.17}{100} = 64.52 \\
F_3 &= \frac{53 \times 33.5 + 83.3 \times 42.33 + 93.15 \times 24.17}{100} = 75.53 \\
F_4 &= \frac{43 \times 33.5 + 98.1 \times 42.33 + 94.75 \times 24.17}{100} = 78.83 \\
F_5 &= \frac{1 \times 33.5 + 97.9 \times 42.33 + 91.94 \times 24.17}{100} = 64 \\
F_6 &= \frac{81 \times 33.5 + 81.3 \times 42.33 + 94.35 \times 24.17}{100} = 84.35 \\
F_7 &= \frac{1 \times 33.5 + 96.7 \times 42.33 + 93.14 \times 24.17}{100} = 63.78 \\
F_8 &= \frac{39 \times 33.5 + 96.4 \times 42.33 + 92.74 \times 24.17}{100} = 76.29 \\
F_9 &= \frac{1 \times 33.5 + 95.4 \times 42.33 + 97.18 \times 24.17}{100} = 64.21 \\
F_{10} &= \frac{33 \times 33.5 + 96.1 \times 42.33 + 92.74 \times 24.17}{100} = 74.15 
\end{align*}
\]

3. Conclusions

To create a full-fledged smart car, it is necessary to rationally approach the choice of systems installed on it. The complex of systems should cover as many possible road situations as possible, both during simple driving and when maneuvering.

Based on the calculations made, the highest value was obtained for the sixth complex, which includes only ESP only with downhill assist control, hill start assist. Since the cost criterion had the largest scatter of points, the cheapest option became the best according to the calculations. ESP may be less expensive compared to other options and has a wide range of driving situations in which it could be useful, but this option has the lowest efficiency value.

The next group of the best solutions can be divided into complexes 1, 4, 8. The first complex: ABS, ESP, adaptive cruise control. Fourth: ESP with hill start assist, hill start assist, PDS, AEB, parking sensors, driver tiredness monitoring system. Eighth: ESP, AEB, adaptive cruise control, collision warning system.

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