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Vision Zero from the Perspective of Traffic Psychology

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ABSTRACT: The presented article reflects a scientific approach to the concept of a traffic system known as Vision Zero, which was postulated in 1997 by prof. Kare Rumar in Sweden. The implications of this approach are explored in terms of psychology. Other documents of the European Commission (including "Towards a European Road Safety Area: policy orientations on road safety 2011-2020") and the development of traffic safety in the Czech Republic are also discussed. The article seeks to provide information about the vision of traffic safety in European countries, which is based on the tenet that each road fatality is unnecessary – "Vision Zero". Attention is focused on the period 2012-2020, trends pursued by the European Union in this area, and the practical implications of such efforts for the Czech Republic, with a view to specific implementation measures. Drawing on their experience, the authors point out the existence of fragmentary and inconsistent approaches to the issue of road safety in the Czech Republic, specifically at the level of practical application (assessment in terms of traffic psychology, driver recruitment, prevention, training, law enforcement, rehabilitation, etc.), where organisations and/or individuals carry out measures which are not beneficial to road traffic safety, or there is no evidence of their contribution to road safety. The roles of psychology, traffic psychology, and traffic psychologists in designing the traffic system inspired by Vision Zero are underlined. The article provides a general background to the topic of traffic safety and the measures that can be adopted to improve it.

KEY WORDS: Vision zero, traffic system, traffic safety, traffic psychology.

1 INTRODUCTION

Out of all human-machine systems used on a daily basis, the road traffic system is the least forgiving; the human factor is reportedly responsible for over 90% of failures within the system. A traffic accident is far from being a totally accidental event: coincidence is involved to a lesser degree than human error. Accidents result from the synergetic adverse effects of several factors (including people, vehicles, road, its surroundings, and traffic conditions), with the human factor playing the crucial role. In comparison to the road transportation system, other well-established systems that have developed over longer periods are characterised by very strong, even insurmountable, tolerance for human failure (Johansson, 1991). One could say that if introduced today, road traffic would have to be banned immediately according to the current safety regulations. While health and safety risks in many areas of public life have been reduced dramatically in the past 100 years, this has not been the case with road transport. With a hint of exaggeration, the road traffic system may be referred to as a "historical relic" in this respect. In people's everyday activities, there is hardly any undertaking as dangerous as participating in the road traffic system. Moreover, roads become the sites of illegal activities and crime, including those not specifically related to traffic, more often than any other public areas. Traffic operations thus give rise to a massive number of criminal offences and impose a disproportionately heavy burden on the criminal justice system (Sheller & Urry, 2006). As a result of the low tolerance for error within the road traffic system, in the Czech Republic there are annually 700 fatal road accidents and 25.000 people are injured, with 3.000 of them being left disabled. In other words, it has been a rule for years that an average of two people are killed every day and over 70 are injured, including 10 left with permanent health consequences. These injuries reduce life expectancy by at least 6 months and cause an average loss of 2.5 healthy life years per citizen. Many people’s lives are affected by pain, limited mobility, and impaired mental capacity.

2 OVERVIEW OF GENERAL EU DOCUMENTS WITH RELEVANCE TO VISION ZERO

While the European Commission’s 3rd European Road Safety Action Programme 2003-2010 (European Commission, 2010) led to a considerable decline in the number of road fatalities and injuries, it fell short of the ambitious objective of reducing the number of road traffic-related deaths within the European Union by half by 2010.

This goal has been set again in the new road safety action plan for the period 2011-2020. According to the EC’s document “Towards a European Road Safety Area: policy orientations on road safety 2011-2020” (European Commission, 2010), the road user is the first link in the road safety chain. Whatever the technical measures in place, the effectiveness of a road safety policy depends ultimately on road users’ behaviour. For this reason, education, training, and enforcement are essential. However, the road safety system also has to take into account human error and inappropriate behaviour and correct it as much as possible – zero risk does not exist. All its components, in particular vehicles and infrastructure, should therefore be “forgiving”, so as to prevent and limit the consequences of these failures for the users, in particular the most vulnerable ones.

The document further sets out the following strategic objectives:

- Improving the education and training of road users (the “educational continuum” – continuous training for non-professional drivers, education of professional drivers, driving schools – practical training, accompanied driving, special focus on young drivers);
- Increasing the enforcement of road rules (cross-border exchange of information, road safety campaigns, and on-board technologies to assist enforcement, such as Alcolock);
- safer road infrastructure (the highest number of fatal accidents occurs on rural and urban roads) and standards for the road traffic infrastructure;
- Safer vehicles (“cooperative systems” involving vehicle-environment-human interaction, environmental impact);
- The use of modern technologies to increase road safety (ITS, V2V, V2I, I2I, ADAS, eCall). Despite their positive contribution to road safety, the development of ITS, in particular on-board systems and nomadic devices, raises a number of safety-related issues (distraction, impact on training, etc.) which will require further consideration;
- Improving emergency and post-injury services;
- Protecting vulnerable road users (such as pedestrians, children, senior citizens, motorcyclists, cyclists, and moped riders).

The document does not refer to any examinations in terms of traffic psychology, the assessment of psychological eligibility for driving, or the work of traffic psychologists in general.

The 2030 Road Traffic Vision for the Czech Republic (Technologická platforma silniční doprava, 2010) articulates the following safety issues as those of key importance for the period until 2030:

- The high rate of accidents involving children;
- The high rate of accidents involving inexperienced drivers;
- The ageing of drivers and other road users;
- The growing number of motorcyclists and their risk-taking behaviour;
- Increasing aggression among drivers (overtaking, speeding);
- Driving under the influence of alcohol and other drugs;
- Road users' low sense of responsibility for their (hazardous, aggressive) behaviour;
- Fatigue;
- Information overload;
- The growing risk posed to vulnerable road users (such as pedestrians and cyclists);
- The insufficient development of road infrastructure;
- The insufficient implementation of road infrastructure management tools;
- The deterioration of road surface adhesion characteristics (as a result of poor maintenance, inappropriate maintenance technologies, enormous heavy vehicle traffic, etc.);
- The disproportion between speed limits and the road arrangement and geometry;
- The growing differences between the vehicles in use, which mostly applies to passenger cars (age, gross weight, ADAS equipment).

The numbers of professional drivers with appropriate training dropped with the abolition of compulsory military service. Inadequate training of professional drivers in road safety issues has also been a problem. While the ageing of the population generally poses a relatively significant risk in terms of road safety, it is a particularly pressing issue among professional drivers.

A lifelong education scheme for road users is planned to be introduced by 2030. This measure should involve not only a legal framework but also practical implications, including dramatically stricter requirements for obtaining different driving licences. Changes in the categorisation of driving licences and the harmonisation of the licensing procedures for drivers across Europe can also be expected.

Particularly in public and corporate transportation, driving under the influence of alcohol and other psychoactive substances should be largely eliminated by the use of technical devices (such as Alcolock) which make it impossible to start the vehicle if a driver is under the influence of a psychoactive substance. The EU-promoted process concerning legislative measures aimed at restricting drink driving can be expected to develop. The member states continue to reduce their general BAC limits for driving and consider introducing zero limits for specific groups of drivers (such as professional and novice drivers).

The upcoming decades are expected to experience rapid advances in on-board technologies that will register and react to the driver's excessive fatigue while the car is in motion. In addition, legislative changes will be adopted in order to restrict non-stop driving for other drivers too, especially those of company cars.

The growing mobility and constrained capacities of the available road infrastructure may exert pressure for drivers to be provided with additional, more up-to-date and, therefore, more frequent information. It is assumed that drivers will respond to such information immediately by adjusting their current speed, as well as reconsidering their choice of route. Drivers are also increasingly distracted by a number of information sources which are not directly associated with road traffic and by various information and entertainment devices used by passengers in their cars. This current and prospective growth in the amount of information should be studied in terms of its impact on road safety.

The 2011-2020 National Road Safety Strategy of the Czech Republic, a document of the Ministry of Transport (Ministerstvo dopravy, 2012), lays down the objectives, general principles, and proposals concerning specific measures aimed at a major decrease in the rate of road accidents in the Czech Republic. The main goal is to reduce the level of road fatalities to the European average by 2020, as well as to reduce the number of severely injured by 40% in comparison to the year 2009. While in 2011 the average number of fatalities in the EU countries was 61 (per million inhabitants), in the Czech Republic it was 73. The highest figure was recorded in Poland (109), the lowest in the United Kingdom (32), Sweden (33), and the Netherlands (33). The strategy was endorsed by virtue of the Resolution of the Government of the Czech Republic No. 599, dated 10 August 2011.

The strategic objective of the National Strategy reflects the European one as set out by the European Commission, specifically to reduce the number of road fatalities within the European Union by half in the period 2010-2020. According to the European objective as declared, the number of deaths should drop by half, i.e. from approximately 70 fatalities per million inhabitants at present to about 35 in 2020. The countries that are currently drawing near to that level include Sweden, the Netherlands, and the United Kingdom. The Czech Republic will have to cut the annual number of people killed in road accidents by an average of 5.5% to reach this goal. In aggregate, it implies the reduction of the number of fatalities by approximately 60% in comparison to 2009, i.e. to 360 people.

The strategy is underpinned by the Vision Zero approach. It proclaims that every traffic accident that results in the loss of a human life or a serious injury should be regarded as a structural failure of society as a whole, not an individual’s error. From a medium-term point of view, it is undoubtedly useful to determine goals involving a specific reduction in the number of casualties and define targeted activities and measures that facilitate the accomplishment of such goals. Nevertheless, the ultimate ideal should be the state of no fatalities at all.

3 THE NOTION OF VISION ZERO

The Vision Zero initiative was first presented in 1997 by its author, Prof. Kare Rumar of Sweden, as a programme of a long-term development of the consequences of traffic accidents in Sweden. In 2001 this vision was also embraced by the European Union and adopted as its goal.

The idea of the vision is very simple: “We cannot reconcile ourselves to the fact of actually planning the toll we are willing to pay for the development of society in terms of road traffic,” and if this is what exists today, we cannot reconcile ourselves to it but must do what we can to cause these numbers to drop all the way down to zero levels (Anderson et al., 1997).

The objective is to achieve a progressive decline in the number of deaths and injuries in road traffic. A “progressive decline” implies the quest for zero fatalities and zero injuries within the traffic system. This objective should be accomplished with the lowest social and economic costs possible, which will be impossible without effective requirements, economic limitations, and the application of an ethical rule: as many people as possible must be “saved” using available resources (Kopits & Kropper, 2003).

If we wish to change the road safety situation, we must stop considering road fatalities to be – although widely accepted – a side-effect of the traffic system which is an inevitable means of the pursuit of social prosperity.

The task of achieving no road casualties can be interpreted as an ethical statement rather than a specific working goal. Nonetheless, it is a vision that should be gradually fulfilled. The resources that may be used in pursuing Vision Zero are already available, but their application is a political rather than a technical issue (OECD, 1990).

4 THE ROLE OF PSYCHOLOGY AND TRAFFIC PSYCHOLOGY IN FULFILLING THE VISION

Vision Zero is based on the notion that the parameters of the traffic system must be determined at all times by those individuals who show the greatest vulnerability and exposure to harm. The system should prevent any failure within such a system from leading to consequences that no longer represent acceptable harm to the health of an individual (Tingvall, 1998).

Where the level of resistance may be exceeded, the level of exposure to harm must be reduced to such a degree as to make it possible for everybody to survive until a safety problem has been solved. If we cannot guarantee, for example, that everybody uses safety belts, the exposure to harm must be reduced to the point where a person who is not using safety belts avoids physical harm. Roads should be constructed on the basis of the same assumption. Maximum speed limits should be determined with a view to the safety parameters of the road in such a way as to ensure that a driver avoids harm to their health even if they run off the road (Tingvall, 2007).

The steps to fulfilling Vision Zero are as follows:

- Identify the individuals and the types of behaviour for which the traffic system is intended;
- Define the acceptable harm to the health of an individual within the system;
- Identify the individuals who show the greatest vulnerability and exposure to harm;
- Use the definitions above to construct the system at all times;
- Define the types of errors which fall below the limits of acceptable tolerance for system failures;
- Define the individuals and the types of behaviour which will be excluded from traffic;
- Describe the procedure used to exclude the individuals and the types of behaviour that need to be excluded from the system;
- Define the relationship between any external harm and unacceptable harm to health within the system (harm resistance curve);
- Develop measures to control, prevent, and ensure protection from external harm in such a way as to ensure that tolerance for harm is never below the level of exposure to harm.

The designers of the Vision Zero system include the government, both governmental and non-governmental organisations, organisations responsible for the construction of roads and other traffic infrastructure, manufacturers of cars and car equipment, and any other entities who are responsible for the design of the system and who manage and monitor road users' behaviour, including traffic psychologists. All the above must be committed to making every effort to achieve the maximum safety of the system. It is vital that the public will also become involved in the process of the continuous enhancement of road safety (Tingvall et al., 1996).

The system must always be constructed in such a way as to reflect the needs of those with the least protection, the worst equipment, and the lowest level of education. For the designers of the system, such criteria outline a category of people who should receive priority attention. The designers of the system are “making a deal” with road users: if the road users respect the legal limits, the designers guarantee that they and their families can use the system and survive.

Today road users may comply with the legal regulations and still be injured or killed. Naturally, this is hardly supportive of law-abiding behaviour. We can assume, nevertheless, that people will accept restrictions on their personal freedoms in exchange for having their lives guaranteed.

People, with their needs, limitations, willpower, abilities, standards, experience, responsibilities, and obligations, remain the key road safety factor. As it is necessary to develop an advanced, fully forgiving traffic system, the responsibilities and obligations on the part of the system designers should also be underlined. The traffic system should be conceived in such a way as to ensure that human errors and their consequences do not result in death or permanent disability. And that is the responsibility of the designers of the system.

In view of the fact that people make mistakes and always will, the strategy cannot rely on road safety issues being solved by eliminating human error. Making mistakes and using new opportunities are the preconditions for human development and survival.

It is human error with grave consequences, however, that must be eliminated. An instant loss of concentration while driving on a rural road must not lead to a collision with another motor vehicle or run off the road and cause physical harm or injury (“forgiveness” may be realised in the form of the V2V collision avoidance system).

In terms of psychology and traffic psychology, the pursuit of Vision Zero should include the following tasks:

- Provide other system designers with evidence-based information about people’s behaviour in traffic:
    - identify the types of mistakes that drivers and other participants in the traffic system make;
    - define general psychological conclusions explaining why people make such mistakes on roads;
    - define the effects of such mistakes on the traffic system;
    - define measures to prevent such mistakes;
- Define the methods and resources needed to enhance the self-awareness of drivers and other people who are active within the traffic environment;
- Define the methods and resources needed to provide road users with feedback concerning the safety of their behaviour in traffic;
- Provide other system designers with clear information about road users’ cognitive and performance assets and limitations;
- Define procedures for work with the public in order to enhance responsible behaviour (in liaison with other fields, such as sociology);
- Define psychology-specific exclusion criteria for people’s being allowed to enter different modes of the traffic system (driver – according to the type of the vehicle, professional driver, etc.) and make subsequent assessments;
- Define criteria and requirements (in terms of psychology) for excluding people from the traffic system, as well as for allowing them to re-enter it;
- Define procedures for lifelong education and training for all the people involved in the traffic system (in liaison with education professionals).

At present there are tendencies to overestimate the impact of psychological eligibility for driving and the results of assessments in terms of traffic psychology on the safety of the traffic system in general and its safety as expressed by the number of deaths and injuries. There is not enough scientific evidence to show what exactly affects the road accident rate and the number of people who are killed or sustain injuries in traffic accidents (Tingvall et al., 1997).

The most relevant indicator of the degree of safe behaviour of drivers and other people participating in the road traffic system is the number of accidents (with regard to the legal definitions of accidents applied in different countries) rather than the number of fatalities (Belin et al., 1997), as it is probably the safety performance of the cars, road structure, and the traffic environment that has the greatest impact on the number of road fatalities. Hence, the key factor in pursuing Visio Zero is the construction of the traffic system rather than the elimination of human error.

When assessing psychological aptitude to drive, we now knowingly accept the probability of the subject's future failure within the traffic system. We measure the probability of failure without being able to define the causes and effects.

Assessment in terms of traffic psychology and the examination of psychological aptitude to drive should be defined within the Vision Zero approach as the minimum requirement for psychological eligibility that an individual must comply with for a given transport mode to be allowed to enter the system (exclusion criteria). The definitions of mistakes which may occur in the testee's prospective behaviour (and which are admissible because the system can absorb them) must also be an integral part of the notion of the assessment of psychological competence.

5 CONCLUSION

The very nature of human behaviour makes it impossible to make 100% predictions. Nevertheless, we can get close by means of effective feedback used for assessing psychological aptitude (this involves the establishment of a clear linkage between the subject, the type of mistake he or she has made, the study methods, and the conclusion that has been drawn). This approach should be used for making ongoing modifications of the definitions of exclusion criteria for the individual modes of transportation, as well as making them more rigorous. When combined with other forgiving components of the traffic system, Vision Zero may be fulfilled even if one allows for the imperfect predictability of human behaviour and the fact that people will always make mistakes.

We can also perceive the issue as a choice between a liberal attitude to mobility and the promotion of public health.

Ethical principles and the principles striving to fulfil Vision Zero must be preferred to individuals' and groups' particular interests, even under free market conditions. The public health interests must come first, and the government must be the patron of the efforts to assert such interests.

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Design of Algorithms for Payment Telematics Systems Evaluating Driver's Driving Style

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ABSTRACT: This article and its issue fall into the area of payment telematics systems in the transportation domain, with specific focus on the evaluation of driver's driving style. The aim of the described research is a suggestion of an algorithmic method of the evaluation of the driving style of the driver for payment telematics systems. This, in its result, allows comprehensively to take into account the differences in drivers' behaviour and therefore also the probability rate of a traffic accident. The output of the algorithm is a projection of the evaluation into insurance payment. The article points out the weaknesses and shortcomings of the Pay As You Drive systems, which do not cover the behaviour of the driver and de facto only focus on the count of the driven kilometres.

KEY WORDS: Driver behaviour, PHYD, fuzzy logic, driving style, payment telematics systems.

1 INTRODUCTION

The systems Pay As You Drive (PAYD)/ Pay How You Drive (PHYD) represent potentially a very strong tool for internalisation of the damage caused by traffic accidents, based on the principle “you drive less, you pay less”. In the time of the increase of road transport, this represents a positive trend.

The systems PAYD are predominantly used around the world. The reason is that the use of these systems does not claim such requirements for the intelligence and set up of the input parameters, which depend on many variables and influence the final evaluation of the driving style. The PHYD systems are quite the opposite. These systems provide a wide potential of use, but due to high requirements for the algorithm and the whole internal logic of the onboard devices, they are currently only in use in limited numbers. The important fact is that at present, none of the implemented and used systems covers the given issues in a really complex way, but only rather marginally.

Today, the PAYD/PHYD systems are offered by insurance companies all over the world. Only in Europe there are 18 of them, in the USA there is more than 15. However, the majority of insurance companies calculate the insurance payment based only on the number of kilometres driven, the mentioned driver behaviour or driving style is not taken into account at all.

The collection of the data needed for functioning of these systems may be carried on automatically or manually, using the onboard device installed in the vehicle. In the case of manual collection of data needed for the calculation of the insurance payment, there are no additional costs in the form of an installation fee. There are also no legislative obstacles pointing terms of privacy. However, this method is rather risky concerning the possible fraudulent actions of vehicle owners and it is impossible to distinguish when and where such vehicle was driven (e.g. during weekend or in peak hours, on a motorway or in the city, etc.). On the other hand, the automatic data collection offers more variability, e.g. concerning the possibility to set up different parameters corresponding with the different times of day, types of roads used by driver, etc. Thanks to the inbuilt GNSS positioning system, the insurance companies can offer more services, such as searching for stolen vehicles, etc. Some negative impacts of the automatic data collection include a potential misuse, i.e. the possibility to find out when and where the driver was to be found – which means the issue of privacy.

Looking at the described current situation from mathematic-algorithmic point of view, we can talk about the following generalized and simplified calculation. The last member of the formula differentiates the standard Pay As You Drive systems from the Pay How You Drive systems.

$$\begin{matrix} Price\ car \\ insurance \end{matrix} = C + k_1 . P_{km} \left(\frac{k_2 .\% \, D_{DAY} + \cdots + k_n .\% \, D_N}{100} \right) \left(\frac{k_3 .\% \, P_1 + \cdots + k_n .\% \, Pn}{100} \right) . (driver's\ driving\ style) \qquad (1)$$

Where C = lump sum insurance fee; k_1,..k_n = constant, P_{km} = number of driven kilometres; $D_{DAY/NIGHT}$ = drive during day/night; D_n = arbitrary daytime; P_1,...P_n = position of the vehicle/type of road the vehicle is moving on.

In its other parts this article focuses on the weaknesses and shortcomings of the current Pay As You Drive systems, which do not cover the behaviour of the driver and actually focuses only on the number of driven kilometres. All around the world, these systems, known as Pay How You Drive, are only represented in minority. They do not take into account the differences between the driving styles of drivers, and therefore also the higher possibility for a traffic accident as a result of aggressive driving style of drivers, etc. The extension by the element of driver’s behaviour has the potential to minimize operator’s costs and indirectly even costs of the insurance company which holds the insurance for the vehicle, and therefore it is the object of this scientific article (Troncoso et al., 2011; Bolderdijk et al., 2011; Ferreira & Minikel, 2013).

2 THE ALGORITHM FOR THE EVALUATION OF DRIVING STYLE (Kantor, 2013)

The following chapter represents the issues in question in the form of a comprehensive algorithm for the evaluation of driving style of driver, which aims towards the possibility of charging the driver based on his driving style. The algorithm consists of six component algorithmic steps.

The order and the linkage between the particular steps are to be seen on the following scheme. The first step taken must be the one concerning the data collection. After this, the steps 2–4 may follow all at once or one by one. After these steps are completed, the step 5 will be executed, i.e. the evaluation of the style of a manoeuvre based on the processed input parameters. Step 5 is followed by step 6, i.e. the assignment of the number of penalty points and determination of the driving style charges.

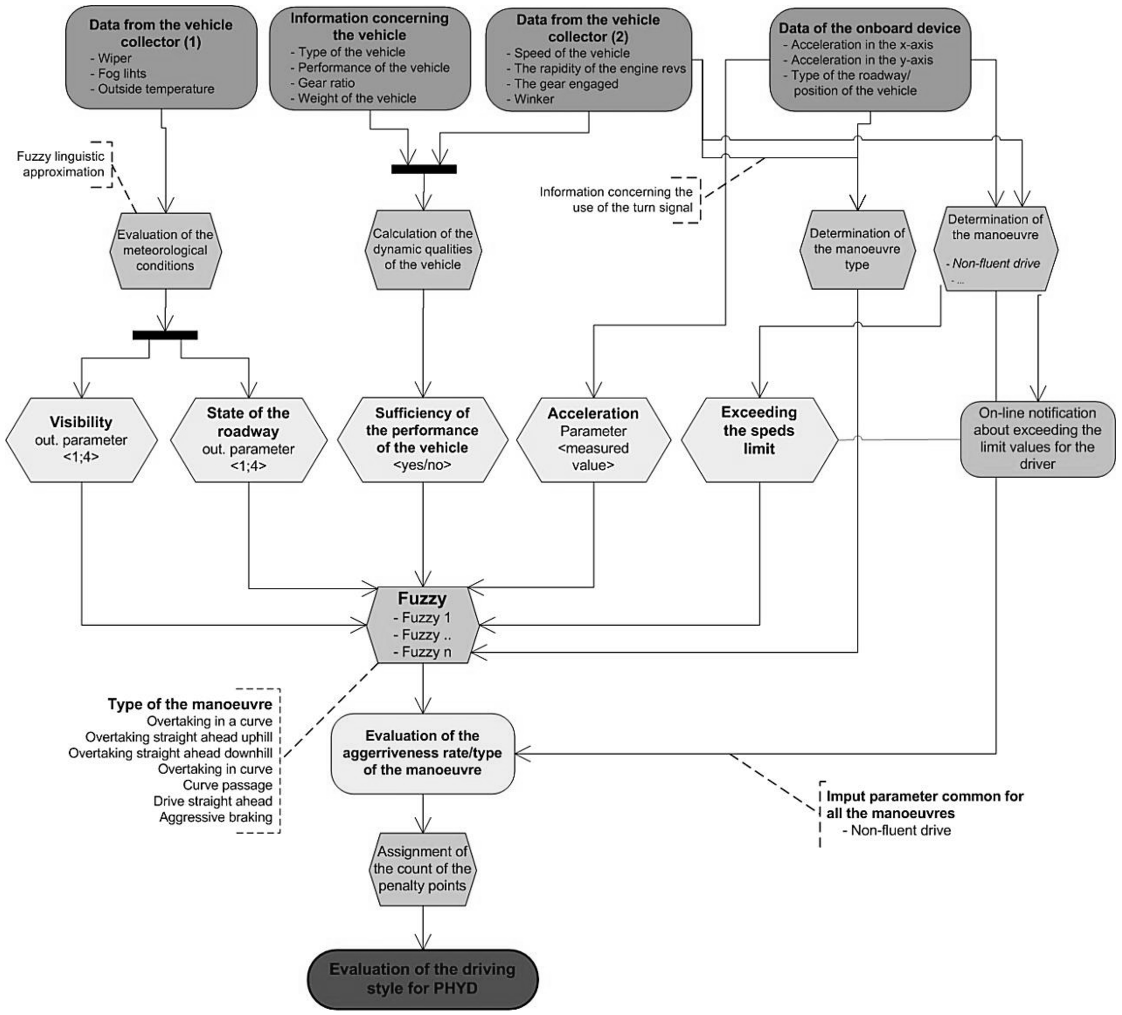

Figure 1: Scheme of the algorithm for the evaluation of the driving style.

2.1 Step 1 – Data collection

The first step leading to the evaluation of the driving style is the collection of data and information that will be entering particular component calculations and algorithmic operations. These are as follows:

- Information concerning the vehicle – type of vehicle, performance of vehicle, gear ratio, weight of vehicle;
- Data of the onboard device – the acceleration in the x and y axis, information concerning the position of vehicle;
- Collected data concerning the vehicle – information about the windscreen wipers and fog lights switched on, outside temperature, engine revolutions, the speed of vehicle, the gear engaged, the information concerning the use of indicators.

All data and information must be marked by a time stamp, which will allow the following matching of particular types of data.

2.2 Step 2 – Evaluation of meteorological conditions

An important factor, which to a large extent influences the driving style, is meteorological conditions, since they may significantly increase the risks related to safe driving of vehicle. The main risk coming from the deteriorated meteorological conditions is the longer braking distance (worse adhesion of tyre), the estimation of speed in consideration to the given conditions on road, and the estimation of distance of vehicles driving in front and in the opposite direction when overtaking. Regarding the probability of a traffic accident occurrence, the behaviour of driver in good or bad weather is very important. The increase in the severity of traffic accidents, also caused by deteriorated meteorological conditions, can be demonstrated by the means of statistical recording of the amount of the total material damage.

The evaluation of meteorological conditions is carried out with the use of a model using the methods of fuzzy linguistic approximation, based on a combination of three input parameters. These are: the parameter of the frequency of windscreen wipers, ambient temperature, fog lights switched on/switched off. All these parameters can be collected from the vehicle itself. The output of the fuzzy linguistic model of the evaluation of meteorological conditions represents two parameters – visibility and road condition. These parameters are used as an input into the fuzzy model evaluating the style of the manoeuvre (step 5).

2.3 Step 3 – Determination of vehicle dynamic qualities

The determination and evaluation of current dynamic attributes of vehicle is, in its result, a composition of a traction diagram extended with the values of the maximum possible acceleration of vehicle in a given driving mode (on a flat road, uphill, with current speed, etc.).

The parameters entered into the calculation are described in step 1, and they are mainly a combination of the data collected from vehicle and information concerning the vehicle.

The output of the step of determination of dynamic qualities of vehicle is the ratio of currently used performance of vehicle and the maximum reachable performance in the given driving mode. The output values are determined based on the calculated traction diagram and further presented in the form of a maximum possible and current acceleration of the vehicle. The result of the calculation is afterwards in subsequent steps of evaluation of the driving style stated in the binary form as a sufficiency or insufficiency of performance in a given driving situation.

2.4 Step 4 – Determination of manoeuvre type

Using the type of manoeuvre it is possible to decompose the drive as a whole to the smallest valuable units. The evaluation of the manner of manoeuvre performance is the key issue of the research.

Based on the values of the parameters defining the individual manoeuvres, it is possible to determine the rate of the risk with which they were conducted from the point of view of traffic safety. For the needs of the evaluation of driving style, the following types of manoeuvres are taken into account: driving straight, turning, overtaking, speeding, aggressive deceleration, non-fluent driving (frequent acceleration and deceleration).

The determination of the manoeuvre type is based on the specification of the parameters defining a given manoeuvre type. For example the manoeuvre of overtaking actually consists of two turns, or turning left, driving straight ahead, and turning right. The sequence of the steps defining for example the manoeuvre of overtaking on a straight road segment is as follows:

- Step 1. – Left turning signal indicating the change of direction (indicator) – Information from the CAN collector of the vehicle;
- Step 2. – Positive value a_y from the accelerometer in y axis (turning left – represents the manoeuvre of deviation from one lane to the lane in which the driver will be overtaking);

- Step 3. – Positive value a_x from the accelerometer in x axis, the speed the same or higher than in step 1. (overtaking the vehicle);
- Step 4. – Right turning signal indicating the change of direction (indicator) – Information from the CAN collector of the vehicle;
- Step 5. – Negative value a_y from the accelerometer in y axis (turning right – the manoeuvre represents return to the previous lane);
- Throughout the whole time the increase in the values from the GPS unit in the z axis is zero.

2.5 Step 5 – Evaluation of manoeuvre style

The determination of the manoeuvre style of driver is primarily evaluated by the means of models of fuzzy linguistic approximation. To estimate the determination of manoeuvre style it is not possible to describe the consequent individual rules in the form of a combination of the input parameters, therefore, a fuzzy system Mamdani was used for the estimation of the manoeuvre style. This system is labelled as a fuzzy system with fuzzy conclusions.

In the fuzzy system of Mamdani type the output variable y is defined on the universe Y and the input variables xi on universes X_i (Jura, 2003).

Let the universe Y be covered by the array of the fuzzy sets B_j and the universes X_i by the arrays of the sets A^j_i. Then it is possible to approximate the non-linear function f by the fuzzy system with a set r of the rules of the following type.

$$\text{If}\left(\mathrm{x}_1 = \mathrm{A}_1^{jk}\right)\text{and } \dots \text{and}\left(\mathrm{x}_n = \mathrm{A}_n^{jk}\right)\text{then}\left(\mathrm{y} = \mathrm{B}^{jk}\right)\ \ \mathrm{k} = 1,2,\dots,\mathrm{r} \quad (2)$$

The manoeuvre style is being evaluated for these manoeuvres: driving straight, turning, overtaking and aggressive braking. The parameters entering into particular models are the following: visibility, deteriorated road conditions, sufficient vehicle performance, acceleration in x and y axes, speeding, motorways and roads (directions separated or not separated).

Table 1: Overview of monitored input parameters in relation to manoeuvre type.

Type of manoeuvre	Input parameters for fuzzy model					
	Speeding	Reduced visibility	Motorways	Style manoeuvre	Vehicle with sufficient power	Deterioration of road conditions
Overtaking on straight road segment	x	x	x	x	x	x
Overtaking on straight uphill	x	x	x	x	x	x
Overtaking on straight downhill	x	x	x	x		x
Driving on straight road segment	x	x				x
Driving in a curve	x	x	x	x		x
Overtaking in a curve	x	x	x	x		x
Aggressive braking				x		x

The particular parameters influence the evaluation of the manoeuvre style in different degrees. This fact can be demonstrated e.g. on an example when the risk rate of overtaking during low visibility is higher than under good visibility.

An individual fuzzy model was compiled for every manoeuvre. From the outputs of this model we will acquire the information concerning the rate of aggressiveness with which a given manoeuvre was carried out. Particular fuzzy models were set up individually both regarding the interferential rules, and regarding the set up individual partial functions corresponding with individual fuzzy sets. The following figure represents the process of the creation of the fuzzy model.

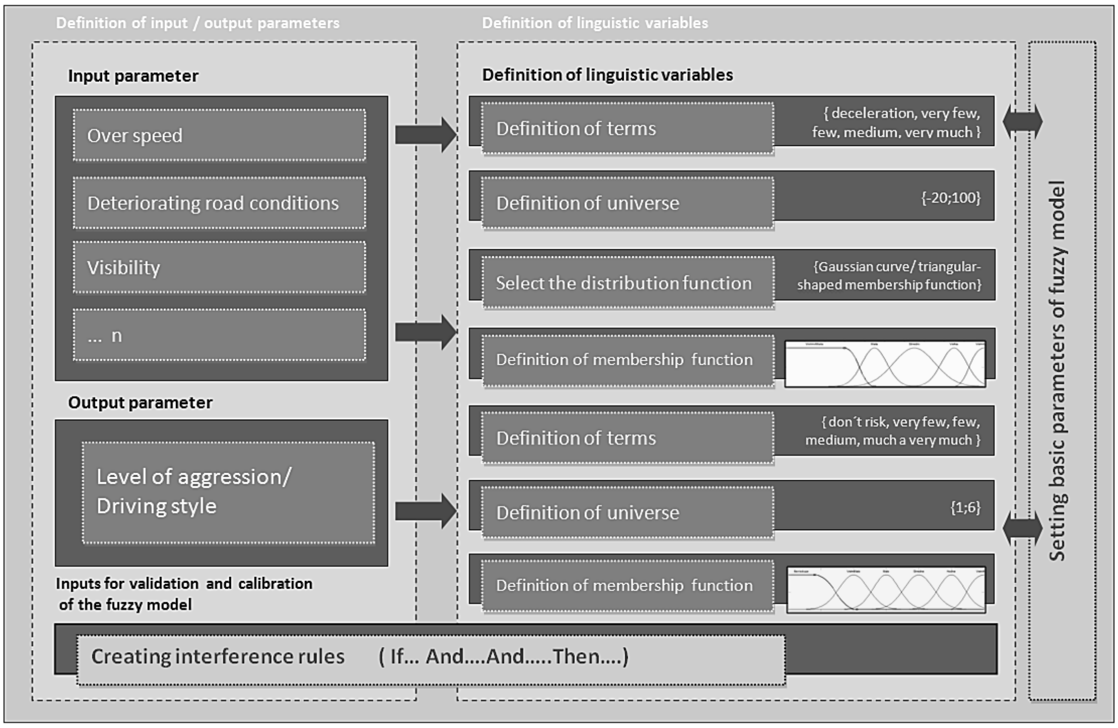

Figure 2: Basic steps leading to determination of manoeuvre style.

The values of the output of the fuzzy models may assume values in the interval <1; 6>. The value 1 represents the manoeuvre style when the driver takes no risks and drives fluently. The value of 6 then represents a very aggressive style of performing the given manoeuvre.

2.6 Step 6 – Assignment of the number of penalty points and determination of driving style sanctions

The final step includes heading towards the possibility of assessment of the fees related to the driving style in which vehicle moves through the road network. These fees are taken into consideration as a variable component of motor vehicles insurance, which represents another level of diversification of evaluation of individual drivers. The resultant amount of the fee will be derived from an assignment of so-called penalty points. These penalty points are used for transporting of the results of the evaluation of the rate of aggressiveness of particular manoeuvres defined in the interval <1; 6>, i.e. outputs of the fuzzy linguistic approximation. The value of 1 represents a fluently performed manoeuvre and the value of 6 a extremely aggressive driving style.

It is important, from the point of view of determining the penalties for driving style, that this “penalisation” was only performed for the manoeuvres with a certain rate of aggressiveness. This means that the introductory point value, which matches the output of the fuzzy model of the value of <0; 1>, is 0 penalty points. The outputs of the evaluation of the manoeuvres ranked in the interval of (1; 2> will correspond with 0-1 penalty point, the outputs of the evaluation of the manoeuvres falling into the interval of (2; 3> will correspond with 1-2 penalty points, etc., up to the value of 5 penalty points.

The total number of penalty points must subsequently be related to the number of kilometres driven or a time period. The resultant amount of the penalty related to the driving style will then be derived from the ratio of penalty points to the number of kilometres driven or the time period. However, the determination of this ratio and the related fee was not the object of the research. This ratio will be determined by the insurance company itself, in relation to its business model, and can also be used as an incentive tool to acquire new clients. For example, speeding in deteriorated weather conditions, which according to statistics means 25% more financial compensation, may be penalized (by insurance companies) more than a traffic accident in good weather conditions.

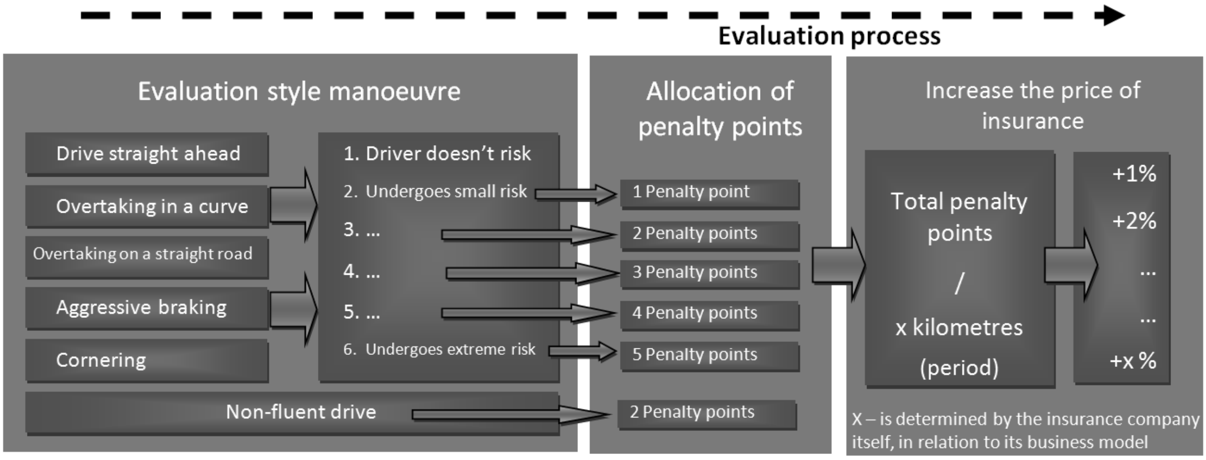

Figure 3: The process leading to determination of penalty points.

The evaluation of driving style may be performed in two reciprocally independent ways, which correspond with the method of processing the input data and information. The first method is the evaluation "during the ride". This method only focuses on speeding, exceeding the side acceleration and aggressive deceleration. When speeding, the driver may be informed immediately (e.g. by an acoustic signal), and therefore he can adjust his driving style. The reason for including only a limited number of parameters is the fact that for the comprehensive evaluation of driving style, it is necessary to have the information and data from different data sources, and these must be evaluated in longer time lines (for the needs of determining the manoeuvre type, etc.). Therefore, the key method for processing the driving data and information is the off-line evaluation, which allows performing a more profound data analysis that is inevitable for the needs of the complex evaluation of driving style.

3 THE POTENTIAL AND BENEFITS OF THE PERFORMED RESEARCH

The benefit is the extension of the Pay As You Drive system with a relevant element taking into consideration the height of paid vehicle insurance in relation to driving style and therefore higher probability of a traffic accident occurrence. The outputs of the research promote these systems to the full-size Pay How You Drive systems. In this sense, the partial benefits may be described in a following way:

- Taking into consideration the difference in the amount of insurance according to the behaviour/driving style of driver: introducing the full-size Pay How You Drive system brings in so far neglected element or parameter usable for fair charging of drivers;
- The motivation of vehicle owners to drive more considerately and less risky: insurance companies will motivate drivers to drive more carefully and not to take risks, and penalize drivers who drive aggressively, take risks and, therefore, increase the risk of a traffic accident and gravity of its consequences;
- More competition on the insurance market: a new product on the vehicle insurance market will lead to a stimulation of the competitive environment between particular

insurance companies and better options in the choice of the type of insurance by customer;

- Decrease in accident rate: vehicle owners will drive more carefully, will be taking less risks and therefore the probability of traffic accident occurrence will decrease indirectly. The safety of road users will improve.

4 CONCLUSION

The motivation for the performed research was based on the weaknesses and shortcomings of the Pay As/How You Drive systems, which currently do not cover the behaviour of driver and actually focus only on the number of driven kilometres.

A proposal of a comprehensive algorithm for the payment systems evaluating the driving styles was stated in this article. This enables take comprehensively into consideration the differences in the behaviour of drivers, and therefore, also the probability of traffic accident occurrence. The output of the algorithm is a projection of the evaluation into the insurance premium. The proposed method uses the fuzzy-linguistic approximation apparatus, which is a suitable tool regarding the insufficient exact knowledge and a large amount of combinations of the input parameters. The values of the input parameters are substituted by setting up partial production functions and expert rules which suitably combine these functions. The process of the evaluation of the driving style was integrated into a comprehensive algorithmic procedure. In general, it is a set up of a sequence of specific steps leading to the evaluation of parts of a ride, on which basis the amount of the final payment is calculated.

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New Concept of Hybrid Drive with Multi-Gear Planetary Transmission

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ABSTRACT: Paper presents an innovative concept of a hybrid drive with two- or three-gear planetary transmission. The arrangement can be extended by one or two additional clutches. Considering the minimum of two-gear planetary transmission, the combustion engine can work in an optimum efficiency mode, i.e., with low consumption and thus with reduced emissions of pollutants, as well as in modes enabling energy storage. Individual gears of the multi-function transmission, constructed as a system as simple as possible, accommodate various driving demands, e.g., serial or parallel driving modes, or parking blockage.

KEY WORDS: Hybrid drive, multi-gear planetary transmission, gear clutches.

1 INTRODUCTION

Hybrid drive of motor vehicles is an important step between vehicles with combustion engines, widely used for about a century, and cars with purely electric drives, considered environmental-friendly and efficient tools for transportation in the future. Mobility of the world population increases, which calls for decrease in total energy consumption and prevention of energy losses in driving systems, e.g., by recuperation.

Nowadays, the ratio of purely electric drives with switched off combustion engine increases significantly for motor vehicles thanks to inventions of new concepts of hybrid drives (e.g., Plesko et al., 2008). A great emphasis is put on reducing the time of running combustion engines to minimum, particularly at short-distance trips in urban areas. The activation of combustion engines is limited to situations requiring high-power or with the lack of energy in the energy storage system, i.e., for the system recharge. Such concepts are known as Plug-In-Hybrids with an electric plug for external charging of the energy storage system, or, as Range Extender-Hybrids, containing an electric drive which gains energy from a combustion engine connected to an electric motor. The latter drive type enables their flexible functioning, thanks to the fact that the combustion engine can work in both modes - being an electric energy generator and/or a mechanical drive of the motor vehicle. However, concepts of vehicles equipped with only electric motors without a combustion engine are too dependent on the size, capacity and power of electric storage systems, which results in a significant limitation of their usage at the moment.

A new idea (Plomer, 2013), introduced in this paper, is based on a hybrid drive of vehicle concepts driven by one combustion engine and equipped with two electric motors and minimum of one two-gear transmission. The designed solution assumes the transmission is of a planetary design with an annulus, a sun, a planet carrier of several peripheral planet gears and several shifting elements that all together allow for shifting of several gears.

2 HYBRID DRIVETRAIN DESIGNS

Similarly to the Plug-In-Hybrids and Range-Extender-Hybrids, the new concept of hybrid vehicle drives (Plomer, 2013) includes two electric motors and one combustion engine (Figure 1, 3, 4 and 5). On top of that, incorporating a multi-gear planetary transmission into the system allows us to optimize revolutions of the combustion engine. The designed drivetrains contain optionally up to two additional clutches for shifting mechanical gears. The first electric motor of the designed hybrid drive plays a role of a generator of electric energy and the other one of the driving electric motor. The power of individual electric motors may differ. In certain driving modes, functions of both electric motors are interchangeable and can be active in parallel.

2.1 Hybrid drivetrain with two-gear planetary transmission

Two electric motors and the planetary transmission are arranged coaxially in the drivetrain as shown in (Figure 1). The input shaft of the transmission is connected with the shaft AN of the combustions engine VM and a rotor of the electric motor EM1, while the rotor of the electric motor EM2 is linked with the output shaft of the planetary transmission. The electric motors EM1 and EM2 are controlled by software of the Energy management EN, based on the required amount of energy. A small energy storage system of only 1-3 kWh capacity forms a part of the Energy management. Two electric motors EM1 and EM2 as well as the energy storage system are designed in such way that the maximum power capability of motor EM2 equals to the sum of power capabilities of the EM1 and the energy storage system. For example, the EM2 can reach the peak power of 30 kW and the EM1 motor and the energy storage system of 15 kW each. The combustions engine VM can be of a Diesel type with the power of 30 kW.

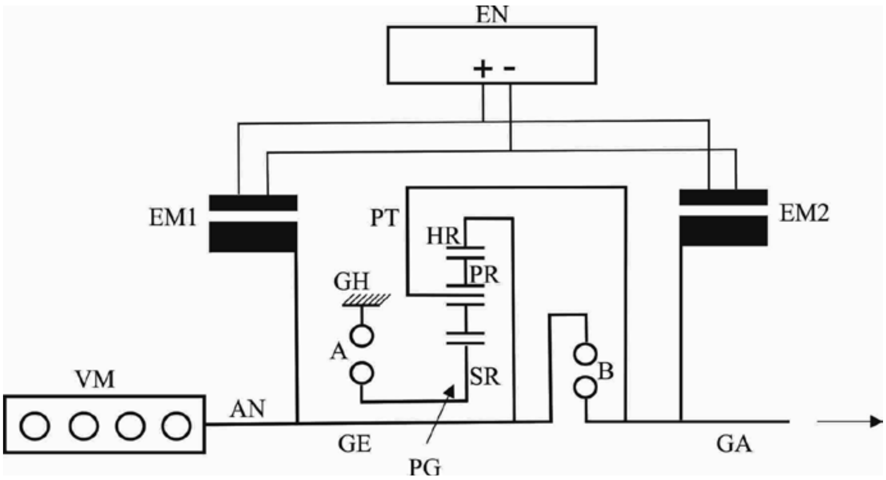

Figure 1: Hybrid drivetrain with two-gear planetary transmission.

The planetary transmission is located in between the electric motors EM1 and EM2. It consists of an annulus HR, a sun SR and a planet carrier PT with peripheral planet gears PR. The planet carrier is under a load of the sun and annulus. The annulus is connected to the input shaft of the transmission and the planet carrier is linked with the output shaft of the transmission. The sun is laid free.

Furthermore, two shifting elements A and B, depicted as gear clutches, are considered in the drivetrain (Figure 1). The sun SR can be fixed to the body of the transmission by clutch A. Clutch B is located in between the annulus and the gear carrier. As a result of this arrangement, the planetary transmission can be blocked and consequently the direct power transfer can be achieved by joining the input and output shafts of the transmission.

Gear scheme (Table 1) presents one purely electric “gear” D0-E, two mechanical gears D1 and D2, backward running R, neutral N and parking blockage P. The input and output shafts of the transmission are disconnected at “gear” D0-E and therefore, power from the EM1 motor cannot be transferred. The car is driven solely by the second electric motor EM2, directly coupled with the output shaft of the transmission. The required power is controlled by the Energy management in dependence on the actual charging of the energy storage system, course of the ride, driver’s wishes or driving mode. The necessary amount of electric energy can be used either solely from the energy storage system without any help of the combustion engine and/or gained from the combustions engine working in the generator mode with the electric motor EM1. A purely electric drive, without activated combustion engine can be realistically used for speeds up to 50 km/h and distances up to 10 km.

Table 1: Gear scheme of two-gear planetary transmission.

Gear	**Clutch**		**Gear ratio i**
	A	B	
D0-E		-	-
D1	x	-	1.622
D2	-	x	1.000
R	-	-	-
N	-	-	-
P	(x)	x	-

(x) optional

Two mechanical gears D1 and D2 are available provided that the input and output shafts of the planetary transmission are connected. Then the annulus represents the input element and the planet carrier the output one. The gear clutch A is closed in the first gear D1 and the sun is stopped. For example, this can result in a gear ratio i=1.622 (Table 1) with the use of gear numbers as follows: the sun 69, the peripheral planet gear 18 and the annulus 111. The gear clutch B is closed at the second gear D2, which leads to the ratio i=1.000. In this case, the planetary transmission rotates as a block. The closing both clutches A and B comes about automatically by actuators depending on the current situation.

The combustion drive can be optionally supported by the electric motors EM1 and EM2, particularly in cases of a sudden demand for increased power of the engine. Thanks to the generator course of the electric motor EM1, a part of the torque of the combustions engine can be stored in the energy storage system assuming the gears D1 and D2 are active. This accumulated energy can be consequently exploited in the electric motor EM2 during the acceleration (Boost function).

The backward running R of the system is performed by a reverse running of the electric engine EM2. By opening both gear clutches A and B, and deactivation of the electric drive, the car is put into neutral N. Parking blockage P can be implemented by closing the gear clutch B and by switching off the combustion engine. The transmission can be additionally blocked by closing the gear clutch A. Short-term torque of electric motor EM2 can be used to unlock the parking blockage.

Figure 2 shows an example of a speed diagram of the combustion engine with the designed planetary transmission. The combustion engine always runs in the optimal operating revolutions and thus with the lowest specific fuel consumption and in the most economic mode. The combustion engine works with the lowest specific consumption in the electric D0–E gear at the speed up to 50 km/h under constant revolutions.

The combustion engine plays an exclusive role of a generator of electric energy in this serial arrangement when using the electric motor EM1. Shifting the first mechanical gear D1 means the combustion engine runs at revolutions determined by the gear ratio. At the speed of 80 km/h, the car is put in the second mechanical gear D2 automatically. The gear change does not interrupt the power flow.

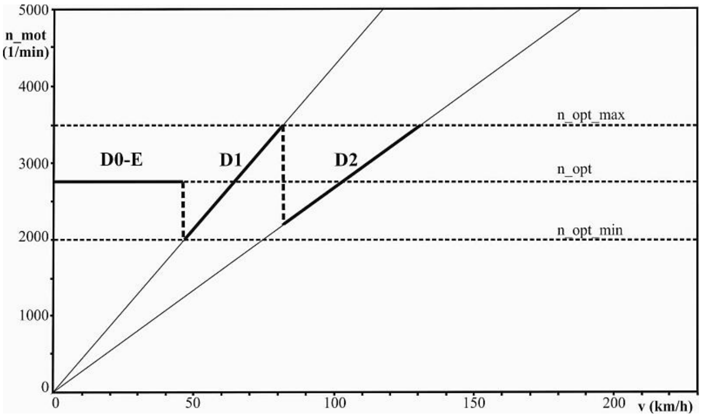

Figure 2: Speed diagram of the new hybrid drive concept.

2.2 Hybrid drivetrain with three-gear planetary transmission

Drivetrain scheme in Figure 3 shows another option of a hybrid drive with three mechanical gears. The planetary transmission is extended with an additional mechanical gear D3 and is presented as a reduction gear mechanism. The transmission consists of two annuluses HR1 and HR2 and corresponding planetary gear mechanisms PR1 and PR2. The two planetary gears are coaxially arranged, have a common planet carrier PT, and in pars join peripheral planetary gears PR1 and PR2. The annuluses H1 and H2 can be connected with the input shaft of the transmission by gear clutches B and C. The sun SR, revolving on the output shaft of the transmission and optionally linked with the stable parts of the transmission by gear clutch A, is continuously integrated with the planetary gear mechanism PR2.

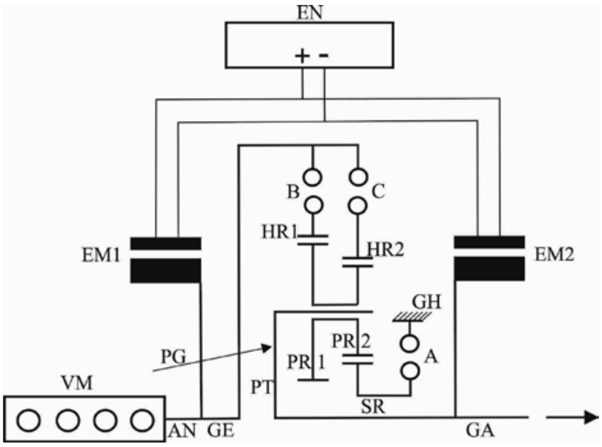

Figure 3: Hybrid drivetrain with three-gear planetary transmission.

Equally to the scheme with the transmission containing two mechanical gears (Table 1), the bottom gear D0-E of the tree-gear mechanical transmission (Table 2) is purely electric one and the car is driven solely by the electric motor EM2. At the gear D1 the connected clutch A stops the sun SR and the gear clutch C links the second planet gear mechanism PR2 to the input shaft of the transmission. At the gear D2 the A clutch again stops the sun SR, but in this case, the input shaft of the transmission is linked with the first planet mechanism PR1 by the clutch B. At the gear D3 clutches B and C are joined simultaneously, annuluses of both planet gear mechanisms are connected to the input shaft of the transmission and the sun SR revolves free.

Table 2: Gear scheme of three-gear planetary transmission.

Gear	Clutch		
	A	B	C
D0-E		-	-
D1	x	-	x
D2	x	x	-
D3	-	x	x
R	-	-	-
N	-	-	-
P	(x)	x	x

2.3 Hybrid drivetrain with extended clutches

The designed hybrid drives (Figure 1 and 3) can be extended with a setting-in-motion clutch K0 located between the combustion engine and the input shaft of the planetary transmission (Figure 4). Then, e.g. a two-gear transmission can be used according to the scheme in Table 3, with the same gear ratios as those presented in Table 1.

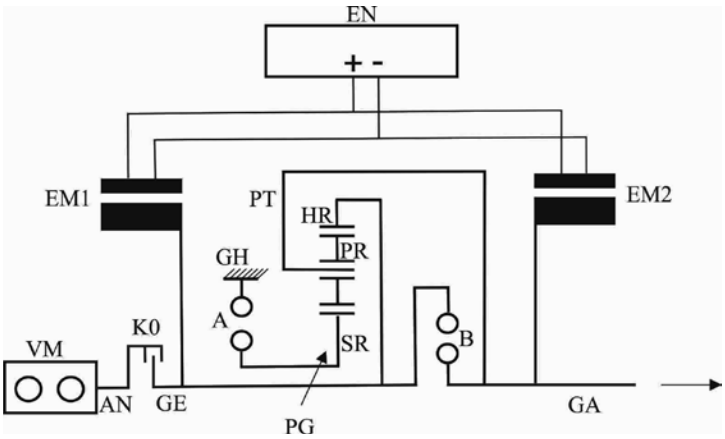

Figure 4: Hybrid drivetrain extended by additional clutch K0.

Table 3: Gear scheme of two-gear planetary transmission with additional clutch K0.

Gear	Clutch			Gear ratio i
	A	B	K0	
R-E	(x)	-	-	-
D0-E	-	-	x	-
D1	x	-	x	1.622
D2	-	x	x	1.000
R	-	-	(x)	-
N	-	-	-	-
P	x	x	(x)	-

Pure electric setting-in-motion of a vehicle, or purely electric ride, is possible, if the setting-in-motion clutch K0 is disconnected and the gear clutch A is closed. In that case, the vehicle is driven solely by the electric engine EM1 because the combustion engine VM is disconnected completely from the drive. On the other hand, the purely electric setting-in-motion and/or ride can be controlled by the electric motor EM2 if the gear clutch B is disconnected. Two mechanical gears are available for the motor EM1 in the planetary transmission. Evenly, the backward running R is performed by two gears of the motor EM1 if the clutch K0 is opened. If the clutch K0 is closed and the gear clutch B is opened, the backward running is possible only with the help of the electric motor EM2. Closing gear clutches A and B simultaneously results in parking blockage P. In this case, the setting-in-motion clutch K0 can also be closed. The combustion engine can support the drive if any sudden power increase is required, e.g., during the engine start uphill.

A drivetrain presented in Figure 5 is extended with another clutch K1, in comparison with the scheme in Figure 4. The coaxially located clutch K1 in between the input shaft and the annulus HR can be of a gear type. The rotor of the electric motor EM1 is placed on the input shaft of the transmission in between two clutches K0 and K1.

If a vehicle with the hybrid drive designed in Figure 5 stops uphill, the parking blockage P is activated by the closing clutches A and B. However, what may happen is that there is not enough amount of energy in the storage system to release the parking blockage P by electric motors EM1 and EM2 and to set the car in motion. In such case, the clutch K0 disconnects and the combustions engine is started up by the electric motor EM1, while the clutch K1 is closed. The starting mode requires only a small amount of energy in comparison with the amount of energy needed to release the parking blockage. When the car is stopped in a steep uphill, a high torque is required to start the car moving. Therefore, after a start of the combustion engine with disconnected setting-in-motion clutch K0 and closed K1 clutch, the clutch K0 connects again under the load and the torque of the combustions engine is transferred into the planetary transmission. Consequently, the gear clutch B disconnects and the torque transfers via the closed clutch A on the output shaft of the transmission. The significant advantage of this hybrid drive (Figure 5) is based on a possibility of energy storage. Under the disconnected clutch K1 and connected clutch K0, the generated energy can be stored in the energy storage system, even if the planetary transmission is blocked and the parking blockage P activated. In such case, the electric motor EM1 works as a generator of electric energy. An example of the gear ratios presented in Table 4 for the hybrid concept in Figure 5 corresponds to the example numbers of gears given in Table 1.

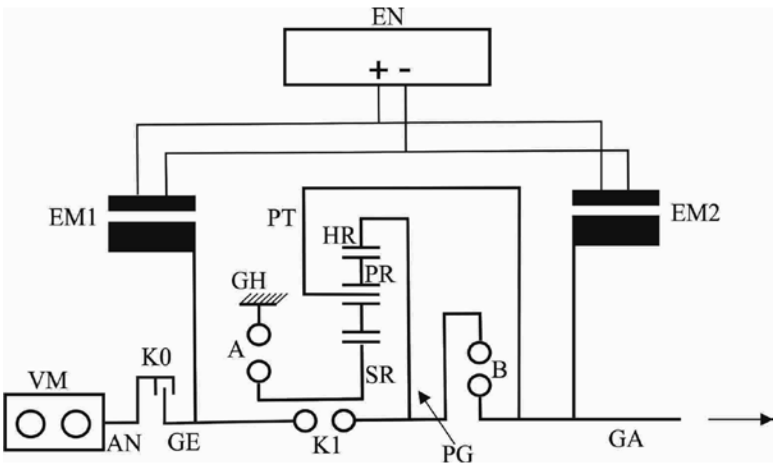

Figure 5: Hybrid drivetrain extended by two additional clutches.

Table 4: Gear scheme of two-gear planetary transmission with extended clutches.

Gear	Clutch				Gear ratio i
	A	B	K0	K1	
R-E	(x)	-	-	x	-
D0-E	-	-	x	x	-
D1	x	-	x	x	1.622
D2	-	x	x	x	1.000
R	-	-	(x)	x	-
N	-	-	-	x	-
P	x	x	(x)	(x)	-

3 INNOVATIVE CONCEPT IN LIGHT OF PREVIOUS PATENTS AND ITS ADVANTAGES

The designed concept with two basic variants of the innovative hybrid drives, potentially extended by additional clutches (patent DE 10 2011 085 149 A1, released on 25 April, 2013; Plomer, 2013) represents an important step in hybrid drive development (Horčík, 2013).

Patent DE 697 32 387 T2 (Ibaraki et al., 2006) of a hybrid drive for a vehicle contains similar basic building elements – one combustion engine, two electric motors and a simple planetary transmission with a sun, a planet carrier and an annulus, but the arrangement of the building elements and the system functioning differ. The two electric engines, the planetary transmission as well as the input and output shafts are arranged coaxially, i.e., in a single axis. The planet carrier is connected to the combustion engine via the input shaft and the annulus is linked to the output shaft of the transmission. The rotor of one of the electric motors is connected to the output shaft of the transmission whereas the rotor of the second electric motor is joined with the sun. The planetary transmission only acts as a dividing element to mechanical torque-split of the combustion engine.

Similar building elements form the hybrid drivetrain of Patent DE 10 2008 053 505 A1 (Hinrichsen & Hofmann, 2010). One of the electric motors is connected with the combustion engine and works as a generator. A clutch is in between the generator and the transmission. The one-gear transmission has a fixed gear ratio which can correspond to, e.g., the highest gear of a common transmission. Instead of two electric motors, or, in addition to them, in-wheel electric motors can be designed (e.g., Kovanda & Kobrle, 2012). An energy storage system, connected to electric motors is also available. The system allows six different driving modes: (1) purely electric drive – applicable in the case of low demands on power, e.g., in a city; (2) mode of recuperation – in which the second electric motor works as a generator of electric energy and braking energy is transferred into electric one, stored afterwards in the energy storage system; (3) serial ride and boost mode – electric energy generated by the combustion engine and in generator are available and usually used for driving car at low speeds; the drive works as a serial hybrid and can use the energy from the energy boost system; (4) serial hybrid driving mode and charging – a part of energy is used for driving and the remaining part is stored in the energy storage system; (5) parallel driving mode and boost - the combustion engine can be supported by the electric motor powered from the energy storage system and the power is mechanically transported by one fixed gear; (6) parallel ride and charging - the combustion engine works as a source of energy to run the motor vehicle. The system is rather complicated and expensive.

Therefore, the fundamental task for the new invention (DE 10 2011 085 149 A1, Plomer, 2013) was to design a hybrid drive which is efficient in running and economical in its production. The designed new arrangement of the building elements and, particularly, the incorporation of the two- or three-gear planetary transmissions into the hybrid drivetrain fulfilled the task and put forward the hybrid drive ideas.

One of the advantages of the hybrid drive according to the presented invention is in its independence on a size of the energy storage system used in the vehicle. Thanks to that, the energy storage system of a capacity of several kWh can be smaller, lighter and thus also cheaper in comparison with that of vehicles using exclusively electric drive, and/or, of the Plug-In- and Range-Extender-concepts. Moreover, no independent heating needs to be installed into the designed hybrids, as residual heat from the combustion engine can be used in the system.

One or two setting-in-motion clutches, incorporated in the innovative drivetrains, are optional, but not necessary. The reason is that even the basic concept includes an electric setting-in-motion function (D0-E, Tables 1-3). In the same way, no separate elements for the backward vehicle running are needed, because the reverse running of the electric motor can be employed for that. The so-called “START-STOP” function of the combustion engine is realized with the use of the first electric engine and thus no extra starter is required.

Production costs of the proposed hybrid decrease further thanks to the fact that parking blockage can be realized directly by blocking of the planetary transmission and thus no additional elements for parking blockage of automatic transmissions are needed. One of the electric motors can be used to release the parking blockage and to open the clutches.

The hybrid drive design is effective in urban traffic, or at low velocities in exclusively electric mode, and also for long-distance trips at higher speeds out of town, when the combustion engine is switched on to generate electric energy for the electric motor EM1 or drives directly the vehicle wheels, if required.

In contrast to the Plug-In-Hybrid and Range-Extender-Hybrid concepts, where the transmission plays a role of only a divider of driving force between the combustion engine and electric motor, the multi-gear planetary transmission included in the new concept enables to optimize operational revolutions of combustion engine in dependence on vehicle speed in such way that the combustion engine runs in optimal mode with a low fuel consumption and high efficiency.

In the simpler version (Figure 1), the transmission is designed as a simple planetary gear mechanism with one sun, a planet carrier with several peripheral gears and two shifting elements allowing two gears to be shifted. The planetary transmission is designed with negative basic gear ratio. In contrast to the transmissions with positive gear ratios, the designed arrangement with the negative ratio is simpler and exhibits greater efficiency of the transmission by having fewer number of gears engaged.

The designed arrangements enable a smooth start-up of vehicle by the electric motor EM2. They have at least two gears in the planetary transmission, one of which is ‘direct’; furthermore, they have electric backward running and, last but not least, possess ability to block the transmission. The significance of exclusively electric mode is decisive in urban traffic, due to repeated startups of vehicles, or stopping and accelerating in traffic jams. The utilization of exclusively electric mode depends on the amount of energy stored in the energy storage system.

The designed system also enables the so-called BOOST function in the case of increased dynamics of the vehicle. Then, both electric motors can be used simultaneously to drive the vehicle, e.g., for acceleration. Thanks to that, a car will exhibit very good ride dynamics, even in case that a relatively weak, and thus cheap and efficient, combustion engine is built in the vehicle.

Both shifting elements of the planetary transmission can be designed with the aim of achieving the highest speed of the vehicle and overdrive. Then the combustion engine constantly operates in the optimal mode and is adjusted for requirements both on maximum power and on economy. The two gear units of the planetary transmission (A and B, Figure 1 and 3) can be made as gear clutches without any synchronization. The torque of the two electric motors ensures the shifting is realized without a break of power flow, which is important and desirable for ride comfort.

In the frame of extensions of combustion engine modes in hybrid drives, the transmission can be designed as a three-gear planetary transmission as well as a reduction transmission with two annuluses, one sun and one planet carrier with several double peripheral planet gears. This arrangement provides a smooth start of a vehicle, three gears in the planetary transmission, one electric reverse running and blockage of the transmission.

Implementing additional clutch (K0, Figure 4) in between the combustion engine and the input shaft of the transmission represents an additional extension in electric motor functions allowing for a possibility of choosing various connections of these elements. In order to fulfill the requirements for an extension of the hybrid drive functionality, one more additional clutch (K1, Figure 5) can be added into the drivetrain. A new feature brought by this version consists in an axial location of the rotor of electric engine EM1 between the K0 and K1 clutches. Since the rotor is connected to the input shaft of the transmission, the energy from the combustion engine, generated by the EM1, can be stored in the energy storage system, supposing that clutch K0 is closed and K1 is opened. This kind of charging of the energy storage system can be executed even if the vehicle is stopped and the parking blockage is activated.

Storing of any kind of energy in systems becomes a challenge for new extensions of hybrid drive concepts. Modern technologies tend to produce flywheels meeting demands on recovering vehicle kinetic energy, which would otherwise be lost, as heat during breaking (e.g., First & Plomer, 2010; Plomer, 2010; 2011; Yang, 2012).

4 CONCLUSION

The new concept of a hybrid drive with two- or three-gear planetary transmission, optionally extended by one or two additional clutches, guarantees a low-cost combustion engine of the system working in the optimum efficiency mode, with sustainable fuel consumption and reduced emissions of pollutants. The multi-gear transmission of the system allows various driving functions and thus additional specific elements are not needed any more. Therefore, the invented hybrid drivetrains represent a promising environmental and economic improvement in constructing vehicle drives for the future.

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Delay Function in Dependence of Dynamic Phenomena

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ABSTRACT: Knowledge of actual road traffic volume and road capacity is a part of the data necessary to know when an emergency event occurs and the traffic needs to be quickly diverted to an alternative route. The method based on Czech standards for calculating traffic volume and capacity was innovated. The first step of the method deals with the determination of road capacity depending on its category and traffic volume. The other part of the method takes into account the calculation with adverse weather conditions, such as rain or snow, low temperature and bad visibility. The latter part is derived from international studies. The actual capacity method is used in a new assistance system for emergency services which is being developed by the Division of Road Safety and Traffic Engineering of Transport Research Centre in cooperation with the Police of the Czech Republic.

KEYWORDS: Traffic volume, capacity, delay function, adverse weather.

1 INTRODUCTION

Decisions about alternative routes which are made by the Police every time a traffic accident occurs have to be quick and alternative routes have to reflect the actual traffic volume. Making this decision is not easy, especially in adverse weather conditions and in winter. A new assistance system which is developed by Transport Research Centre, in cooperation with the Police of the Czech Republic, is going to help in these difficult situations. The system collects data from different sources and contains e. g. information on locations of emergency vehicles, gritting vehicles, information from police databases NDIC (National Traffic Information Centre), CDI2 (localized traffic information) and on meteorological situation. For computing of traffic volume and capacity the data from SDB (road database operated by Road and Motorway Directorate of the Czech Republic) will be used. This data contains information on road parameters in the Czech Republic, such as a category of road, segment length, width and number of lanes.

The main objective of the paper is to determine time delay on a road segment. The time delay needs to take into account the dynamic factors of traffic flow. The delay function should include the effect of traffic volume and influence of adverse weather conditions on road capacity. Although actual volume assessment is implemented into the project according to Czech standards (ČSN 73 6101, 2009; TP 189, 2012; TP 225, 2010), road capacity in different weather conditions has no support in Czech standards. The factors used in the project are derived from international studies. Only significantly influencing parameters (precipitation, temperature, reduced visibility) were used in the calculation.

2 DELAY FUNCTION

In case of a road accident, an area restriction or a traffic closure is employed. In such situations it is necessary to consider using road diversions. The traffic flow is moved from the original route to a temporary one, which has to be evaluated in order to guarantee smooth traffic diversion.

Czech standards classify the road network into seven categories. Each category has different traffic engineering parameters and is able to provide various levels of service. These parameters need to be collected and assessed so that the temporarily diverted traffic runs smoothly.

Parameters, such as road category, section length, number and width of lanes, slope or respective traffic volume can be searched or derived from the road databank of the Czech Republic. Those parameters are essential to define the capacity of each road section. The calculation of the capacity setting is defined by Czech standards (ČSN 73 6101, 2009). On the other hand, the loss of travel time is not. And it is mostly this parameter which determines the driver’s satisfaction.

Foreign literature (Ortúzar & Willumsen, 2011) states that the calculation of travel time between two points depends on road traffic volume and capacity. Free travel time means a time period during which a vehicle is moving between points 1 and 2 with no outside distractions. This is, however, impossible in reality. The calculation is therefore corrected by increasing the travel time by adding the time influenced by capacity and traffic volume.

$$\boldsymbol{S_a = t_a \cdot \left(1 + \alpha \left(\frac{I_a}{C_a}\right)^{\beta}\right)}$$

S The average time delay (s)
I_a Traffic volume (veh/h)
C_a Capacity (veh/h)
t_a Free travel time (s)
α Calibration coefficient – linear (-)
β Calibration coefficient – exponential (-)

The model of the Bureau of Public Roads (Ortúzar & Willumsen, 2011) is the most suitable for the average travel time loss for road sections in the Czech Republic. Since it is the only one which considers seven roads categories on Czech road network (Interstate, limited Access Highway, principal Arterial, Minor Arterial, Major collector, Rural major Collector, Urban local).

This model was experimentally verified in the USA on 37 junctions and road sections (Jeihani, Lawe & Conolly, 2006). Figure 1 shows the dependence of individual time losses on traffic volume, with regard to the calibration parameters of each road category (α and β).

The model of the Bureau of Public Roads considers the time loss with two-component exponential growth. The first component contains the time loss only in free or zero traffic volume. The other component covers the exponential growth in dependence on the ratio between traffic volume and capacity on the section sections. Coefficients α and β are parameters of the growth curve. For example, using speed V = 80 km/h, volume 1000 veh/h and capacity 1200 veh/h, the model yields time loss of approx. 110 second.

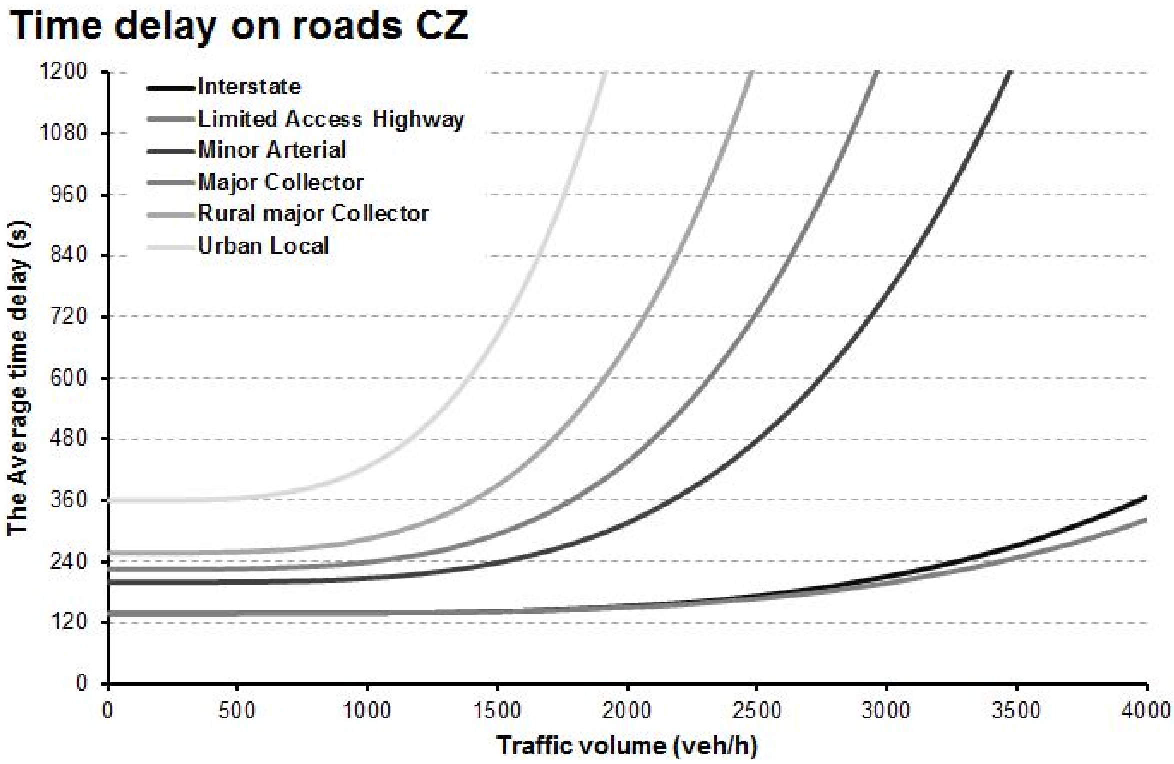

Figure 1: Time delay on czech roads.

The result is then the average time of vehicle ride from point 1 to point 2. The calibration parameters α and β may be adjusted for every road category. Furthermore, it is recommended to take into consideration two-way traffic because there may be changes in the traffic volume or other unexpected occurrences in both cases. The following Table 1 contains the list of input values for the calculation of medium time delay according to Czech standards. Speeds are chosen with regard to road category speed limit. Coefficients α and β are taken from studies which consider the same roads categories like in Czech Republic. The road section capacity of a given road category is chosen according to table values of Czech standards.

Table 1: Input parameters for the delay function.

	Interstate	**Limited Access Highway**	**Principal Arterial**	**Minor Arterial**	**Major Collector**	**Rural Mmajor Collector**	**Urban Local**	**(-)**
Speed	130	130	90	90	90	90	50	(km/h)
Distance in 1 s	36.11	36.11	25.00	25.00	22.22	19.44	13.89	(m)
Minimal time delay t_a	138.47	138.47	200.00	200.00	225.02	257.20	359.97	(s)
Capacity according to ČSN 736101	4000	4000	3600	2500	2165	2050	2500	(veh/h)
α	1.65	1.33	1.10	1.39	1.28	1.75	6.60	(-)
β	4.00	3.90	3.90	3.90	3.90	3.90	3.90	(-)

It is useful to integrate the variable traffic volume into the model. Traffic volume is heavily influenced by the time of day as well as traffic demand. Traffic demand is not observed in this project but the daytime is. Traffic volume is converted to AADT based on TP 189 standard (2012) and after that back to the demanded day and hour.

The overall result of the delay function should be the medium time delay on the diverted route taking into consideration variable traffic volume, road category (capacity) and the relevant vehicles speed. The next step of the calculation of road capacity takes into consideration the weather influence (rain, snow, temperature), too.

3 INFLUENCE OF SIGNIFICANT FACTORS OF ADVERSE WEATHER CONDITIONS ON ROAD CAPACITY

The first studies of the influence of weather on road capacity appeared in the 1950s (Tanner, 1952). Adverse weather conditions reduce road capacity, but the specific value differs in each country worldwide, depending on geographic location. Drivers are used to drive in specific weather conditions. For example in areas with high precipitation, there will be bigger decrease in capacity compared to the area with low precipitation. The reason is that the drivers in the latter group do not adapt well to changes in conditions such as worse adhesion or longer breaking distances. They drive with higher risk not being aware of it. The drivers of the former group, in areas with higher precipitation, are aware of the risks, they slow down and maintain greater distances between each other.

Differences in speed and capacity were observed depending on the day of week, too. At weekdays, the decrease is lower than at weekends. The decrease is also higher at night. This is probably caused by different levels of risk which drivers take for different reasons of trips and by the value of time in different times.

The observed decrease of capacity is empirical in studies under consideration. It is sometimes possible to find an equation, but it also only depends on empirical data (Alhassan & Johnnie, 2011; Chung et al., 2006; Hranac et al., 2006; National Academic Press, 2004; HCM, 2010).

Regarding the differences between studies, the values used in the project were rounded to five per cent. The values lower than five per cent were removed. In the end, only the effect of precipitation, low temperature and reduced visibility were used.

It is only possible to use the percentage of decrease showed in the tables below for macroscopic models. These values are derived from the studies produced in the USA, in Germany, Great Britain and Japan. For smaller scale models it is inevitable to make measurements in specific localities.

The values are divided according to the amount of precipitation in each region into three groups. The scale used for the classification has eight degrees in accordance with the rain map, snow map and the climate map (temperature) of the Czech Republic (ČSN EN 1991-1-3, 2012; Český hydrometeorologický ústav, 2012).

Table 2: Precipitation groups of regions of the Czech Republic.

Group 1 - below average rainfall	
Region	**The average value on a scale 1-8**
Ústí nad Labem Region	2.8
Plzeň Region	2.0
Pardubice Region	3.0
South Bohemia Region	2.7
Central Bohemia Region	1.7
South Moravia Region	1.6
Prague Region	1.0
Group 2 - average rainfall	
North Moravia Region	3.5
Vysočina Region	3.5
Olomouc Region	3.6
Zlín Region	3.4
Group 3 - extreme rainfall	
Karlovy Vary Region	4.0
Hradec Králové Region	4.3
Liberec Region	5.3

Table 3: Percentage reduction in road capacity due to precipitation at different times of day and different days of week.

Amount of precipitation	Group	Weekday *daylight*	Week day *night*	Weekend *daylight*	Weekend *night*
Rain					
1 - 10 mm/h	1	10	25	20	25
	2	10	30	20	30
	3	10	40	20	40
Over 10 mm/h	1	15	25	30	35
	2	20	35	35	40
	3	20	40	40	40
Snow					
1 – 10 mm/h	1	10	25	20	25
	2	15	30	20	30
	3	25	40	40	40
Over 10 mm/h	1	15	30	30	35
	2	20	35	35	40
	3	25	40	40	40

3.1 Precipitation

The actual precipitation situation is drawn from the meteorological radar data. A figure of the updated situation is published every 10 minutes on a specialized server operated by the Czech Hydrometeorological Institute (Český hydrometeorologický ústav, 2012).

The figure is analysed by RGB detection in a defined area (where the traffic issue occurs) and the intensity of the rainfall or snow is recognized according to the colour scale. The day of week and daytime are analysed and in the last step the value from Table 2 is used for reducing of the road capacity.

Daylight and night are calculated with the use of an algorithm for dealing with sunrise and sunset. The algorithm is developed by Jarmo Lammi, published in Scout Report for Science & Engineering in 1997.

3.2 Temperature

The influence of temperature is not as crucial as the influence of precipitation. There was observed a reduction in capacity by a several percentage points. Only in case temperature is really low, it becomes more significant. In the project, only temperature lower than -20 °C is used, see Table 4. The data and method used for the assessment of the current temperature are the same as for precipitation.

Table 4: Percentage reduction in road capacity due to low temperature.

Temperature	
< - 20 °C	10

3.3 Reduced visibility

The last weather factor which is a part of the used calculations is reduced visibility. In this group the influence of night on dry road and the influence of fog and possibly of smoke are included. The data for identification of fog are drawn from a website operated by Road and Motorway Directorate of the Czech Republic (RSD), which contains updated data from meteorological stations. The network of the data is rather sparse, so there will be a chance to enter it manually by a police officer. Data for night are calculated with the use of the algorithm described in paragraph 3.1.

Table 5: Percentage reduction in road capacity due to reduced visibility.

Reduction of visibility	Weekday	Weekend
Lighting conditions		
Night, dry road surface	20	25
Fog, smoke, etc.		
For any detection (regardless of the degree of reduction in visibility)	10	

4 CONCLUSION

The assessment of the actual road capacity is important in situations when traffic needs to be transferred from higher class roads to lower class roads due to emergency events. This can cause a new traffic issue.

A partial aim of the project is to find an optimal alternative route for all types of vehicles. Capacity and traffic delay are two of the used parameters in the decision-making process. Capacity defines the throughput of road and traffic delay which is based on the level of service. Therefore, the values are derived from the state-of-the-art materials. The data are usable for macroscopic models where a large number of parameters is considered. For a project on the microscopic level, specific model of traffic delay and adverse weather impact needs to be derived.

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Determination of Trajectory of Articulated Bus Turning along Curved Line

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ABSTRACT: The paper focuses on the presentation of a single-track dynamic model of articulated bus, a simplified linear model, which is based on reducing the double-track dynamic model with suitable assumptions that the front body lateral accelerations and rotational angles of the articulated bus are small. On the other hand, the phenomena of friction and interstice, such as articulated system (fifth wheel), are neglected. A coordinate system is defined to precisely describe the translational and rotational motions of the vehicle. In details, the author provides the dynamics model, sets up the kinematics and dynamic relations and builds differential equations of kinematic parameters presenting the articulated bus motions. These are objective functions, which are necessary to determine the gravity centre trajectory of the articulated bus, movement of the joint system and bodies of vehicle in addition to the swept path width of articulated bus. Matlab-Simulink is used to solve mathematical problems and simulate responding dynamics of vehicle. The modelling results are the functions of kinematic and dynamic parameters that allow to determine the motional trajectory and the swept path width of articulated bus, joint system and bodies of vehicle. These suitable results represent the fundaments for exact evaluation of the dynamic model and investigation of dynamics of articulated bus at a higher and more complex level.

KEYWORDS: Articulated bus, trajectory, dynamic model, articulated system.

1 INTRODUCTION

Nowadays, roads are becoming more and more congested, with increasing economic losses due to delays resulting from traffic jams and road accidents. Such problems may be reduced by using public transport systems. In order to make a public transport system attractive, it has to be cheap, fast and reliable. In cities, many types of public transport are in use, subways, trams and buses being the most common. However, each type has its advantages and disadvantages.

Articulated buses with their advantageous features in carrying capacity, transport productivity and reduction of transport costs have been exploited effectively. However, traffic safety of the above mentioned vehicle type should be improved and this topic is outlined in our specific study. Accidents which occur to buses usually cause serious consequences, great damage on human lives and property. The mathematical study of the motion trajectory can contribute to the safety of articulated buses.

There are two basic conceptions of articulated buses:

- Articulated bus with engine in the front body (so-called puller articulated bus);
- Articulated bus with engine in the rear body (so-called pusher articulated bus, which is the main type and more popular nowadays.

The paper presents the motion of articulated buses on the road plane, which can be considered as a displacement of a double physical pendulum with two masses (front body and rear body of the vehicle).

2 THE MAIN OBJECTIVES OF RESEARCH

Since the aim of the research is to determine the motion trajectory and swept path width of articulated bus, the objective functions of this issue are given:

- Lateral (side) slip angles of front body and rear body of articulated bus: α_1, α_2 and their derivatives: $\dot{\alpha}_1;\dot{\alpha}_2$; $\ddot{\alpha}_1;\ddot{\alpha}_2$;
- Yaw angles of front body and rear body: ε_1, ε_2 and their derivatives: $\dot{\varepsilon}_1;\dot{\varepsilon}_2$; $\ddot{\varepsilon}_1;\ddot{\varepsilon}_2$;
- Rotational angle of front body to rear body: φ and its derivative: $\dot{\varphi};\ddot{\varphi}$;
- Direction velocity vectors of front body and rear body: V_1; V_2.

3 DYNAMIC MODEL OF ARTICULATED BUS

The dynamic model of articulated bus with appropriate assumptions (Vlk, 2005; Nguyen Khac Trai, 1997):

- Articulated vehicle moves on a smooth and flat road;
- Tyre side slip angles of front steering wheel are the same;
- Front and rear bodies are absolutely rigid;
- Only the variability of kinematic and dynamic parameters on the ground plane are considered;
- The air resistance is neglected;
- The deformation of tyre is linear and the elastic moment is neglected;
- Joint is assumed as an ideal knuckle joint with no interstice and no frictional joint moment. The joint is located slightly ahead of the centre of the tractor rear axle.

3.1 Double track linear dynamic model

The motion of articulated bus is defined by different translational and rotational components. The linear velocity and acceleration of the vehicle, forces and moments are the motion phenomena of the vehicle during the ride. Two coordinate systems in the SAE convention (Society of Automotive Engineers) and ISO (International Standards Organization) are used for the vehicle dynamic simulation. The vehicle coordinate system has its origin at the centre of gravity of the vehicle. All movements of articulated vehicle bodies are given within the reference to this co-ordinate system.

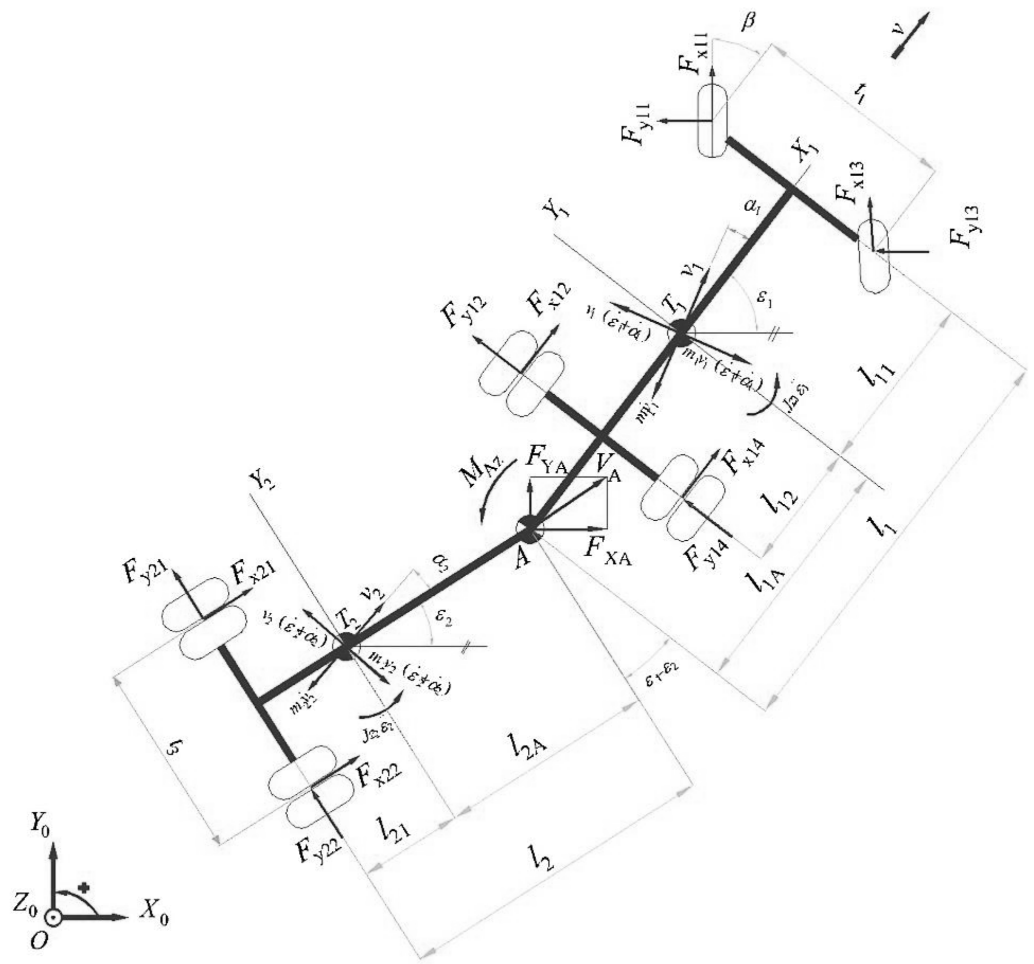


Figure 1: Double track model of articulated bus on planar phase.

The inertial (Earth fixed) coordinate system ($OX_0Y_0Z_0$) is selected to coincide with the vehicle coordinate systems ($T_1X_1Y_1Z_1$) on the front body and ($T_2X_2Y_2Z_2$) on the rear body. The absolute motion quantities are defined with respect to this coordinate system and the components of these quantities are defined along the axes of the vehicle fixed coordinate systems. The orbit motion of articulated bus is determined by the fixed coordinate system $OX_oY_oZ_o$.

With this coordinate system, it can be assumed that articulated bus is a mechanical system with two solid bodies. The first one has the centre of mass at the centre of the front body and the other one at the centre of the rear body. The knuckle joint system (point A) connects the two bodies.

On the $T_1X_1Y_1Z_1$ axis system: the origin of the axis system is the centre of front body (T_1). The X_1 axis is the front body longitudinal motion. The Y_1 axis is in lateral direction and in the ground plane. The Z_1 axis is perpendicular to the ground plane with a positive direction upward. The positive direction of rotational angle is counterclockwise.

On the $T_2X_2Y_2Z_2$ axis system: the centre of gravity co-ordinate system, whose origin is the centre of the rear body (T_2). The X_2 axis is the rear body longitudinal motion. The Y_2 axis is lateral direction and perpendicular to X_2 axis. The Z_2 axis is perpendicular to the ground plane. The positive direction of the rotational angle is counterclockwise.

3.2 Single – track linear dynamic model

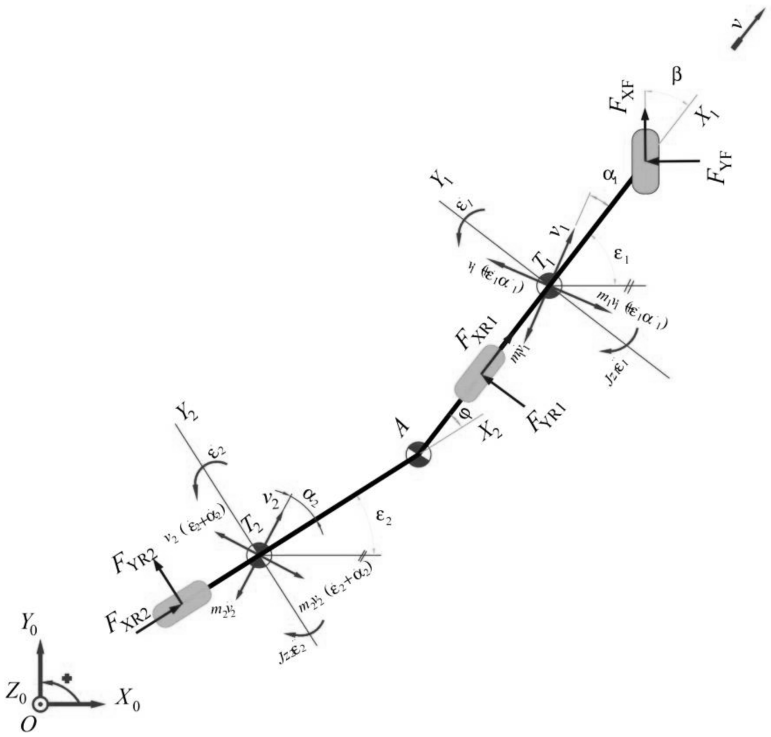


Figure 2: Single track model of articulated bus on planar phase.

The overall dynamic model of articulated bus is shown on respective figures. In order to build up vehicle motion equations, dynamic functions were determined and the connecting joint of the front body of articulated bus was separated from the rear body and replaced by constraint reactions.

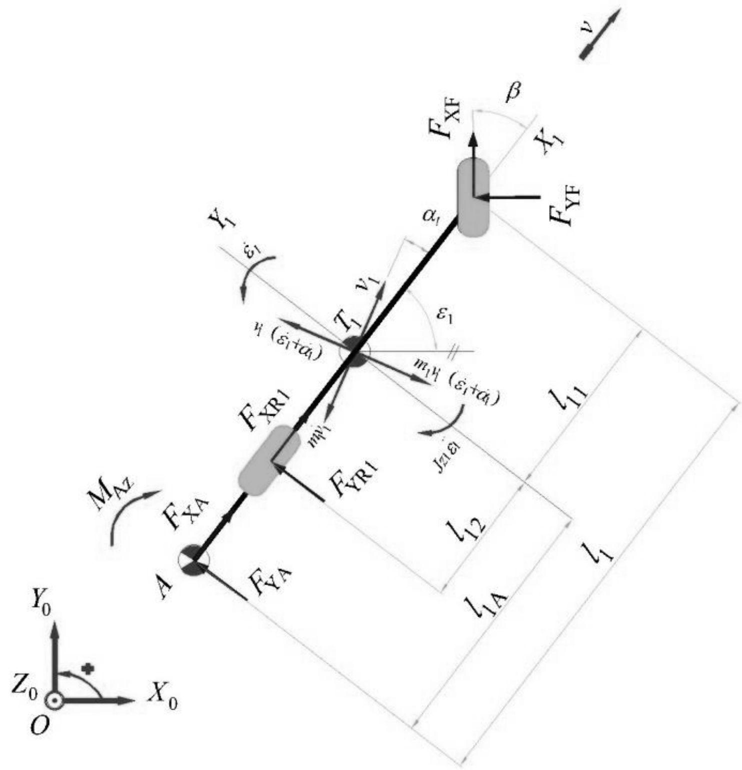


Figure 3: Single - track model on front body of articulated bus behind separating joint.

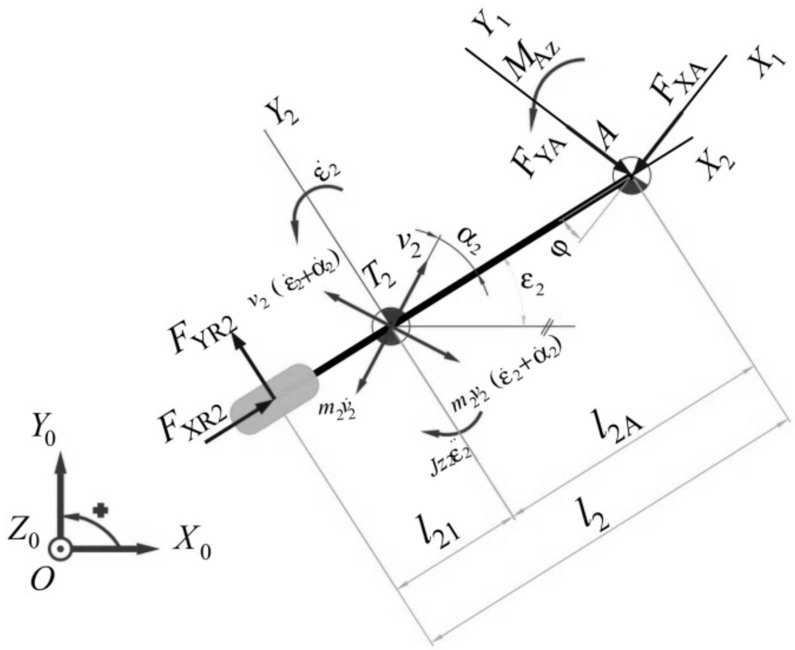


Figure 4: Single - track model on rear body of articulated bus behind separating joint.

The equations of the motion with respect to the axles fixed to the front or rear body are given and after reducing these equations, four differential equations are shown:

$$\dot{v}_1 = \frac{1}{m_1}\begin{pmatrix}(F_{XF}\cos\beta - F_{YF}\sin\beta + F_{XR1} + F_{XA})\cos\alpha_1 + \\ +(F_{XF}\sin\beta + F_{YF}\cos\beta + F_{YR1} + F_{YA})\sin\alpha_1\end{pmatrix}$$

$$\dot{\alpha}_1 = \frac{1}{v_1.m_1}\begin{pmatrix}-(F_{XF}\cos\beta - F_{XF}\sin\beta + F_{XR1} + F_{XA})\sin\alpha_1 + \\ +(F_{XF}\sin\beta + F_{YF}\cos\beta + F_{YR1} + F_{YA})\cos\alpha_1\end{pmatrix} - \dot{\varepsilon}_1$$

$$\ddot{\varepsilon}_1 = \frac{1}{J_{Z1}}(\left[F_{XF}\sin\beta + F_{YF}\cos\beta\right].l_{11} - F_{YR1}.l_{12} - F_{YA}.l_{1A})$$

$$\ddot{\varphi} = \frac{1}{J_{Z2}}\left[F_{YR2}.l_{21} + (F_{YA}.\cos\varphi + F_{XA}\sin\varphi).l_{2A}\right] + \ddot{\varepsilon}_1$$

3.3 Trajectory and swept path width of articulated bus

During the motional process, the tractor gravity center changes position and it is determined from instantaneous velocity V_1 making tangent line to curve of orbit considered in the fixed intertial system.

The motional trajectory of articulated bus is defined by the 3 following points: the centre of gravity of tractor, the joint and the centre of gravity of semi-trailer (Dang Hoang Anh, 2009).

The centre of gravity location of the front body of articulated bus at T_1:

$$X_{T1} = \Delta X_{10} = \int_{t_i}^{t_i+\Delta t} V_{1Xo} dt = \int_{t_i}^{t_i+\Delta t} V_1 \cos(\alpha_1 + \varepsilon_1) dt$$
$$Y_{T1} = \Delta Y_{10} = \int_{t_i}^{t_i+\Delta t} V_{1Yo} dt = \int_{t_i}^{t_i+\Delta t} V_1 \sin(\alpha_1 + \varepsilon_1) dt$$

Joint location A:

$$X_A = X_{T1} - l_{1A} \cos(\varepsilon_1)$$
$$Y_A = Y_{T1} - l_{1A} \sin(\varepsilon_1)$$

The centre of gravity location of the rear body of articulated bus at T_2:

$$X_{T2} = X_A - l_{2A} \cos(\varepsilon_1 - \phi)$$
$$Y_{T2} = Y_A - l_{2A} \sin(\varepsilon_1 - \phi)$$

The swept path width of articulated bus in motion is determined by the location of the outer edge point in proportion to limited dimensions of the vehicle.

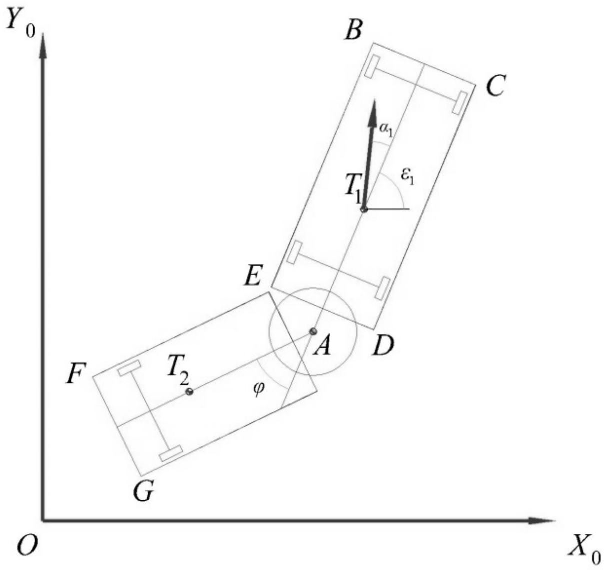


Figure 5: Swept path width of articulated bus with limited dimensions.

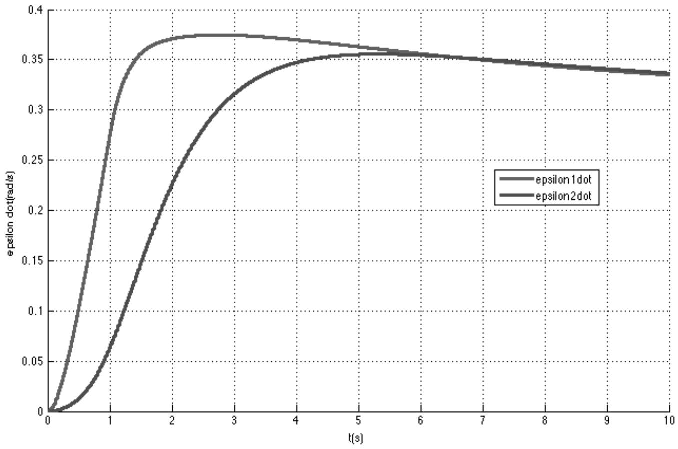
4 SIMULATION

Excitation functions of the mechanical system of articulated bus occur in the above mentioned equations.

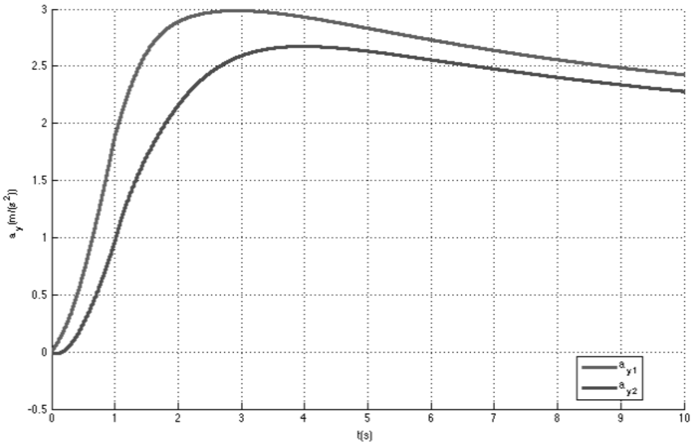
- Excitation function of the turning angle of the steering wheel: Excitation function of the steering wheel is specified by the front wheel turn angle of the vehicle front body. The rule of the front wheel turn is shown in the figure below; in stable wheel turning conditions the front wheel will turn at the maximum angle of 0.14rad (8^0);
- Longitudinal force function: In the content of the research, we suppose that articulated bus moves in a stable way and the total tractive force produced by the driven wheel equals the total rolling resistance of wheels in vehicle axles.

5 SIMULATION RESULTS

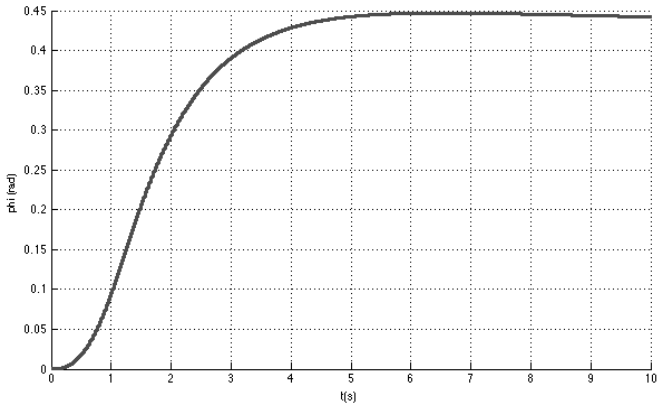
The Matlab – Simulink tool was used for vehicle dynamics simulation. The total time for the program simulation is 10 seconds. The velocity of the vehicle is constant 8m/s. The results are shown on the figures below:



a) *Velocity slip angles* $\dot{\varepsilon}_1 ; \dot{\varepsilon}_2$ *(1.rad^{-2}).*



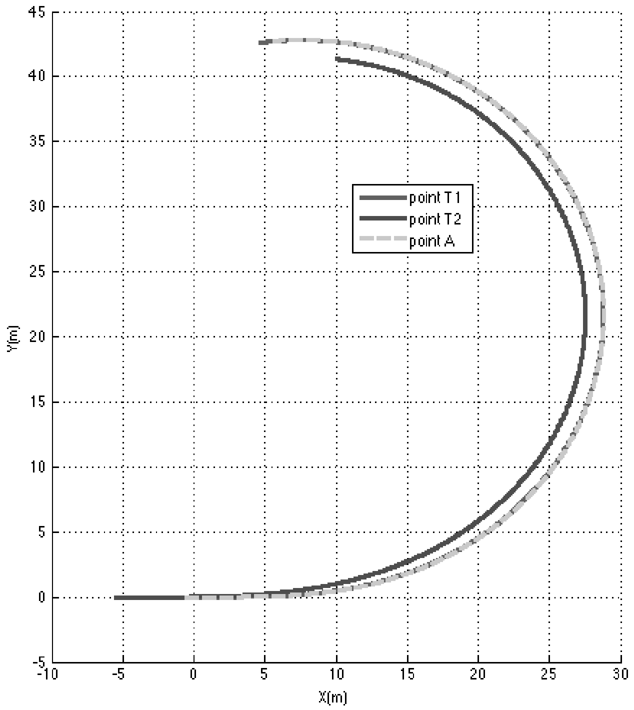
b) *Acceleration slide side a_y (m.s^{-2}) of front body and rear body.*



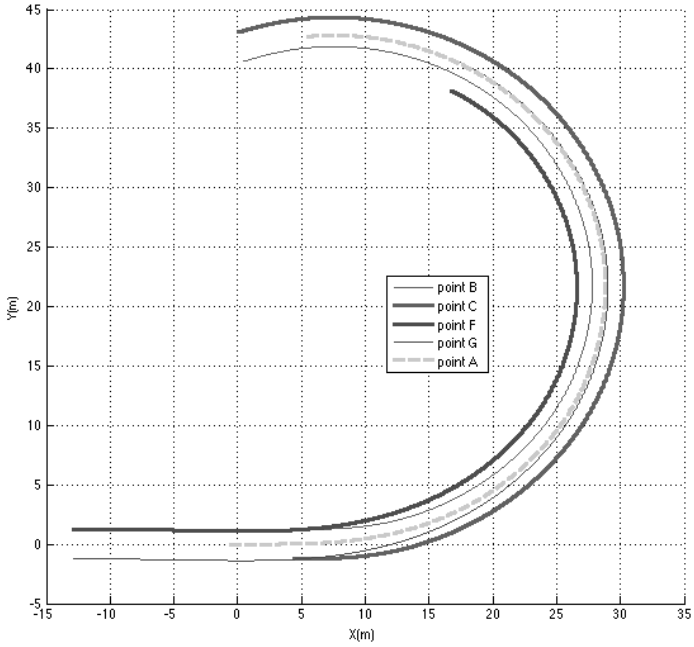
c) Slip angles of front body with rear body φ (rad).

Figure 6: Simulation dynamic of articulated bus turning on curve line.

The dynamics of articulated bus in stable conditions when turning on curved line without break forces (this is a basic case in comparison with another cases) shown in the figure above. The figures present the response of vehicle dynamics.



a) *Trajectory of centre gravity points.*



b) Swept path of vehicle by trajectory of points.

Figure 7: Determination of swept path hand trajectory of centre gravity points of vehicle.

Figure 7 presents points trajectory: the centre of gravity T_1 of the front body with the starting point has co-ordinate (0,0); Joint A with the starting point has co-ordinate (-0.5,0); the centre of gravity T_2 of the rear body starting point has co-ordinate (-5.5,0).

- During the first initial second of translational movement, (in the first 8 meters), the front body of articulated bus moves mainly forward;
- Translational movement is finished to maintain the steering wheel angle, trajectory of articulated bus continues to change and follows a stable circle.

7 CONCLUSION

Within its limited content, the article presents the trajectory of tractor-semitrailer on a single-track linear model with appropriate assumptions.

However, this was examined in an area of minor changes with little lateral acceleration. Research in the areas of major changes (non-linear area) is necessary for the creation of a complex model.

The research results can be used as reference material for following dynamic research with a complete spatial model.

At the same time, the method of calculation as well as the vehicle design parameters indicate a driving corridor at the road plane.

Besides, it is possible to explore situations which influence the structural data in order to optimize the movement of the vehicle.

ACKNOWLEDGEMENTS

The research was supported by the Josef Bozek Research Centre of Engine and Automotive Engineering TE0102002.

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Technical Note on Description of Impulse Vessel

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ABSTRACT: The biomechanical research projects deal with different fields of vehicle passive safety, especially with mechanisms of injury, their investigation and predictions of injury severity. The presented article describes a device which helps to understand the spreading of the pulse wave. It causes very dangerous diffuse brain injury, which is responsible for 75% of deaths in traffic.

KEY WORDS: Pulse wave, impulse vessel, diffuse injury, pressure, experiment.

1 INTRODUCTION

Diffuse brain injury is caused by propagation of the shock wave in the brain tissue. This occurs most often during traffic accidents, when the brain tissue is exposed to high overload under the vehicle impact. The propagation of the shock wave, which is initiated by an impact, is a difficult issue researched using exact and experimental methods. The problem is to determine the limit value of the impact which results in diffuse brain injury. The damage occurs at the cellular level without any visible damage of the organ anatomy or tissue structure. The mechanism of diffuse brain injury is accompanied with the damage of neural fibers. This leads to dysfunction of the neural network. In the situation when a certain amount of synapses is damaged, brain is not able to disseminate information and death occurs (Kramer, 2008).

2 DESCRIPTION OF MEASURING DEVICE

The propagation of the shock wave through human tissue during the traffic accident can be simulated using a special device called an impulse vessel. For this purpose, the Faculty of Engineering of the Czech University of Life Sciences in Prague, designed and subsequently constructed and installed a special tool. The base unit of the device is a sliding mechanism connected with a thick-walled steel vessel for a biological sample. The cylindrical vessel is filled with physiological saline. To initiate a shock wave, which has a character of a pressure wave, the defined mass is used that hits the vessel and gives it some acceleration. In the center of the vessel there is a circular aperture, which is closed by a piston. The piston acts to the filled vessel and infers a pressure shock wave. The vertical mechanism ejects the weight to required height and thereby changes the energy transmitted to the piston, which closes the vessel. Therefore, the magnitude of the shock wave can be varied as an impact energy function.

The pressure profile in the fluid is recorded using pressure sensors. One sensor is located in the upper part of the pressure vessel and the other at the bottom. The course of the pressure in the vessel, obtained from pressure sensors, is a basic output parameter. With respect to the biological tissue and its possible changes, temperature is also observed. All sensors are connected with a PC and the obtained data are subsequently processed and evaluated in LabVIEW software made by National Instruments. This software application enables both, the visualization of measured values as well as processing and detailed analysis of the record of the experiment.

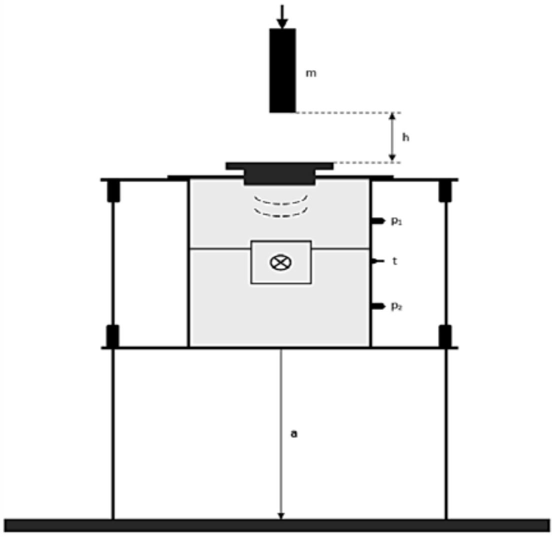

Figure 1: Schematic representation of a vessel for a biological sample.

To extend the use of this device a test track for head impact was constructed. This is a guidepath, in which it is possible to place the head of crash test dummy. In the head´s center of gravity an acceleration sensor is installed. The head of the test dummy, start from different heights, falls down to the pad of defined surface properties. The sensor, located in the dummy´s head is also connected to the PC and in that software the progress of the measured acceleration is evaluated. This device faithfully simulates the hard impact of passenger´s head on some elements in vehicle interior during traffic accident. Based on these measured data, it will be possible to design and recommend materials that can mitigate consequences of the injury.

3 RESULTS AND DISCUSSION

The article describes a unique device which is still under development. The results of this research intend to clarify and describe the viscous injury mechanism. The aim is to predict the severity of injury and determine load limits which do not cause permanent changes in human tissues.

ACKNOWLEDGMENT

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