MODELING THE INTELLIGENT TRANSPORT SYSTEMS ELEMENTS FUNCTIONALITY TESTING PLAN: A CASE STUDY

Ján Ližbetin *, Jan Pečman, Jiří Hanzl, Ondrej Stopka

Department of Transport and Logistics, Institute of Technology and Business in Ceske Budejovice, Ceske Budejovice, Czech Republic

*E-mail of corresponding author: lizbetin@mail.vstecb.cz

Resume

Autonomous control and the associated development of relevant intelligent control systems have become an issue of interest in the automotive sector decades ago. This article deals with the issue of subsystem validation planning. The theoretical part describes the issue, characterizes the current state of the researched issues in selected scientific publications and characterizes the data and methods with which the authors work. The practical part of the article analyzes a case study in the form of a model project, its structure, testing requirements and design of a test campaign plan. The output is a calculation and decision tree, which determines the optimal variant of the number of vehicles so that the validation is completed, while minimizing time and financial resources.

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1 Introduction

The autonomous operation of road vehicles, which will no longer be operated by a natural person, has become increasingly specific in recent decades, with developers being able to discover and validate a number of technologies relevant to this issue. However, the implementation of these systems was preceded by extensive research and development. Only then were the individual intelligent systems gradually delivered to pre-specified and controlled series of vehicles and tested [1]. Now, those technologies are slowly becoming the standard of comfort, as well as an element for increasing car safety. It can be assumed that the growing demand and pressure to ensure that vehicles equipped in this way are standardly delivered worldwide would increase in the coming years. For the manufacturer of a given vehicle type, this means creating a specification that meets the widest possible range of operating conditions. These, of course, vary considerably from one part of the world to another, so there is a need to ensure that these systems work properly and safely wherever the vehicle is operated, or that the user is informed of limited uses.

The article deals with the proposal of an optimized testing plan for intelligent transport systems (ITS) for autonomous management. This is a model in which the testing requirements are fixed. These are mainly the number of kilometers, the type of road, different lighting conditions and driving speed. According to the specific driving plan, the final decision on the number of used test vehicles is determined using the so-called decision tree method. The input information is, for example, the purchase price of the test car and possible sanctions in the case of non-compliance with the delivery date of the final product to the customer [2-3]. Proper testing is a key prerequisite for validation of any developed system. In the case of ITS for autonomous vehicle control, it is a question of verifying the correctness of the system's response to a given traffic situation. The validation procedure consists of the design and assembly of the test vehicle, the analysis of testing requirements, the planning of the test campaign, its implementation, the subsequent analysis and the synthesis of the collected data. The article also defines the individual terms that relate to the topic and provides links to other areas that affect validation. It is an explanation of the essence of ITS for the software management and testing automation, outlining the methodology of creating the testing requirements and a description of the practical implementation of tests.

2 Literature review

The issue of the ITS and autonomous vehicle management has been discussed very often in recent years and countless erudite and professional articles have been published. Much of the research and published output is devoted to ITS testing. Most published professional articles focus on development, testing and evaluation of autonomous systems. For example [4] deals with the so-called intelligent vehicle. In their Intelligent Vehicle Lab at the Technical University of Cartagena, authors designed a vehicle navigation application that provides a clear and reliable platform for the development of autonomous driving technologies as well as for the testing purposes. The open and modular architecture is able to easily integrate a wide range of sensors and actuators that can be used to test vehicle control algorithms and strategies. Algorithms are used to perform the global and local route planning on board autonomous vehicles.

A similar procedure is characterized, for example, in [5]. The article defines a path planning algorithm based on potential fields. Potential models are modified so that their behavior is appropriate to the surroundings and dynamics of the car and they can face almost any unexpected scenarios. The response of the system takes into account the characteristics of the road (e.g. maximum speed, lane curvature etc.) and the presence of obstacles and other users. The algorithm was tested on an automated vehicle equipped with a GPS receiver, a measuring unit and a computer vision system in real environments.

In publication [6], the authors discuss the problem of the method of "stereo" depth estimation into a model designed for in-depth learning of an autonomous vehicle control system using the neural networks. The authors came up with a "self-improving" pyramid stereo network that can obtain direct regression disparity without complicated post-processing. In addition, online learning can not only solve the problem of data reduction, but also save time spent on training and hardware resources in practice. At the same time, the proposed model has the ability to self-improve new scenes, which can quickly adjust the model according to test data over time and improve prediction accuracy.

Other selected publications directly address the design and the ITS system, but they do not directly address the way and procedure of testing these elements and systems. In other articles, the ITS testing is dealt with, for example, [7-11] or [12].

The publication [7] presents a complete framework capable of testing each component involved in the ITS and which is able to control the interoperability of all the components. This framework provides for testing the conformity of all the ITS components in terms of their specifications (especially communication protocols that ensure interoperability at different layers), as well as testing the interoperability of these components to ensure their proper functioning where they work together. It also notes that some standard specifications (either protocols or test case specifications) need to be improved.

In publications [8-10], the authors address simulation as a tool for the ITS testing and evaluation because it provides a cost-effective and safe alternative to testing and evaluation. A combination of simulators can be used to create accurate and realistic test scenarios, especially if the systems being tested are complex. Interconnected and automated driving in the context of the ITS is another area of research on the transport systems, dealt with in [9]. In the article, authors present a simulation framework consisting of driving, traffic and network simulators for testing and evaluating ITS applications. Examples of adaptive cruise control applications that are used as the test cases for the simulation framework, as well as for development of the real scenarios of its use, are given. Authors examined the reliability of communication tools in the vehicle, between vehicles and between the vehicle and the transport infrastructure or transport equipment, [10].

However, the issue of planning the scope of testing such systems is addressed very marginally. Most authors discuss either the systems themselves, the design of these systems, the method and possibilities of testing the reliability of ITS, but they no longer address the planning of the scope of testing. When planning the testing, the financial and operational capabilities of the development company must be taken into account, as well as customer requirements for reliability guarantees and system delivery dates. The publication [13] is closest to this topic. The authors present a checklist of critical steps and considerations that are part of successful ITS planning and implementation.

According to authors interesting is study [14] that tested some elements of intelligent transport systems, namely elements of adaptive cruise control in conjunction with passive safety features.

The results revealed that driver and passenger interaction with the seatbelt reminder system led to large and significant decreases in the percentage of trips where occupants were unbelted, in the percentage of total driving time spent unbelted and in the time taken to fasten a seatbelt in response to system warnings. The seatbelt reminder system was rated by drivers as being useful, effective and socially acceptable and led to a decrease in drivers' subjective workload.

The analysis of the examined documents shows that the issue of the ITS testing planning optimization is insufficiently addressed in the available scientific literature and the authors deal with it only marginally. This topic is addressed to a limited extent, which is considered a gap in articles published in professional and scientific journals. The topic of the ITS testing planning optimization is not sufficiently researched and analyzed. This proves and highlights the topicality of the researched subject and the fact that there is still room for further research in this area. The authors outline the possibility of optimizing the ITS s testing plan using the so-called decision tree and Gantt charts. The authors did not identify this view of the ITS testing planning in any of the analyzed literature.

3 Data and methods

Intelligent transport systems ensure active safety and increased comfort for drivers and other passengers while driving. Those systems can partially or completely interfere with the steering of the vehicle, while some maneuvers can be performed by the vehicle independently. It is another step towards autonomous driving, where the driver will not have to control the vehicle and will be able to engage in other activities. Individual ITS are based on monitoring the environment by sensors, mainly based on laser, radar, ultrasound, camera and their mutual cooperation. Individual sensors collect data from the environment and can detect individual objects. If the object is close to the vehicle, the sensor sends a message to the control unit, which passes this information on and ensures, for example, braking or adjusting the position of the vehicle in the lane.

Development of these systems is very time and money consuming and consists of several parts. After the development itself, the testing phase begins. First it is necessary to test the sensor and function on simulations, then in a test vehicle on a closed test polygon and then it is necessary to verify the correctness of the system functionality in real conditions [15]. This phase is called the final system validation and usually takes place in several countries and under different conditions. Testing requirements are usually determined by the purpose of the function. If this is a function to keep the vehicle in the lane on the highway, most of the test campaign will take place on the highways. However, if it is a parking assistant, the test campaign will focus on the greatest possible variability of parking spaces and scenarios that the end user can encounter. The data that uploaded as a part of the test campaign is then analyzed and the results are passed to the customer to verify the reliability and proper functioning of the system.

3.1 ITS software testing

Software is a very important part of ITS, although far from the only one. However, the final testing phase of the system focuses mainly on the results of the software, as the other parts were tested before they were put into operation. The final validation is therefore a check of the functionality of the unit with an emphasis on software.

The software testing is an integral part of its development and accounts for up to 50% of the time and costs of its development. If the software is not tested, errors or even a complete malfunction of the device could occur. Thorough testing of the software is therefore intended to ensure its smooth and correct functioning [16].

Due to the integration of software into virtually every aspect of life, great emphasis is placed on the proper testing to the satisfaction of the end user. In order to avoid all the malfunctions, the software would have to be tested several times longer than it took to develop and it would still not be possible to detect every bug. It is therefore necessary to find the point of the optimal level of testing so that all the fundamental errors are detected and at the same time software development still pays off economically. This point describes [17].

3.2 Testing procedure

Testing is defined as the process of assessing whether a particular system meets the originally specified requirements defined by the client or user. The test result is a report describing the difference between the expected and actual result.

During the testing, code errors and missing or incomplete requirements coverage are searched. The result demonstrates the quality of the product as a whole. There are several steps and levels in the testing process. The three basic steps are unit testing, integration testing and system testing. Software development is divided into several modules and each module is worked on by a different person or team of developers. Those modules are then tested separately and are unit testing. Integration tests check the correct assembly of modules. This step often reveals errors that make the modules incompatible. The development of individual modules separately is important especially so that the entire software is not tied to one person. In the event of termination of cooperation, the entire development project would be jeopardized. The individual modules must meet the given standards and requirements and must be mutually compatible and follow each other. The third step is system testing, in which all the aspects of the software as a whole are tested. When testing complicated and branched software with a large number of combinations, it is appropriate to incorporate testing automation [17].

The testing itself takes place in cycles, which consist of planning, analysis and preparation of tests, execution and evaluation and final monitoring of defects. In the planning phase, a project analysis is performed and it is defined which aspects are to be checked and evaluated within the testing, i.e. how the tests are to be performed. Of course, it is also necessary to consider human and financial resources and, based on these inputs, subsequently create a timetable. The output of this phase is a test plan, which indicates the division of roles and responsibilities, the timetable and the financial estimate of the activity [18].

3.3 Security of ITS functions

To ensure security testing, a statistical model needs to be defined. The statistical model is a term that defines the number of hours or kilometers in each condition to be tested. Vendor Functional Safety Specialists ITS functions, in collaboration with the customer-side experts, jointly create testing requirements to cover all the test scenarios and ensure maximum safety according to ISO 26262 and ISO 21448 [19-20]. The customer's requirements for the function of the ITS system are also included in this analysis. Based on this thorough analysis, a table is created with a combination of given conditions. The number of hours or kilometers, required to verify safety, is determined based on calculations by functional safety experts so that the individual risks are statistically covered.

This statistical model also serves as a basis for testing planning. It can contain conditions such as the road type, driving speed, number of lanes, lighting, weather conditions, as well as many others. The greater the number of basic conditions, the greater the final number of hours or kilometers that need to be recorded and the higher the costs associated with testing. The basic conditions should be defined in such a way that the basic possible combinations of conditions are covered and at the same time that they are achievable and their upload is not in conflict with the law. If it is necessary to upload a combination of conditions that does not occur so often and it is impossible or very difficult to upload the conditions, it is possible to simulate these conditions. This step is again associated with increased costs. Therefore, the proper preparation and a plan designed to minimize the time required to work with other participants, such as the profession of fire brigade or the closure of a public road, should be carried out.

ISO 26262 and 21448 standards are the basic pillars of the safety of the ITS functions and their scope covers all aspects of these functions in the development and subsequent operation phase on public roads. This topic is very sensitive, as it is a new issue and the public is still skeptical about the credibility of ITS systems. It can be assumed that the ITS functions will become the standard in transport over time and life without them will be difficult to imagine. Responsibility for the lives of drivers, crew members and other road users is an integral part of this issue and therefore safety always comes first [21].

3.4 Practical implementation of tests

To perform the tests, it is necessary to equip the vehicle with systems that can collect data for subsequent evaluation. These are mainly the tested sensor, the reference sensors and the computer that collects all this data. Reference sensors are sensors with greater accuracy than the tested sensor and are already available on the market. Based on the comparison of the recorded data, it is possible to compare the data recording results of the reference and tested sensor or a prototype.

4 Case study

The model project described in the feasibility study is a fictitious project that does not have its own project structure, customer or final product design. It is a universal model to which it is possible to apply all the processes of real projects without the risk of leakage of sensitive information. This project does not provide any specific functions, but collects general information from the real projects.

The aim of the study is a practical illustration of the testing process. In this part of the article, the authors want to explain to readers how and under which conditions data collection and evaluation would take place. Each test plan is developed primarily from customer requirements. The customer defines what he wants to test, what test results he expects and under what conditions the test should take place. Subsequently, a testing plan is compiled that reflects all the input factors defined by the customer. The reader will thus get a more specific idea of the testing process and how to evaluate the obtained data.

4.1 Requirements from customers

The selected model project is focused on several functions of autonomous management. Testing requirements are therefore composed of the real requirements for individual functions for specific customers. As the areas of operation of the individual functions are very different, the final conditions for testing cover a wide range of possibilities and their mutual combinations. The purpose of testing autonomous control functions is to cover as many combinations of conditions as possible that a vehicle can get in normal traffic on public roads [22-24]. Covering all the entered combinations at a given time requires very detailed planning and knowledge of transport conditions in other countries.

One of the basic building blocks for creating a statistical model is the type of road. In this case, the road type can be defined by three basic categories: "Rural", "Urban", "Highway". These are rural roads, urban roads, the so-called district roads and motorways.

Another group of conditions are lighting

***Table 1** Overview of testing requirements, [27]*

	Description	%	Number of hours
Traffic orientation	Left-sided	30	300
	Right-sided	70	700
Country	Germany	20	200
	France	10	100
	Czech Republic	10	100
	Hungary	10	100
	Denmark	10	100
	Belgium	10	100
Light conditions	Day	80	800
	Night	15	150
	Low light	5	50
Type of road	Urban	15	150
	Rural	15	150
	Highway	70	700
Total		100	1000

conditions. Some sensors change their behavior based on the lighting conditions. This can be caused by poor visibility at dusk and at night, glare from public lights or oncoming vehicles. Each function needs to be tested in all the variants of lighting conditions to minimize the risk of malfunction that could lead to an accident. The lighting conditions have three categories: "Day", "Night" and "Low light". The individual conditions are precisely defined by the Meteorological and Astronomical Institute. The Low light category includes civil, nautical and astronomical dawn and dusk, as well as the golden hour. Civil dawn and dusk are defined by the position of the center of the solar disk, which is located 6° below the horizon. At this time, it is possible to perform most common daily activities without artificial lighting. Nautical dawn and dusk take place when the center of the sun's disk is between 6° and 12° below the horizon. The first stars are beginning to be seen and the horizon is also very noticeable. Astronomical dawn and dusk are the moment of the first or last rays of the sun. The stars are clearly visible in the dark sky and the center of the sun's disk is located 18 ° below the horizon. The golden hour is the part of the day when the center of the sun's disk is between 10° and 12° above the horizon. The golden hour is often accompanied by golden lighting. Sunrise and sunset are events when the center of the sun's disk crosses the horizon. The day is therefore the part of the day from the time when the sun is 12° above the horizon in the morning until 12° above the horizon again in the evening. The night runs from astronomical twilight to astronomical dawn [25-26].

For the purposes of the model project, it is also important whether it is right-hand or left-hand traffic. Although the left-hand traffic is associated mainly with Japan and the United Kingdom, it affects more than seventy countries around the world. They will probably not be so significant in terms of overall size or population, but the fact that the number is more than a third of all the states is certainly worth noting. This is also one of the biggest differences in the road transport one can find in the world. In such a case, it is necessary to at least know the shortcomings of the functions of autonomous control, in the best case to verify that the function works properly even in such changed conditions and is able to adapt. Table 1 lists all the parts of the statistical model that are applicable for each country. Only European countries were chosen for the purposes of the model project, but it is no exception that data needs to be uploaded in the USA, China, Japan, South Korea and many other areas.

The total number of recordings must be at least 1000 hours. At least 30% of the total must be on the left-hand drive roads. The volume of data uploaded in Germany must be double that of other right-handers. The volume of data for the remaining countries must be evenly distributed. Other countries, where data upload and subsequent function validation are required, are: France, the Czech Republic, Hungary, Denmark and Belgium. The required distribution of data from individual types of roads is as follows: Urban = 15%, Rural = 15%, Highway = 70%. The distribution of data recorded in individual lighting conditions is as follows: Day = 80%, Night = 15%, Low light = 5%.

4.2 Draft test activity plan

Based on customer requirements, it is then necessary to create a specific plan for the test campaign. This plan may change during the campaign. The reason

__Table 2__ Length of recording in individual countries, [27])

Country	Hours of recording	Days of recording	Weeks of recording	Estimated number of km
Great Britain	380	64	13	32200
Germany	252	42	9	21320
France	131	22	5	11000
Czech Republic	131	22	5	11000
Hungary	131	22	5	11000
Denmark	131	22	5	11000
Belgium	131	22	5	11000
Total	1287	216	47	108520

for changing the plan may be, for example, specifying or changing some requirements or changing the start of the campaign due to delays in previous development steps. Another possible stimulus for change may be the sudden occurrence of an unexpected event, such as an accident or breakdown of a test vehicle, natural influences and disasters, or a loss of human resources. It is necessary to respond to each of these facts operatively, but it is not necessary to include them in the planning. The test campaign plan includes a Gantt chart, a plan of each path to be uploaded and the estimated financial amount of the entire campaign.

The maps.google.com server was used to plan accurate routes due to its worldwide reach and ease of use. For the purposes of this test campaign, the assumed average speed was set at 100 km.h^{-1} for the Highway condition, 70 km.h^{-1} for the Rural condition and 30 km.h^{-1} for the Urban condition. The total estimated mileage and length of recording in each country are shown in Table 2.

As an example of testing in individual European countries, the article presents the test in Germany. The complete course of testing in all the selected European countries is detailed in [27].

Germany is the second country in terms of the total number of hours needed to validate the system. For the Rural condition, the estimated number of kilometers to meet the requirement is almost 3,000 km. To meet this requirement, one only needs to upload the defined route once. The Highway condition is represented by a larger number of hours, so the expected number of recorded kilometers is also higher. In the case of Germany, it is 17,500 km. To meet the requirement, the selected route needs to be uploaded four times. Again, it is possible to use both directions of one route to increase the variability of the recorded data.

The following cities were selected for the Urban condition: Berlin, Munich, Stuttgart, Hamburg, Dresden, Cologne and Frankfurt. Only one day will be recorded in each of these cities. These are cities that are important not only for their history, but especially for their technical sophistication and are therefore also important for development of autonomous management.

The number of hours required to record does not vary in other countries. Individual countries differ in the composition of the infrastructure and the area, which affects the total number of repetitions of individual routes, but this is not important in the case of a model project.

However, some specific projects may regulate the number of iterations. It is also necessary to incorporate the requirements of lighting conditions into the planning of individual shifts. During the eight-hour shift, six hours are expected to be used effectively for recording. The loss of two hours is expected due to the need to prepare and calibrate the in-vehicle recording system, report daily results and upload data samples for inspection. The distribution of shifts under lighting conditions depends on the exact location and time. In the case of covering the Day, Low light and Night conditions, it is advisable to schedule afternoon shifts during which all the three categories of light conditions will be met on an ongoing basis. Due to the organization of accommodation and breaks between the shifts, this option is more suitable than planning several night shifts. Due to the constant shifts, night shifts are inappropriate. If the shift ends at 6:00, for example, accommodation would have to be paid for two days and the costs would double. In exceptional cases, it is possible to insert a night shift if the crew stays in the same location for several days. If the night shifts are not planned for the whole week, it is advisable to include them at the end of the working week in order to observe the rest periods and, at the same time, to make efficient use of the time during the working week. The plan of individual campaigns also needs to be monitored in terms of time.

For the project management, it is important to have an overview of when which vehicle will move in each location. Not only for these purposes, the Gantt chart will be used, which provides a simple weekly overview of ongoing activities. For the needs of the model project, only the length of individual variants of the test campaign is determined, as its beginning is not specified. The project requirement is that the total duration of the test campaign does not exceed twenty weeks. If this limit is exceeded, a fine would be imposed for non-compliance with the agreed deadlines with the customer, which is subsequently included in the decision tree [28].

5 Results

The performance of the whole static model of testing and the processing of the obtained data was done within the diploma thesis [27]. The student of the combined form of study worked in an unnamed company, which deals with development of elements of intelligent transport systems and was given the task to process the requirements and testing plan. She worked in the team that implemented the test plan and was able to obtain a relevant amount of data. Based on the entry requirements and the developed plan, she processed the obtained results of individual tests within her diploma thesis.

If only one test vehicle was used for the entire test campaign, this activity would last 54 weeks. In such a case, the set limit would be exceeded more than twice and high fines would be imposed. It can therefore be assumed that this option will not be suitable for the implementation of the campaign. Table 3 contains a Gantt chart of the testing process with one test vehicle.

If the two vehicles are used, the total length of the campaign will be reduced to 27 weeks (Table 4). In this variant, the set limit will also be exceeded, but the difference is not as significant as in the first variant with one vehicle. As the number of vehicles increases, the total number of kilometers travelled by one vehicle decreases, thus reducing the risk of a serious fault.

The variant, in which three test vehicles are available, is reduced to a total length of 19 weeks. This is the first option in which the set limit is observed without the need to pay a fine for non-compliance with the agreed deadline for submission of the project. If exceeding the limit would mean the final unsuccessful completion of the project, there would be a minimum number of three vehicles with which this deadline can be met. The total length of the test campaign was reduced by eight weeks (Table 5). Saving eight weeks can have a major impact on the overall progress of the project and can be a key factor leading to the final successful completion of the project.

Using four test vehicles would only use sixteen weeks out of a total limit of twenty weeks per test campaign. The four-week reserve is relatively large and would probably not be used. It would be possible to shorten the total time, but in this case, there would be long inefficient vehicle crossings, which is not necessary in this case due to not using the entire set time for the test campaign. The total inefficient time spent in the service is again six weeks. Therefore, adding another

Table 3 *Gantt chart for one test vehicle (TV 1), [27])*

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TV 1			CZ			H	service		H			DK		service
Week	15	16	17	18	19	20	21	22	23	24	25	26	27	28
TV 1		DK			D		service			D				service
Week	29	30	31	32	33	34	35	36	37	38	39	40	41	42
TV 1			F			BE	service		BE			GB		service
Week	43	44	45	46	47	48	49	50	51	52	53	54		
TV 1			GB				service			GB				

Note: CZ - Czech Republic, H - Hungary, DK - Denmark, D - Germany, F - France, BE - Belgium, GB - Great Britain

Table 4 *Gantt chart for two vehicles, [27])*

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TV 1			F			BE	service		BE			GB		service
TV 2			CZ			H	service		H			D		service
Week	15	16	17	18	19	20	21	22	23	24	25	26	27	
TV 1			GB				service			GB				
TV 2			D				service	D			DK			

Table 5 *Gantt chart for three vehicles, [27])*

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TV 1			CZ			BE	service		BE			GB		service
TV 2			H			F	service		F			GB		service
TV 3			DK			D	service			D				service
Week	15	16	17	18	19									
TV 1			GB											
TV 2		GB												
TV 3	D													

Table 6 Gantt chart for four vehicles, [27])

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TV 1			GB				service			GB				service
TV 2			D				service		D			DK		service
TV 3			BE			F	service		F					
TV 4			CZ			H	service		H					
Week	15	16												
TV 1	GB													
TV 2	DK													
TV 3														
TV 4														

Table 7 Gantt chart for eight vehicles, [27])

Week	1	2	3	4	5	6
TV 1			CZ			
TV 2			H			
TV 3			D			
TV 4	D			F		
TV 5	D			DK		
TV 6			BE			F
TV 7			GB			
TV 8			GB			

vehicle does not result in the more efficient use of vehicles (Table 6).

Another variant is set at eight vehicles (Table 7). In this variant, there is no need to service the vehicles during the campaign and therefore the time is used most efficiently. The entire test campaign could be implemented in just six weeks, which is the same time that the vehicles spent in service on the previous three variants. In this variant, there are also minor changes in the composition of countries. It is not a condition that one vehicle records a single area, so it is possible to combine individual countries. Two vehicles can be allocated to the UK to speed up the test campaign. The route to be loaded will then be split between the two vehicles, so the vehicles do not have to travel together. In a shorter time, they will be able to cover most of the required route.

Each vehicle is associated with the costs of its purchase, purchase of test equipment and subsequent installation. Specific prices are very sensitive information for all the companies. Therefore, the prices were converted to the number of units. Factors such as the price of the data upload itself, the price of the test car and its equipment, the price of the vehicle service and the possible amount of the fine in the case of non-compliance with the set deadline are included in the price calculation. Detailed calculations and characteristics of individual items for individual testing variants are given in [27].

6 Discussion

The performance of the whole static model of testing and processing of the obtained data was done in [27]. The student of the combined form of study works in an unnamed company, which deals with the development of elements of intelligent transport systems and was given the task to process the requirements and testing plan. She worked in the team that implemented the test plan and was able to obtain a relevant amount of data. Based on the entry requirements and the developed plan, she processed the obtained results of individual tests. Based on those results, a decision tree was compiled.

The final tool for deciding on the number of vehicles to be used for the model project test campaign is the decision tree. The decision tree (Figure 1) takes into account different variants and compares them to each other in order to minimize the costs [28-30]. The options that can ultimately be chosen are the choice of one, two, three, four or eight test vehicles. Based on this decision, it is also necessary to adapt the specific plan for each shift and to ensure sufficient human resources to carry out this campaign, as well.

Based on the decision tree, it is necessary to decide how many test vehicles will be used for the test campaign. It is possible to choose from variants 1, 2, 3, 4 and 8 vehicles. The number of service operations is determined based on the interval in the Gantt chart for each variant. Seven service tasks are required for one vehicle; for a variant of 2 to 4 vehicles it is six service operations. In the case of eight vehicles, there is no need to interrupt the test campaign due to the necessary service and all maintenance on the vehicles can be carried out after the end of the test campaign at the expense of another project, if the vehicles continue to be used.

If the service intervals are not observed, there is a risk of more serious breakdowns on the vehicle and the consequent higher costs of servicing. It is assumed that the time saved by neglecting regular service would subsequently have to be used to carry out emergency service during the campaign, so the overall length of the campaign is unlikely to change. If the time limit of 20 weeks is exceeded, there is a fine for not meeting the deadline. The number of weeks for the one-vehicle variant is 54, for two vehicles it is 24 weeks, for three vehicles 19 weeks, for four vehicles 16 weeks and for eight vehicles only 6 weeks. There are no penalties or benefits for the earlier termination of the project.

The evaluation of the decision tree in individual nodes is as follows:

1) Step 1 - testing or termination (7-16): 3 900 < 22 500
2) Step 2 - with service or without service (2 - 6):
   a) (3 900 + 420 = 4 320) < (3 900 + 450 = 4 350)
   b) (3 900 + 360 = 4 260) < (3 900 + 900 = 4 800)
   c) (3 900 + 360 = 4 260) < (3 900 + 1350 = 5 250)
   d) (3 900 + 360 = 4 260) < (3 900 + 1800 = 5 700)
   e) (3 900 + 0 = 3 900) = (3 900 + 0 = 3 900)
3) Step 3 - number of testing vehicles:
   a) 4 320 + 4 500 + 35 700 = 44 520
   b) 4 260 + 9 000 + 7 350 = 20 610
   c) 4 260 + 13 500 + 0 = 17 760
   d) 4 260 + 18 000 + 0 = 22 260
   e) 3 900 + 36 000 + 0 = 39 900
   f)

Based on evaluation of the decision tree and taking into account all the risks, the optimal number of vehicles was determined to be three. In this variant, the time set for the completion of the test campaign is sufficiently used and at the same time it is possible to coordinate the operation of all three vehicles without major difficulties [31-32].

Based on the result, it can be noted that it is more advantageous to adhere to regular service intervals of vehicles, so as not to cause more serious failures, the repair of which would be many times higher. Although the service life of the test vehicle is around five years, it

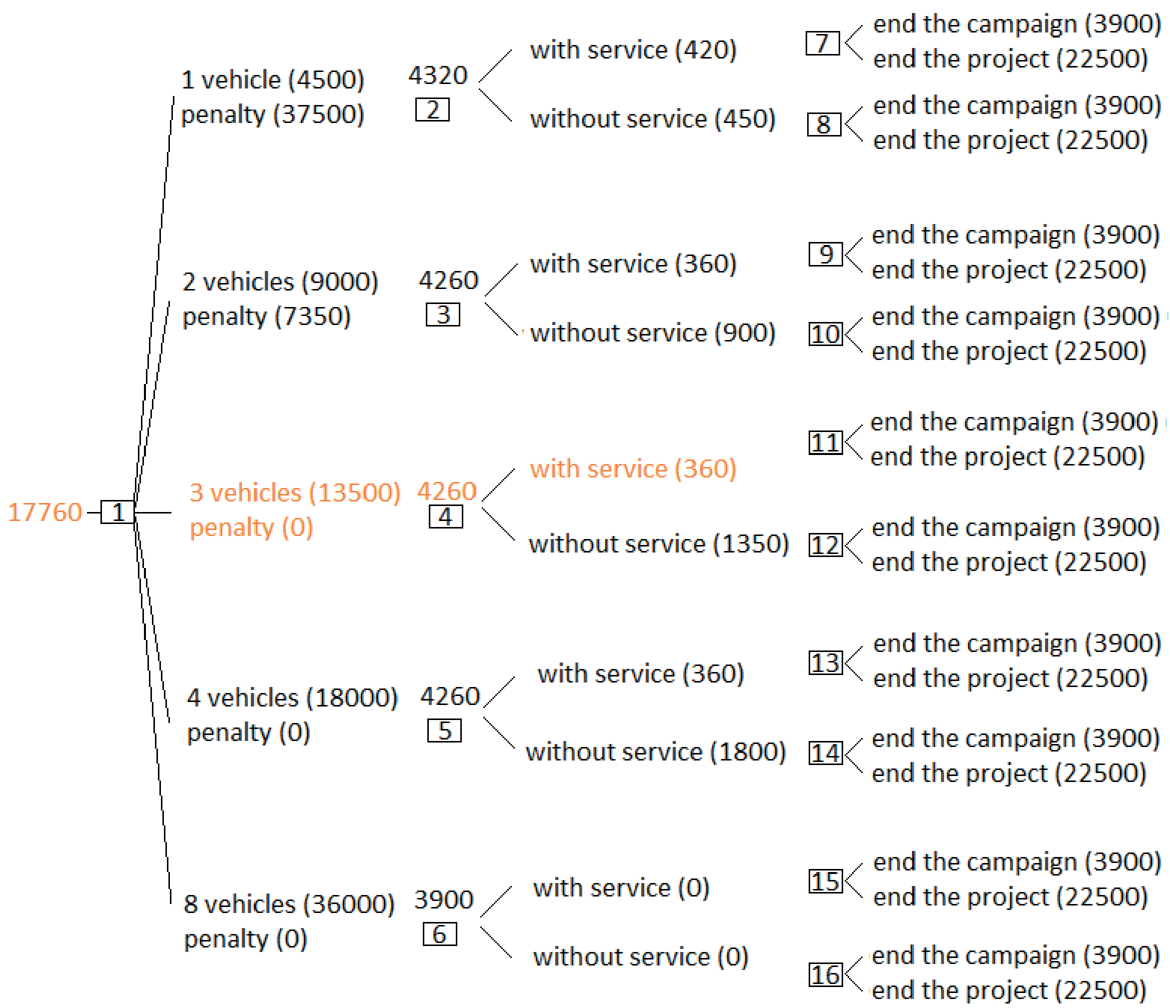

***Figure 1** Resulting decision tree, [27])*

is very undesirable to encounter an unexpected vehicle failure during the test campaign. Risks arising from unplanned repairs are, for example, insufficient service capacity or unavailability of spare parts. Those risks can jeopardize the entire course of the test campaign and thus the entire project.

At the same time, it was also found that in the case of this model project, the fines for exceeding the set deadline are so high that it pays to invest in the acquisition of more test vehicles and thus meet the deadline. For another project, however, it could be the other way around. This decision depends on the amount of the fine for non-compliance with the deadline and price of the vehicle and its equipment, so it is necessary to find out at the beginning of the project what factors could affect the final result and what the impact could be on the whole project.

The three-vehicle test campaign will last 19 weeks and will require a total of 6 test crew members. The total costs of the test campaign are 17760 units. The variant of one vehicle was in the total amount of 44520 units, and it is therefore the most expensive variant. By increasing the number of vehicles to three, the total costs were reduced by 60 %.

During this campaign, each of the vehicles will undergo a total of two regular services, which will ensure a sufficient service life of the vehicle throughout the test campaign. After the end of the test campaign, the vehicles can be used on another project, or as obstacles to testing functions on the test site. Vehicles that have been modified and equipped with test technology must not be returned to normal operation. If no other activity is found for the vehicle, it will have to be eliminated. The test equipment can also be used on other vehicles.

7 Conclusions

Intelligent transport systems help the driver to control the vehicle and their main task is to increase the road safety and driving comfort. Examples of these functions are parking assistant, traffic congestion assistant and automatic emergency braking. Those functions are usually based on sensors that collect information about the environment and then take control or warn of possible obstacles. In the automotive field, laser and ultrasonic sensors, cameras and radars, or combinations thereof, are used for this purpose. The combination of multiple sensors ensures greater reliability of functions. If one of the sensors does not have sufficiently accurate data about the vehicle's environment, the other sensor can replace it, or they compare the information collected from the environment and evaluate the whole situation together.

The development of these systems is very time and money consuming and consists of several parts. After the development itself, the testing phase begins. The data that is uploaded as a part of the test campaign is then analyzed and the results are passed to the customer to verify the reliability and proper functioning of the system.

The article deals with creation of a plan for the final verification of the functionality of intelligent transport systems, taking into account the minimization of time for vehicle testing and minimization of testing costs. After creating five proposed variants, one variant was selected based on the decision tree. Using this option, the test campaign will be completed within the set time limit. This limit is twenty weeks of uploading and the three-vehicle variant will cover the entire test campaign in as little as nineteen weeks. The test campaign will take place in the United Kingdom, Germany, France, the Czech Republic, Hungary, Denmark and Belgium. It is estimated that over 100,000 km will be recorded during this campaign, divided into different road conditions and lighting conditions.

The solution that was originally expected to be the most economical was to use a less than optimal number of vehicles. It would be necessary to pay a fine for not meeting the agreed deadline, but the total costs could still be lower. This assumption was not confirmed and despite the high purchase price of the test vehicle and other equipment, the three-vehicle variant was less costly. From the customer's point of view, meeting the deadline is also a sign of reliability.

In conclusion, the authors state that the aim of this article has been achieved. The case study, which is part of the article, provided an insight into the issue of creating a plan for testing elements of intelligent transport systems so that it brings relevant data for the customer. This data also serves the customer as a basis for declaring the functionality and reliability of its components. In the final evaluation of the achieved results, the authors state that the overall results of reliability and functionality testing limit two basic factors - the total costs of the test room and the time required to perform a sufficient number of tests. It is very difficult to optimize the total costs of testing while maintaining the required time range. A possible further goal of the research could be the study and design of a more exact testing methodology, which would bring a sufficient amount of relevant data needed to state the reliability, namely the system unreliability.

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