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SYSTEM DYNAMIC MODEL OF MEASURES FOR REDUCING THE NUMBER OF ROAD ACCIDENTS DUE TO WRONG-WAY MOVEMENT ON MOTORWAYS

ABSTRACT

This paper provides a system dynamic model for reducing the number of motorway accidents due to wrong-way driving. Motorway accidents are often fatal due to high speeds. It is therefore necessary to carry out all the possible countermeasures in order to achieve adequate traffic management. One of the reasons for motorway accidents is driving in the wrong direction. Based on the analysis of the data on motorway accidents caused by driving in the wrong direction and based on the knowledge of individual project elements of junctions and slip roads, this paper will focus on this area. The possible countermeasures, presented here for preventing drivers from driving in the wrong direction on motorways drastically reduce the number of U-turn maneuvers that result in driving in the wrong direction and influence the level of safety on motorways. With the help of this model of system dynamics the countermeasures for reducing the number of such drivers will be confirmed and their effects will be shown.

KEY WORDS

traffic safety, motorway, direction, (road) accidents, measures, system dynamics

1. INTRODUCTION

Wrong-way movement on roads with spatially separated carriageways is a serious and contemporary worldwide issue. Reasons as to why drivers (too) often make wrong-way entries onto motorways are still under-researched. This can be seen from the average number of motorway accidents caused by wrong-way movement that amounts to about two road accidents per one-million population (statistical data on motorway accidents in the most developed countries). In most cases the consequences are fatal. It is not always the drivers who are responsible for this but also inadequate road surfaces as well as road signalisation. In order to prevent such extremely dangerous traffic situations and hence fatal crashes, it is necessary to get to know and implement adequate and spatial countermeasures that will systematically prevent wrong-way movement or at least sufficiently warn drivers of the fact that they are driving in the wrong direction and prevent them from doing so.

To be able to find out whether the implementation of particular measures has been legitimate one needs to determine the effects of a particular measure to reduce the number of wrong-way movements and motorway crashes. The research Countermeasures for Wrong-Way Movement on Freeways [1] showed that the use of correctly located traffic signs to a great extent reduces the number of accidents. The research of the so called reduction factors of motorway accidents (the reduced number of road accidents on specific interchanges due to specific road signalisation) was based on the data from the number of road accidents on precisely determined interchanges [2]. An analysis of the number of motorway accidents was conducted prior to and following the implementation of countermeasures for managing traffic, from which a particular reduction factor was determined. For the results to be as accurate as possible we compared them with the findings from other countries. The findings from this research show that a single traffic sign can reduce the probability of motorway accident occurrence by 15% to 70%. By introducing a higher number of road signalisation it is necessary to integrate individual reduction factors (AR_n).

Particular measures for traffic management, which are stated below, are taken into account in this paper and have a positive influence on reducing the number of traffic accidents. The methodologies of determining reduction factors have to a great extent already been studied as well as applied in the paper by Agent et al. [1, 3]. Appropriate models for reducing the number of motorway accidents in relation to individual reduction factors has not yet been included in professional literature, especially not in the field of wrong-way movement on motorways.

2. CHARACTERISTICS OF MOTORWAY ACCIDENTS CAUSED BY WRONG-WAY DRIVING AND POSSIBLE PREVENTIVE MEASURES AND REDUCTION MEASURE FACTORS

The drivers being the ones that intentionally or unintentionally make a U-turn, one has to take their characteristics and psychophysical factors into account that have negative impact on them. The characteristics data of such accidents and their circumstances are taken from the study entitled "Preventing wrong-way driving on motorways" [4]. Over 80% of motorway accidents are caused by wrong-way drivers of private vehicles, an assumption that is taken into account in the model. Male drivers cause more than 80% of motorway accidents due to wrong-way movement. Even more interesting is the fact suggesting that the majority of motorway accidents caused by wrong--way movements are caused by drivers over 64 years of age (25%). The reason for the increased number of accidents caused by elderly drivers may lie in their age-related decline in cognitive capabilities of selective and divided attention and the sensory/perceptual capabilities. Due to unclear or unseen signing and marking techniques and due to unsuitable project elements of the roads drivers make U-turns and start driving in the wrong direction. Even more worrying is the information on high alcohol levels. In Europe, between 35% and 45% of all motorway crashes caused by wrong-way movement are caused under the influence of alcohol, in the USA this percentage amounts to about 50% (CAIP) [4]. Data on traffic situation, weather and traffic volume are not the primary reasons for motorway accidents caused by wrong-way movement. Thus, the main reasons for such motorway accidents can be found and consequently, the most suitable countermeasures can be applied.

Around 10% of all motorway crashes caused by wrong-way movement start at intersections, at which traffic from both directions moves to physically separated lanes [5]. Here, the following countermeasures are recommended: removal of the existing traffic sign "one way sign"; correct placement of the traffic sign "drive on the right"; placing additional "one way" traffic signs; placing arrow markings on slip and exit roads as well as the sign placards "wrong way". In the case of

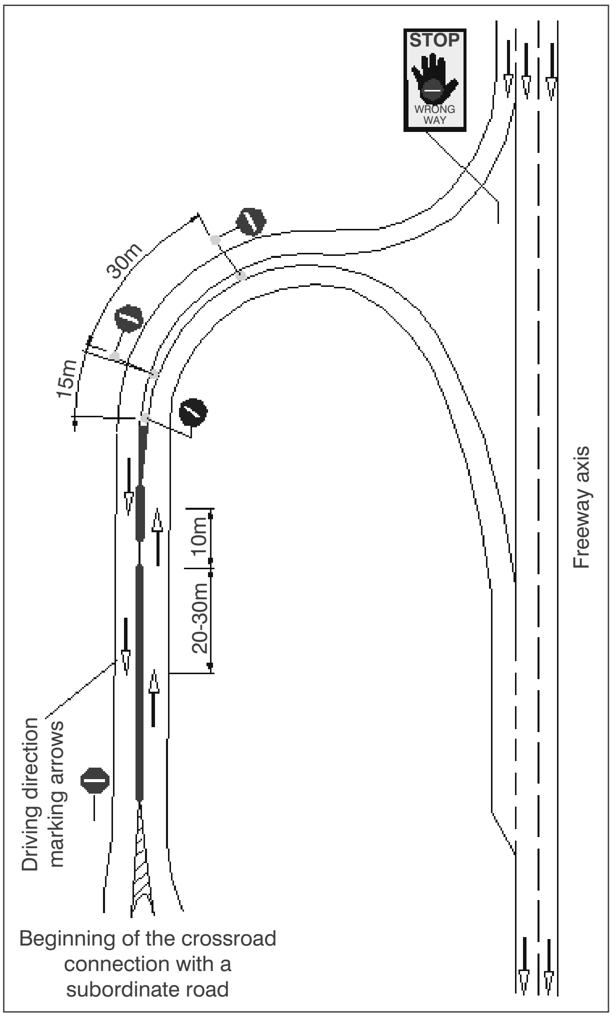

Figure 1 - Recommended signing and road markings on slip and exit roads

Source: Topolšek, 2004

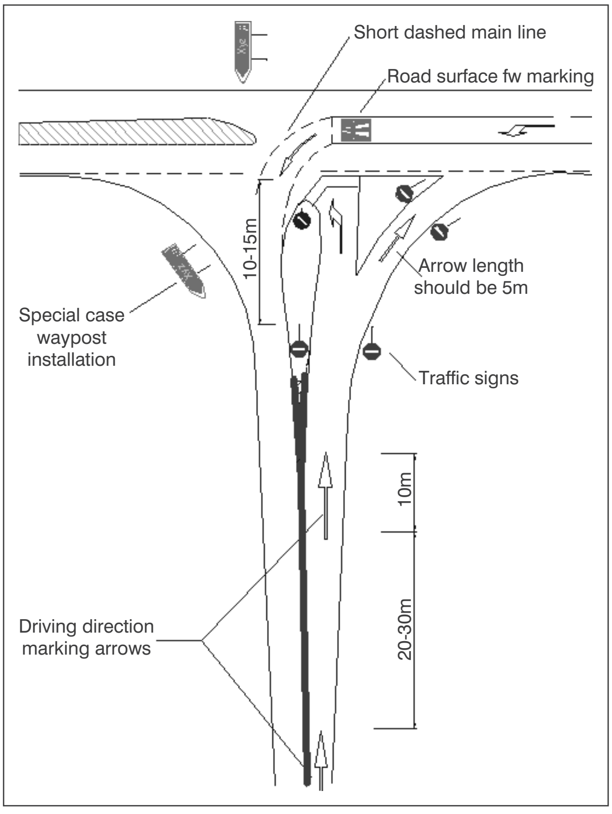

Figure 2 - Recommended signing and marking layout on the intersection of the slip road and a minor road

Source: Topolšek, 2004

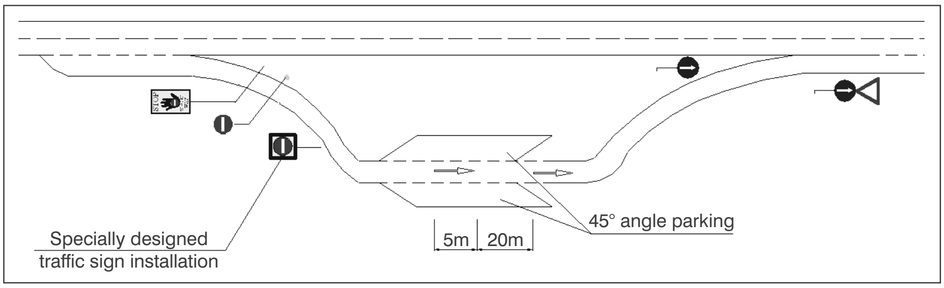

Figure 3 - Recommended signing and marking layout at service stations and petrol services

Source: Topolšek, 2004

frequent WWD causing traffic manoeuvre occurrence it is advisable to install a "Stop, wrong way" traffic sign. The traffic sign should be turned in the direction where it will remain invisible to the correctly directed driver. To see how measures are located in practice see Figure 1.

If the exit road is physically separated from the slip road then the driver may start driving in the wrong direction only if the wrong maneuver has been made on the intersection of the road and the slip/exit road. On a three-leg intersection with a slip road the following signing is the correct placement of the existing traffic sign "drive on the right", placing the traffic sign "one-way" and correctly chosen markings as well as correctly formed slip road. The said measures in case of physically separated slip roads and exit roads are presented in Figure 2.

Different findings show that around 3% of all offences due to wrong-way movement start at service stations and petrol services [5]. These areas should be equipped with a traffic sign "one-way" and a traffic sign "wrong way", and road markings should be also included [4]. The location of measures is presented in Figure 3.

Based on the aforementioned measures and the knowledge of the mentioned reduction factors, a system dynamic model of the number of motorway accidents caused by wrong-way movement can be made taking the measures and influential factors into consideration.

3. A SYSTEM DYNAMIC MODEL OF MOTORWAY ACCIDENTS CAUSED BY WRONG-WAY MOVEMENT

The proposed system dynamic model is based on our findings and findings of others, on the one hand from integrating the number of motorway accidents caused by wrong-way movement with reduction factors and on the other, based on the influential factors of increase. The model is based on the basic hypothesis, claiming that an average number of motorway accidents caused by wrong-way movement amounts to about two accidents per one million population [4, 6]. The number of accidents is expressed with the factor per one million population, where the data between individual states seems most effective; data on kilometres driven on motorways are not always available. The number of such road accidents is influenced by the set measures. Such measures reduce the number of accidents, their efficiency stems from the reduction factors. The size of the latter has been examined in the light of Agent et al.

In the previous chapter, the aforementioned measures for reducing the number of such road accidents are divided into three main areas: prohibited access to the opposite lane of the slip road/exit road; wrong-way driving from a minor road onto the slip road/exit road junction and the wrong-way driving from the motorway service station, parking lot or gas station.

Based on the findings of others, the following denominators have been determined. Regarding the prohibited access onto the opposite lane of the slip road/exit road a total reduction factor is 63 per cent (removal of the existing traffic sign "driving in one-way prohibited" – 15 per cent; correct placement of the traffic sign "keep right" – 15 per cent; placement of additional traffic signs "driving in one-way prohibited" – 15 per cent; placement of arrow traffic signs on slip roads/exit roads – 15 per cent and placement of "Stop, wrong way" signs – 30 per cent). Regarding wrong-way driving from a minor road onto the slip/exit road, the total reduction factor was 54 per cent (correct placement of the existing traffic sign "keep right" - 15 per cent; placement of the traffic sign "wrong one-way driving" - 15 per cent; correctly chosen and marked road markings – 15 per cent and correctly designed slip road – 25 per cent). Regarding rest stops and gas station services a total reduction factor of 50 per cent was determined (placement of the traffic sign "driving in one-way prohibited" – 15 per cent and traffic sign "Stop, wrong way" – 30 per cent and additional road markings – 15 per cent).

Their total reduction factor is determined as follows [2]:

$$ARF = 1 - [(1 - AR_1) \cdot (1 - AR_2) \cdot (1 - AR_3)] \qquad (1)$$

whereby AR_n presents a reduction factor of a particular measure.

The total reduction factor of the aforementioned measures which is used in the model below presents one of the basic parts of the presented model.

The number of such motorway accidents is influenced by the growing number of older drivers, for as mentioned before they are most likely to cause accidents most frequently. Due to the growing number of elderly drivers the increased number of such accidents is set as a proportion between the number of motorway accidents caused by wrong-way driving that amounts to 25% [4] and the value of the yearly increase in the number of drivers over 64 years of age (7.9%) (Ministry of Foreign Affairs).

On the other hand, the number of drivers, driving under the influence of alcohol has increased. Due to the fact that one half of wrong-way crashes are caused by drivers with traces of alcohol or drugs in their blood, their increase must also be included in the system dynamic model. The increased number of drivers with high alcohol levels and their influence on the increased number of the aforementioned accidents is determined based on the relationship between the number of road accidents, caused year after year by drivers with alcohol in their blood (35% to 45%) [4g] and the increased number of drivers with alcohol levels, that is between 6% and 12%; [CAUP; MNZ-P].

As road accidents are expressed in proportion to the number of the population their increase must also be taken into account in this model. The increase in population refers only to the addition to the population (1.2% per year (EUROSTAT)) and the average life expectancy (78 years) (EUROSTAT)), due to insufficient data on driving activities the percentage of the immigration and migration population is not taken into account.

Based on the claims a system dynamic model is created and shown in Figure 4.

The diagram of the impact specific factors have on the model (Figure 4) shows a number of positive and negative reverse connections. A positive and causal connection between individual variables means that the change of the first variable influences the change of the other one in the same way. Negative causal connection between individual variables means that the

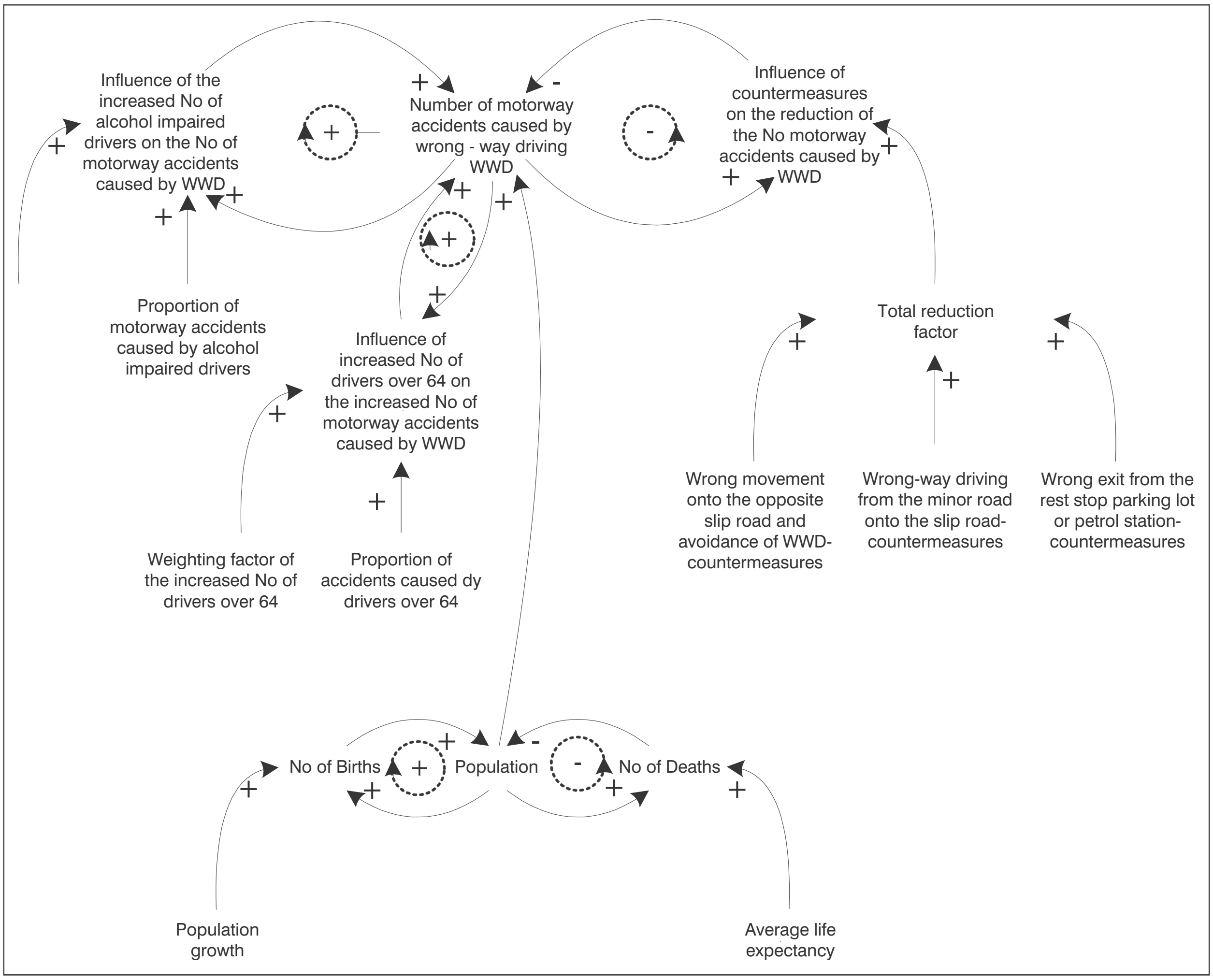

Figure 4 - Diagram of the impact that specific factors have on the model

Source: Topolšek, D.

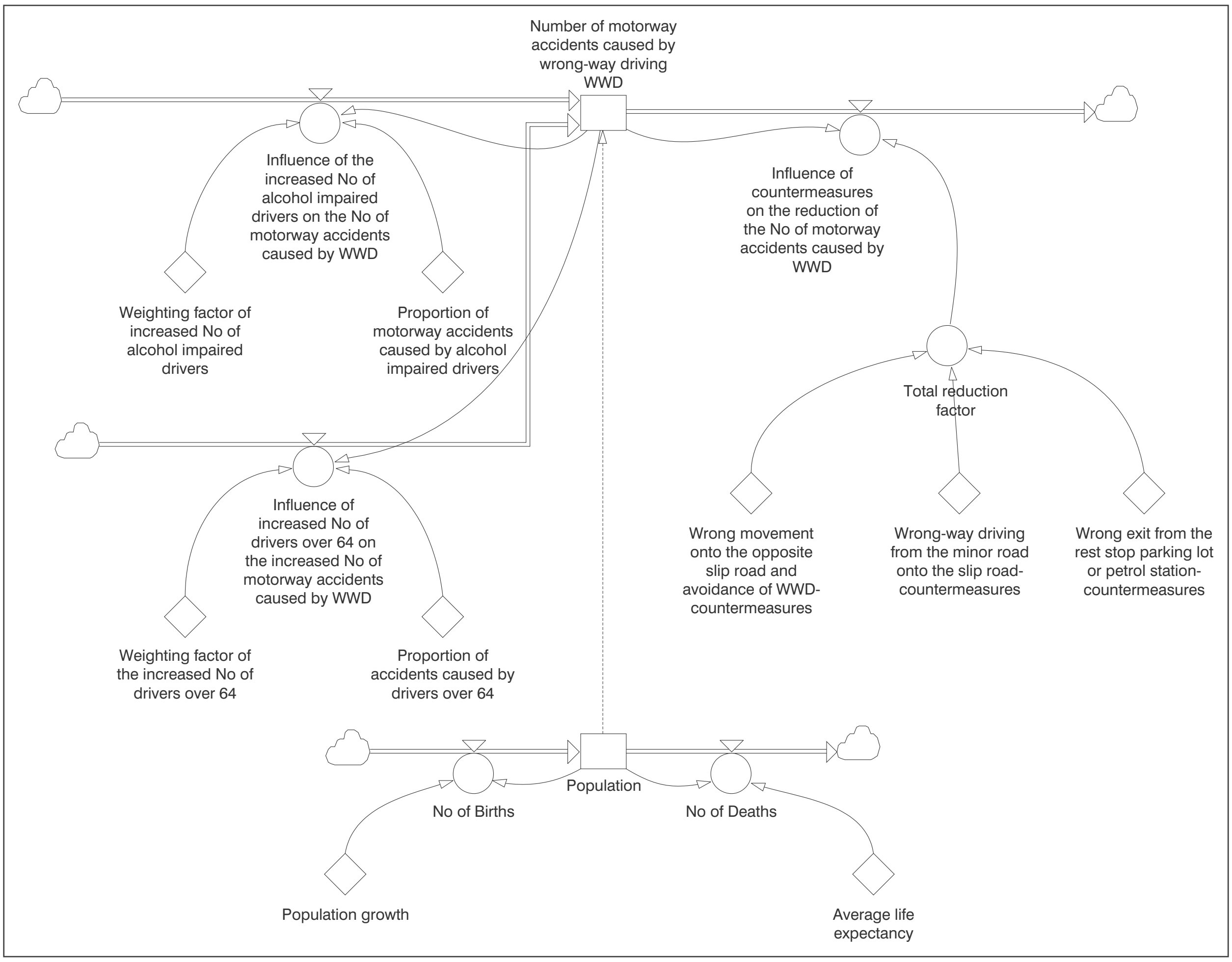

Figure 5 - System dynamic model of influential aspects per number of motorway accidents cause by wrong-way movement.

Source: Topolšek, D.

change in the first variable influences the change of the second one in a reverse way. In the real model this means that all causal connections except the impact of the number of deaths per population and the impact of measures on the reduction of the number of motorway accidents caused by wrong-way driving have a positive impact on the model or a particular variable, or a change in the first variable can influence another variable in the same way.

The following system dynamic model shows positive and negative reverse connections. Positive reverse connections make the change stronger, the negative reverse connection strive towards reaching a balance. This model has three positive reverse connections and two negative ones. The countermeasures for preventing the movement in the wrong direction on motorways represent a negative reverse connection, which means that they reduce the number of accidents. On the other hand, the factors affecting drivers with alcohol involvement and the increased number of elderly drivers (over 64 years of age) have a positive reverse connection, which means that by increasing one of these factors the number of such accidents will also increase.

Based on a diagram of impact a system dynamic model is created (Figure 5) that includes all aforementioned factors.

Influential factors that present a system of positive reverse connection are caused by drivers with increased alcohol levels that increase the number of motorway accidents, and drivers over 64 years of age. The main negative reverse connection, striving towards achieving a balance presents the influence countermeasures have on reducing the number of motorway accidents.

The result of the model will show the dynamics of the number of road accidents due to wrong-way movement on the motorway. The number of road accidents will be reflected in relation to the population number and will reflect the influence of the given factors in relation to the time period which in this case was restricted to five years.

As already mentioned before, for the analysis of this model a dynamic simulation needs to be carried out. A dynamic simulation is needed for the changing elements of the model that are based on the changing subjects and their behaviour and scope in road traffic. The need for the dynamics in the number of elderly drivers especially needs to be taken into account. Today, this number is rapidly increasing; however, it is true that after a while the growth will stop or start declining (this has not been taken into account in this system, as it would be inappropriate to make such forecasts in this rapidly changing development).

The System dynamic model has been implemented according to the Euler integration method using the fixed step (1st order, Euler). The Euler function returns the value of Input at the beginning of the current integration step. This can be useful when higher order integration methods are used, where several computations are performed in each simulation period.

The simulation was implemented for different time periods. As the value of road accidents after five years moves towards zero, the result of the simulation shown below is restricted to this time period.

The results of the dynamic simulation that has been carried out for the period of five years are shown in Figure 6.

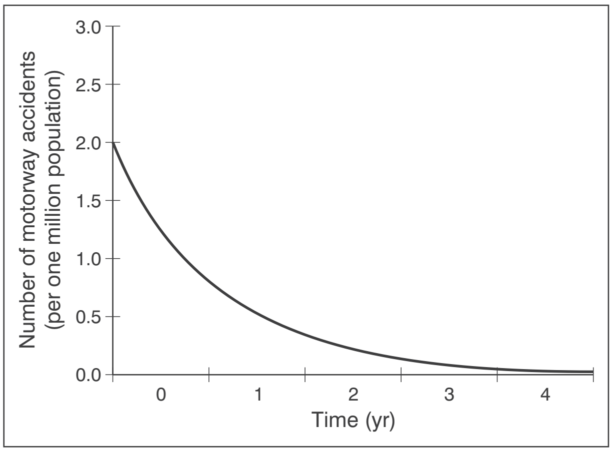

Figure 6 - Simulation of the number of motorway accidents (per one million population) caused by wrong-way drivers in relation to the given influential factors.

The simulation (Figure 6) shows that within five years of carrying out the measures to prevent wrong--way driving on motorways the number of motorway accidents can in fact be reduced to a minimum. However, it needs to be emphasized that while the system of motorway accidents has been dealt with theoretically, in practice it is a variable assumption that depends on drivers' psychophysical characteristics that were not included in this model due to their scope. In practice the simulation curve (Figure 5) could be reached under optimal circumstances; however, it could seem a sector-specific or spatially-dependent variable. This means that in some countries an optimal decrease in motorway accidents could be achieved in an even shorter period of time as calculated by the simulation whereas in other countries the number of motorway accidents would decrease at a much slower rate. Naturally, motorway accidents caused by wrong-way drivers will still occur; however, their number will have to be further decreased. Countermeasures are always most efficient in the year of their implementation, then their efficiency slowly starts to drop. Nevertheless, the set objective regarding the number of motorway accidents is yet to be achieved - "Zero Accident Program" (http://www.spa.usace.army.mil/ec/zero/zero.html). If we could at least meet the results of the simulation half way, we could justify the implementation of the said measures. Thus, we would be one step closer to the mentioned Zero Accident Program.

4. CONCLUSION

The system dynamic model of measures and their impact on decreasing the number of motorway accidents caused by wrong-way driving provides simulation values of reducing the number of motorway accidents in relation to specific countermeasures. In the negative way, the model is influenced by the factors such as increased number of drivers with alcohol levels in their blood and drivers of over 64 years of age. In a positive way, the measures for traffic management have been presented. The model is based on specific influential aspects that increase or decrease the number of motorway accidents on a yearly basis for a specific percentage value that is determined based on empirical or experience data. The model has shown that with appropriate measures that should prevent the wrong U-turn maneuver and driving in the wrong direction, almost all motorway accidents could be eliminated within a short period of time.

The results of the model show clearly the theoretical possibility of reducing the number of road accidents. Since the model is based on the actual data on road accidents and on the theoretical data on reduction factors of reducing the number of road accidents in relation to individual measures, the simulation results may not be so available in practice. Hence, the model is the basis for understanding the influence of assumed measures for reducing the number of such road accidents and facilitates the use of such measures in practice. As the word "simulation" as such, already states that it is about showing expected results or outputs, a drawback of the model may lie in the possible huge differentiation of practical and theoretical results. It is therefore plausible to theoretically upgrade the model in more than one direction. One of such directions presents a more detailed thinking about the increased number of elderly drivers and the implementation of appropriate measures.

The proposed model can be also further expanded considering other aforementioned influential factors or measures that have not been taken into account.

The development of computer technologies and intelligent transport systems places a great deal of influence on the improvement of transport safety. It would therefore make sense to further research in this direction. In the case of frequency of "driving in the wrong direction" on specific junctions, additional physical barriers along or on the road could be set up, this way, continuous wrong way driving could be disabled. Further research of the proposed model could also be based on IT and physical measures.

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POVZETEK

MODEL SISTEMSKE DINAMIKE VPLIVA UKREPOV NA ZMANJŠEVANJE ŠTEVILA PROMETNIH NESREČ ZARADI NEPRAVILNE SMERI VOŽNJE NA AVTOCESTAH

Članek podaja model zniževanja prometnih nesreč zaradi nepravilne smeri vožnje na avtocestah. Prometne nesreče na avtocestah so zaradi velike hitrosti vožnje velikokrat tragične, zato je potrebno izvesti vse možne ukrepe za ustrezno upravljanja prometa. Eden od vzrokov nastanka prometnih nesreč na avtocesti je nepravilna smer vožnje. Na podlagi analiz podatkov o prometnih nesrečah zaradi nepravilne smeri vožnje na avtocestah ter na osnovi poznavanja posameznih projektnih elementov vozlišč in priključkov se pričujoče delo usmerja na to področje. Predstavljeni možni ukrepi za preprečevanje nepravilne smeri vožnje na avtocestah v veliki meri znižujejo število nepravilnih prometnih manevrov, ki imajo za posledico nepravilno smer vožnje in s tem pozitivno vplivajo na raven prometne varnosti na avtocestah. S pomočjo modela sistemske dinamike bo potrjena upravičenost ukrepov za zmanjševanje števila primerov nepravilne smeri vožnje in prikazani njihovi učinki.

KLJUČNE BESEDE

prometna varnost, avtocesta, smer vožnje, (prometne) nesreče, ukrepi, sistemska dinamika

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