P R A C E N A U K O W E P O L I T E C H N I K I W A R S Z A W S K I E J
z. 126 Transport 2019

Tomasz Kamiński, Małgorzata Pędzierska, Kamila Gąsiorek
Motor Transport Institute, Transport Telematics Center

SELECTED ISSUES OF RESEARCH ON THE IMPACT OF INTELLIGENT TRANSPORT SYSTEMS ON ROAD SAFETY WITH THE USE OF DRIVING SIMULATORS

Manuscript delivered, June 2019

Abstract: The article describes the impact of information displayed to drivers on boards with variable content and presented on the static table, on drivers' decisions regarding the selection of an alternative route. The results of the research obtained in the RID 4D project titled "Impact of the use of Intelligent Transport Systems services on the level of road safety" financed by the National Center for Research and Development and the General Directorate of National Roads and Motorways (DZP/RID-I -41/7/NCBR / 2016 agreement).
The article describes an attempt to assess the economic effects of implementing selected ITS solutions. Based on the impact of selected ITS solutions on the speed of driving, an assessment was made of the increase of safety on the road, using as a measure the number of people killed, severely and slightly injured. The whole article is summarized by conclusions.

Keywords: transport, road safety, Intelligent Transportation Systems, driving simulators

1. INTRODUCTION

The research described in this article referred to the impact of Intelligent Transport Systems on the road safety. In a course of the study a high-end AS 1200-6 driving simulator (fig. 1) was used. The simulator allows to compose experiments taking into account various road and atmospheric conditions. It is possible to control both the behaviour of the road traffic participants and the ambient conditions: weather and lighting. Modifications may include: atmospheric conditions (snow, rain, fog), road surface (slippery, icy, wet), time of day (day, night), type of road (motorway, municipal road, rural road, etc.) and the traffic situation. An advanced computer graphics and high image quality, which is projected onto a panoramic screen, allow to create a very realistic driving experience. In addition, the vehicle cabin is located on a moving 3DOF platform operated by electric actuators. It can move in three planes and rotates in relation to three axes. Thanks to this, the examined driver receives the kinaesthetic impressions, e.g. acceleration, turning or braking which occur during driving in real conditions.

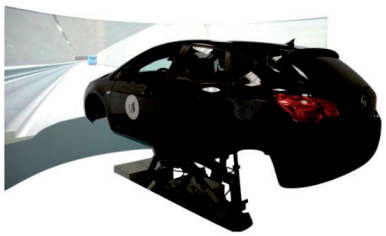

Fig. 1. The AS 1200-6 driving simulator

Controlling the simulation program and recording of the driving round is possible from the operator's position. The data logging system allows to record traffic parameters of all vehicles and events occurring while driving. It is possible to acquire several dozen different variables at the same time. The extended system allows the projection of up to 100 road objects simultaneously and imitating driving over 200 km of virtual roads. At the operators position it is also possible to monitor the driver's reactions related to driving, such as: pressing the pedals, steering wheel movements and eye movements. A mechanical stimuli (cabin and seat vibrations) and sound effects can be generated inside the simulator cabin.

Increasing the level of traffic safety is one of the main goals of implementing and developing Intelligent Transport Systems. The following actions serve this purpose [9]:

- development of traffic management systems on the expressways,
- traffic control at the entrances to the expressways (so-called Ramp Metering),
- development of the systems diverting the vehicles on to the alternative routes,
- area traffic control,
- development of road accident management systems,
- application of the modern electronic toll collection systems.

Numerous analyzes have shown the following impact of the service on the traffic safety [2, 3, 8, 12]:

- decrease in the number of fatalities by 51%,
- average speed reduction by 15%,
- reduction of the number of accidents by 10 – 30%,
- reduction of the number of collisions by 4.5 – 8%.

One of the basic and at the same time effective methods of conveying commands and recommendations to the drivers, including information about the changing traffic situation, road works, traffic jams and weather conditions, are messages displayed on Variable Message Signs (VMS). In the empirical studies on VMS, the most frequently analyzed are: vehicle speed, sudden acceleration and sudden braking as well as the distance of the longitudinal axis of the vehicle from the axis of the lane.

The research shows that the driver reduces the speed when approaching the sign. This means that drivers notice and respond to VMS signs, but they need additional time to process the information they provide. An example is the Boyle and Mannering study [1]. The researchers checked how the system informing about unfavourable weather conditions and road incidents affects the behaviour of the driver. The message conveyed by the internal system in the vehicle with external information (via a variable message sign) was compared. The speed

of 51 drivers aged between 16 and 70 was measured. Four conditions of the experiment were taken into account:

- driving without notification,
- driving with the possibility of a message appearing on the VMS,
- driving with the possibility of an internal system message in the vehicle,
- driving, during which the driver was simultaneously notified about the traffic situation using an external and internal message.

For each of the conditions, two research scenarios were developed, related to weather (presence of fog or lack of it) and the possibility of a dangerous event (presence of a snowplough or its absence).

The following three messages appeared on the VMS signs: "Fog – slow down to 45 mph" (72.6 km/h), "Winding road - drive slowly" and "Snowplough in front - slow down to 35 mph" (56.5 km/h). A total of eight messages were presented to each person tested. The yellow colour information, placed in two lines, on the black background was displayed on the VMS signs. Based on the analysis of the results, it was found that VMS signs have similar effectiveness to the driver's notification system located inside the vehicle and cause a reduction in the driving speed. The drivers who were not informed about weather conditions or warned about the danger were driving much faster (on average 116.3 km/h) than the drivers who were notified about the traffic situation through the internal system and by the VMS sign (average 102.6 km/h). The analysis of the results led to interesting conclusions. As it turns out, the driver after reading the message from the sign and complying with it by decreasing the speed, has a tendency to compensate for this speed reduction by increasing it, when there are no more such adverse conditions, which is important from the point of view of the road safety [1].

2. RESEARCH SCENARIOS

Variable message signs (VMS) in Poland should meet the requirements set out in the following documents:

- Annex No. 1 to the Ordinance of the Minister of Infrastructure of July 3, 2003. "Detailed technical conditions for vertical road signs"),
- European Standard PN-EN 12966-1: 2005 "Vertical road signs - Road information signs with variable content - Part 1: Product standard,
- European Standard PN-EN 12966-2: 2005 "Vertical road signs - Road information signs with variable content - Part 2: Initial type testing,
- European Standard PN-EN 12966-3: 2005 Vertical road signs - Road information signs with variable content - Part 3: Factory production control.

It is recommended that the text panels be made as freely programmable. It gives the possibility of displaying content programmed both at the very beginning and any content programmed in the course of later use. The size of the sign matrix should consist of 5 columns and 7 lines. The character of the road affects the dimension described. The length and height of the panel must be inversely proportional multiple of the height and width of the matrix,

e.g. length - 70, height - 50, however, the length-height ratio, e.g. length - 350, height - 100 does not have to be maintained.

In order to investigate the impact of information provided to the drivers using VMS, a set of research scenarios was built, under which commands and recommendations were passed to the drivers using a variety of information. The tests were carried out for good and bad (rainfall) atmospheric conditions. The following graphical contents were presented on the gantries (tab. 1).

Tab. 1

Graphical contents presented on the gantries - scenarios with choice of route

Gantry 1 area in the scenario 1	Gantry 6 area in the scenario 3
	
Gantry 1 area in the scenario 2	Gantry 6 area in the scenario 0
	An alternative route without dynamic information

One of the main causes of the road accidents is an excessive speed of the vehicle. Speed during the impact directly affects the consequences of an accident (fatal accident, accident with people who are seriously or slightly injured). Therefore, during the experiments carried out, the speed was recorded in particular at a distance of 30 m before VMS, at the VMS location, 30 m behind the sign and 200 m after the variable message sign. A separate group of research scenarios were simulated situations where drivers chose an alternative route. Then the number of people who chose the alternative route and the number of people who remained on the main road were registered.

The research group included 60 people. The condition for participation in the research was the possession of a valid category B driving license and driving a minimum of 2000 km a year. The subjects were divided into three age groups:

- 18–24 years old,
- 25–49 years old,
- 50 and more years old.

Each group consisted of 20 people.

3. THE TEST RESULTS OBTAINED

Selected test results are described in articles [10, 6]. The highest speed reductions were noted for the signs:

- speed limit with the given reason for the restriction - decrease by 17.6%,
- information about the accident, the need to change the lane along with the speed limit- a decrease of 15.75%,

– speed limit on the board - decrease by 15.65%,
– information about slippery surface - decrease by 12%.

In addition to a significant decrease in vehicle speed, an increase in the distance from the preceding vehicle was also noted, which reduces the likelihood of a collision with the vehicle in front. There is therefore an increase in the level of road safety.

In the case of gantry 1 area in the scenario 1 (table 1), the numbers of drivers remaining on the main route and those choosing an alternative route depending on the weather conditions were analyzed. The table shows a small difference in the length of the main road (25 min) and the alternative route (20 min).

In case of, both, good weather conditions, as well as the rain, 20 drivers remained on the main road and 10 of the tested ones chose the alternative route.

On the gantry 1 in the scenario 2 (tab. 1) a sign informing about the possibility of selecting an alternative route, was placed. The board contained the phrase "Recommended diversion". The reason for displaying the information and the time of driving the main route and the recommended detour, were not given. The aim of the experiment was to find out how many drivers would use the alternative route in such conditions. In the case of good weather conditions, 11 drivers remained on the main road, and 18 of the respondents chose an alternative route. In the case of rain, an alternative route was chosen by 20 drivers.

On the gantry 6 in the scenario 3 (tab. 1), an information on a significant difference in the driving time of the main route (40 min) in relation to the alternative route (20 min) was placed. In the case of good weather conditions, 9 drivers remained on the main road, and 22 chose the alternative route, while in the case of rainfall, 14 of them remained on the main road and 15 chose an alternative route. Based on a comparison of the average values, it can be concluded that opting for an alternative route was chosen more often in good weather conditions.

In the case of gantry 6 in the scenario 0 (tab. 1), apart from the driving speed analysis, it was checked how many respondents chose to go the alternative route, despite the lack of information on this. In the case of good weather conditions, 24 people remained on the main road, and 6 (20%) chose the alternative route. In the case of the rainfall, 26 people remained on the main road and 4 used the alternative route (13.3%).

The results presented above indicate a small effect of a static sign informing drivers about the possibility of selecting an alternative route on making their decision.

4. AN ATTEMPT TO EVALUATE THE ECONOMIC EFFECTIVENESS OF THE ITS SOLUTIONS USE

Due to the adopted priorities, ITS systems may include, in particular, the improvement of the traffic conditions by reducing driving time and reducing the number of stops as well as improving the road safety. The system manager decides on the priorities adopted, which should be in line with the generally applicable laws and mobility policy covering the ITS area. In addition to the above-mentioned effects of the system implementation, one can consider the economic aspects of their operation, which include:

- costs reduction for the society, by minimizing time losses related directly to the reaching the driving destination (losses related to the stoppage or low average vehicle speed, in the absence of a system),
- costs reduction thanks to shortening the total driving time due to the use of modern ICT solutions in the form of intelligent travel planners, dynamic information for passengers etc.,
- costs reduction related to the reduction of fuel consumption by vehicles in the area covered by the system (including reduction of the number of stops and time losses),
- costs reduction related to the wear of mechanical vehicle components, in particular of brake pad linings and tires,
- more effective planning and the possibility of shortening the time of road works,
- limiting the impact of transport on the natural environment (e.g. by pollution, noise, vibrations),
- increasing the efficiency of goods transport,
- reducing the costs of collisions and traffic accidents.

The effects on health and life of people are particularly important. In the monograph [7] an attempt was made to evaluate these effects based on the data obtained as part of the RID 4D project. For this purpose, the state of non-implementation of ITS solutions and the state in case of their implementation were taken into account. For the purposes of the analysis, it was assumed that ITS services will be introduced in places where they have not been used so far. The evaluation may be conducted referring it to the road sections on which the implementation will take place, while taking into account the effects of the application of individual ITS solutions, which was analyzed in the RID 4D project. Table 2 lists the average impact values of individual ITS services at a distance of 200 m behind the variable message board/sign, with the use of which information for the drivers was provided.

Tab. 2

Average impact values of the individual ITS services at a distance of 200 m behind the variable message board

No.	Service description	Speed before the board [km/h]	Change of speed [km/h]
1.	Speed limit on the board	107.59	-15.65
2.	Speed limit with the reason for the restriction	108.22	-17.60
3.	Limitation - static sign	98.85	-14.95
4.	Information - blocked lane	110.90	-5.65
5.	Information - accident, change the lane	112.62	-5.15
6.	Information - accident, change lanes and speed limit	103.94	-15.75
7.	Information - strong wind	105.74	-4.00
8.	Information - fog, slow down	107.86	-12.60
9.	Information - slippery - inscription and pictogram	99.10	-11.80
10.	Restriction on the board and on the sign (sign at the next gantry, speed reduction value given for the sign)	99.46	-5.22

Source: Own study

The estimated costs related to the road accidents victims were calculated based on the "Valuation of costs of accidents and road collisions on the road network in Poland at the end of 2015, with the separation of average socio-economic costs of accidents on the trans-European transport network" [5]. The reduction of accidents numbers indicator was estimated using the "Power model" model, presented in the paper "The Power Model of the relationship between speed and road safety. Update and new analyses" [11]. For the needs of calculations, it was assumed that there was an average of one traffic incident per year in the place of using the service. Based on data on the vehicle speed reduction due to the use of ITS services (Table 3), the reduced numbers of fatal accidents, accidents with seriously injured persons and events with slightly injured people were calculated. To this end, the following equation was used:

$$L_2 = L_1 \left(\frac{V_4}{V_1}\right)^x \quad (1)$$

where:
L_2 - number of fatal accidents, with severely and slightly injured people - after speed reduction, depending on the value of the "x" coefficient used,
L_1 - number of fatal accidents prior to the speed reduction,
V_4 - vehicle speed at a distance of 200 m behind the board/sign (within the impact zone),
V_1 - vehicle speed at a distance of 200 m before the sign (before the impact zone),
x - empirically determined value of the coefficient, depending on the type of evaluation - number of fatal accidents, accidents with severe and slightly injured persons.

Costs of road accidents provided by the KRBRD are:

- unit cost of a road accident - PLN 1.02 million,
- unit cost of a fatal victim - PLN 2.05 million,
- unit cost of a seriously injured victim - PLN 2.3 million,
- unit cost of a slightly injured victim - 26.7 thousand PLN.

By referring the above information to particular services, one can calculate the economic effects resulting from the application of ITS services examined in the project, assuming that one person died or one severely or lightly wound person participated in a traffic accident (Tab. 3).

Tab. 3

Economic effects of using ITS services in the case of a single service

No.	Description of the service	Reducing the cost of fatal accidents [mln PLN]	Reducing the cost of accidents with seriously injured people [mln PLN]	Reduction of the cost of n accidents with slightly injured people [mln PLN]
1.	Speed limit on the board	1.49	2.21	1.08
2.	Speed limit with reason for the limit	1.36	2.09	1.06
3.	Limitation - static sign	1.44	2.17	1.07
4.	Information - blocked lane	2.41	2.90	1.22
5.	Information - accident, change lane	2.48	2.94	1.22

C.d. Tab. 3

6.	Information - accident, change lane and the speed limit	1.44	2.17	1.07
7.	Information - strong wind	2.57	3.00	1.23
8.	Information - fog, slow down	1.73	2.40	1.12
9.	Information - slippery - inscription and pictogram	1.71	2.39	1.12
10.	Restriction on the board and on the sign (sign at the next gantry, speed reduction value given for the sign)	2.40	2.89	1.21

Source: Own study

This assumption simplifies the analysis, because this incident may not happen at all. Also, in reality, an alternative to a road incident in which a person is killed is not always the lack of such an event, but it may be a limitation of its consequences. The frequency of road events can be assessed based on the real data or a statistical model.
In both cases, however, we encounter difficulties related to the lack of data or high complexity of the analyzed issue, respectively.

5. SUMMARY

In addition to the analyses described, the conditions for an alternative route selection were compared, depending on the sign posted on the gantry. In the scenario 0, a static sign was placed on the gantry 6, while in scenario 1, the dynamic sign was placed on the gantry 1. Comparing these conditions led to the conclusion that in the first case, in good atmospheric conditions, 6 out of 30 drivers chose an alternative route, in the case of a sign on a variable message board, 10 out of 30 drivers left the main route. In the case of rainfall at the static sign 4 out of 30 drivers left the main route, and behind the variable message board 10 out of 30 (33.3%) drivers changed the route. The remaining continued to drive the expressway.
In addition to a significant drop in vehicle speed in case of the ITS solutions, increase in a distance from the vehicle in front has been noticed, which reduces the likelihood of driving into that vehicle, for example in the event of a sudden braking.

The use of ITS solutions positively affects the safety and efficiency of the road traffic, enabling the reduction of economic effects, which absorb about 3% of GDP.
A separate issue that requires analysis is the optimal way of ITS deployment in order to have the best possible impact on the traffic situation.

References

1. Boyle L.N., Mannering F.: Impact of Traveler Advisory Systems on Driving Speed: Some New Evidence. Transportation Research – C, Vol. 12, 2004, pp. 57-72.
2. Crowthorne, UK; N. Fudala, Work Zone Variable Speed Limit Systems: Effectiveness and System Design Issues Virginia DOT, 2010, Virginia.

3. Gupta N., Bisantz A.M., Singh T.: "The effects of adverse condition warning system characteristics on driver performance: an investigation of alarm signal type and threshold level", Behavior and Information Technology, 21(4), pp. 235–248 (2002).
4. Jaździk-Osmólska A.: Wycena kosztów wypadków i kolizji drogowych na sieci dróg w Polsce na koniec roku 2015, z wyodrębnieniem średnich kosztów społeczno-ekonomicznych wypadków na transeuropejskiej sieci transportowej", Krajowa Rada Bezpieczeństwa Ruchu Drogowego, 2016.
5. Jaździk-Osmólska A.: Wycena kosztów wypadków i kolizji drogowych na sieci dróg w Polsce na koniec roku 2015, z wyodrębnieniem średnich kosztów społeczno-ekonomicznych wypadków na transeuropejskiej sieci transportowej", Krajowa Rada Bezpieczeństwa Ruchu Drogowego, 2016.
6. Kamiński T., Pędzierska M., Filipek P.: Influence of selected ITS services on the driver's behaviour – results of simulation test carried out on top-of-the-range driving simulators, MATEC Web of Conferences Volume 231, 2018.
7. Kamiński T.: Wybrane zagadnienia Inteligentnych Systemów Transportowych, Wyd. Politechniki Warszawskiej, Warszawa, 2019.
8. Kolisetty V.G.B., Iryo T., Asakura Y., Kuroda K.: Effect of variable message signs on driver speed behavior on a section of expressway under adverse fog conditions – a driving simulator approach, http://www.benefitcost.its.dot.gov/ [dostęp 20.11.2018].
9. Koźlak A.: Inteligentne systemy transportowe jako instrument poprawy efektywności transportu, Logistyka, 2/2008.
10. Pędzierska M., Kamiński T.: Wykorzystanie usług Inteligentnych Systemów Transportowych do poprawy poziomu Bezpieczeństwa ruchu drogowego, Ochrona Mienia i Informacji 6/2018, s. 2-5.
11. The Power Model of the relationship between speed and road safety. Update and new analyses, Report 1034/2009, Institute of Transport Economics, Oslo, Norway, 2009.
12. Winnett M., Wheeler A., Vehicle-Activated Signs; A Large Scale Evaluation, TRL Report 549, Transport Research Laboratory, 2002.

WYBRANE ASPEKTY BADAŃ WPŁYWU INTELIGENTNYCH SYSTEMÓW TRANSPORTOWYCH NA BEZPIECZEŃSTWO RUCHU DROGOWEGO, Z UŻYCIEM SYMULATORÓW JAZDY

Streszczenie: W artykule opisano wpływ informacji wyświetlanych kierowcom na tablicach o zmiennej zawartości i prezentowanych na statycznej tabeli na decyzje kierowców dotyczące wyboru alternatywnej trasy. Wyniki badań uzyskanych w ramach projektu RID 4D pt. „Wpływ wykorzystania inteligentnych systemów transportowych na poziom bezpieczeństwa drogowego" finansowanego przez Narodowe Centrum Badań i Rozwoju oraz Generalną Dyrekcję Dróg Krajowych i Autostrad (DZP/Umowa RID-I-41/7/NCBR/2016).
W artykule opisano próbę oceny efektów ekonomicznych wdrożenia wybranych rozwiązań ITS. Na podstawie wpływu wybranych rozwiązań ITS na prędkość jazdy dokonano oceny wzrostu bezpieczeństwa na drodze, wykorzystując jako miarę liczbę zabitych, poważnie i lekko rannych. Cały artykuł podsumowano wnioskami.

Słowa kluczowe: transport, bezpieczeństwo ruchu drogowego, Inteligentne Systemy Transportowe, symulatory jazdy