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Experience from In-depth Analysis of Road Accidents

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ABSTRACT: Official road accident statistics are, in most countries, not sufficiently detailed to allow an in-depth analysis of accidents. In-depth studies try to provide a detailed reconstruction of events that lead to accidents and to identify the factors that caused injuries. According to Elvik (2010), the purpose of performing in-depth analyses of accidents is both to understand factors leading to accidents and to identify the best way to prevent accidents. In-depth studies of fatal accidents have a long history in Finland (VALT, 2004) and the United Kingdom (Staughton & Storie, 2000), but have more recently been introduced in Sweden (Sagberg & Assum, 2000) and Norway (Assum & Sørensen, 2010). In recent years, in-depth studies in Finland have focused on factors that influence the injury severity (Toivonen, 2006). Germany (Otte, 1994) and the Netherlands (Vollenhoven, 2001) also perform in-depth studies of accidents, as well as Denmark (Larsen, 2004).

KEY WORDS: In-depth analysis of road accidents, transport infrastructure, vehicle engineering, psychological experts in transport, road accident, traffic area, vehicle, accident with injuries.

1   INTRODUCTION

In 2011, the Czech Transport Research Centre (Centrum dopravního výzkumu, v.v.i.) started an R&D project of the Ministry of Interior entitled In-depth Analysis of Road Accidents (Hloubková analýza silničních dopravních nehod), project No. VG20112015007 (hereinafter referred to as HADN). A specialized team of experts in transport infrastructure, vehicle engineering, psychology in transport, and cooperating medical experts from The University Hospital Brno investigate accidents on the spot occurring in Brno and its surrounding, and later analyse them and record them in a database specifically created for this purpose (Andres, 2009). A similar project GIDAS, which has been running in Germany for several decades, is a model and guideline for this work. The project aims to create a database of detailed information on road accidents which can be used for making important transport and political decisions and to operatively design road safety measures in the above mentioned areas. Within the duration of the project HADN, i.e. in 2011 and 2012, more than 300 accidents, which included injuries and, in some cases, fatal injuries, were investigated. By the end of the project, i.e. by 2015, it will have been necessary to have analyzed nearly 750 road accidents. Although the existing "sample" of accidents is still statistically insignificant, some of the findings and relationships which are the topic of this

article are already obvious (Andres, 2011). Therefore, the in-depth analysis of road accidents can lead to the application of effective road safety measures, as well as to the reduction of the number and severity of road accidents.

2 DESCRIPTION OF ACTIVITY

2.1 Transport infrastructure

Road safety also depends on the safety of road infrastructure. Although the majority of accidents are caused by drivers, their behaviour is often influenced by the traffic environment. While various sources indicate that in up to 25% of cases the transport environment influences the occurrence of road traffic accidents, HADN investigations of accidents found that the transport infrastructure more or less affected almost 42% of all investigated traffic accidents! And it may not only concern the typical limited visibility or fixed obstacles to traffic, but also the problem of a poor road surface (motorway D1 is an example) or its inappropriate gradient. Based on the dealings with accidents, recommendations concerning road safety were designed that should eliminate the possibility of further accidents. Although from the viewpoint of statistical significance, the number of accidents is still insufficient, several measures were generalized and their incorporation could begin to start to lead to the relevant technical regulations. The following graph shows the designed measures (recommendations) to improve safety in traffic area.
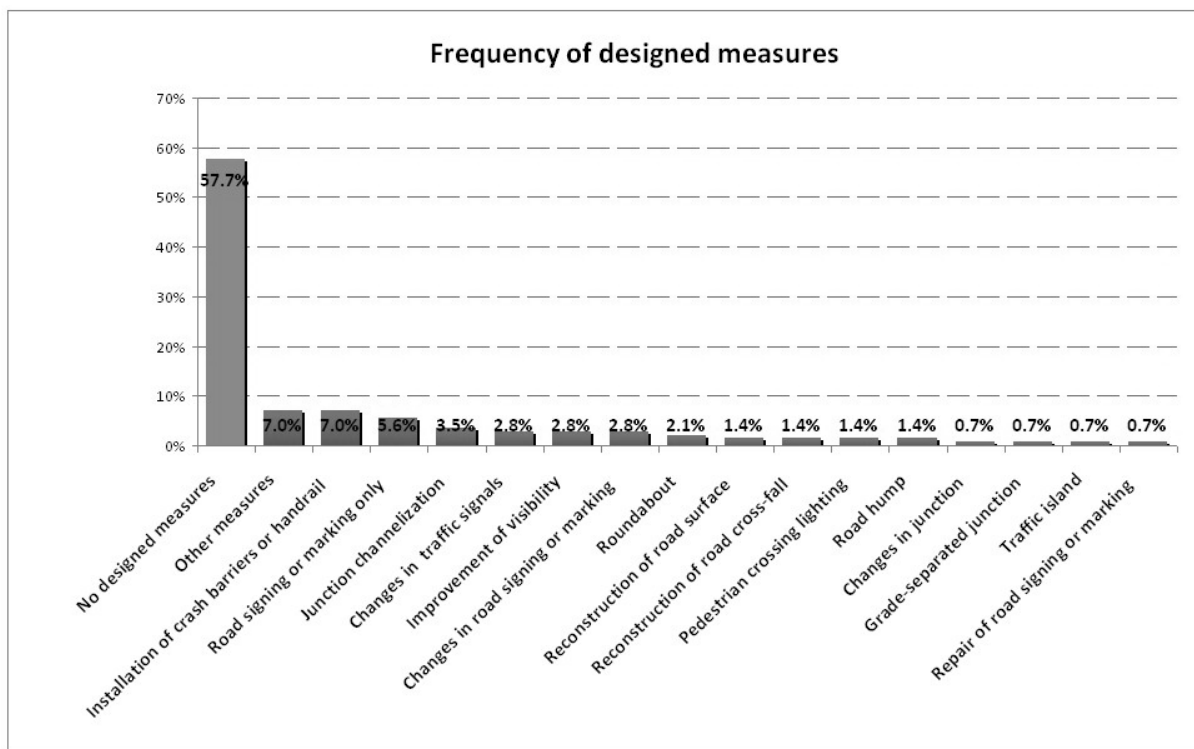
Figure 1: The proportion of road safety measures in the area of transport infrastructure.

Regarding the graph above it should be mentioned that the first column "No designed measures" does not mean that the researchers analyzing accidents did not deal with the influence of the traffic area on the accidents, but rather that within an in-depth analysis of the accident spot, no deficiency was found that could have had an effect on the occurrence of traffic accidents and their consequences.

2.2   Vehicle engineering

As part of a comprehensive investigation of all the circumstances under which the accident occurred, it is also important to examine in detail the technical condition of the vehicle. The purpose of the work of vehicle engineers is to confirm or disprove that the main causes of accident were technical faults in the vehicle. By October 2012, a total of 412 vehicles were involved in 257 investigated traffic accidents. All types of motor vehicles and bicycles were involved. A detailed analysis of traffic accidents in terms of vehicle engineering revealed that a defect in the vehicle, as the only cause of an accident, was detected in only one case. So in terms of vehicle engineering, we can only talk about implications and not the causes of traffic accidents resulting from a technical fault in the vehicle. The most common factor of traffic accidents included particularly neglecting the condition and pressure of tyres, lack of inspection of the vehicle before driving, failure to ensure sufficient field of vision from the vehicle under difficult weather conditions, unused passive safety features provided as part of the vehicle equipment, and underestimation of necessary driving skills, or their lack.

During the research it was found that most accidents occurred due to the insufficient ability to stop a vehicle, followed by a collision with a vehicle driving in front. The number of vehicles involved in a collision were two (in 94 accidents), three (in 18 accidents) and in four cases even four vehicles travelling closely one behind another. The most frequent cause of accidents was a failure to keep a safe distance and adjust the speed to the situation on the road. The second largest group was represented by an accident between a pedestrian and a vehicle (51 accidents). These accidents occurred mainly because of a sudden move of the pedestrian into the path of the vehicle, and due to overlooking the pedestrian by the driver (collision with a pedestrian at low visibility, dark colour clothing of a pedestrian, etc.). It was found that vehicle drivers were liable for the accident in 22 cases. The Figure 2 shows a relatively high occurrence of accidents where a motorcycle was involved and accidents of a motorcycle and one car. In each of these groups, 40 accidents were investigated. Accidents of motorcycles and those involving motorcycles occurred mainly due to loss of control of the motorcycle when taking a curve at high speed, or the falling of a motorcycle when braking. In 13 cases, one-vehicle accidents involved the vehicle overturning. An important group of traffic accidents is represented by the accidents of cyclists (alone in 9 cases) and accidents involving cyclists (19 accidents). Similar to accidents with motorcyclists it showed that the main causes involved the loss of control of a bike on uneven surfaces and overlooking a ridden bicycle by a vehicle driver. Other significantly represented groups of traffic accidents are those that involve a collision of a vehicle with a fixed obstacle, and accidents involving public transport vehicles.
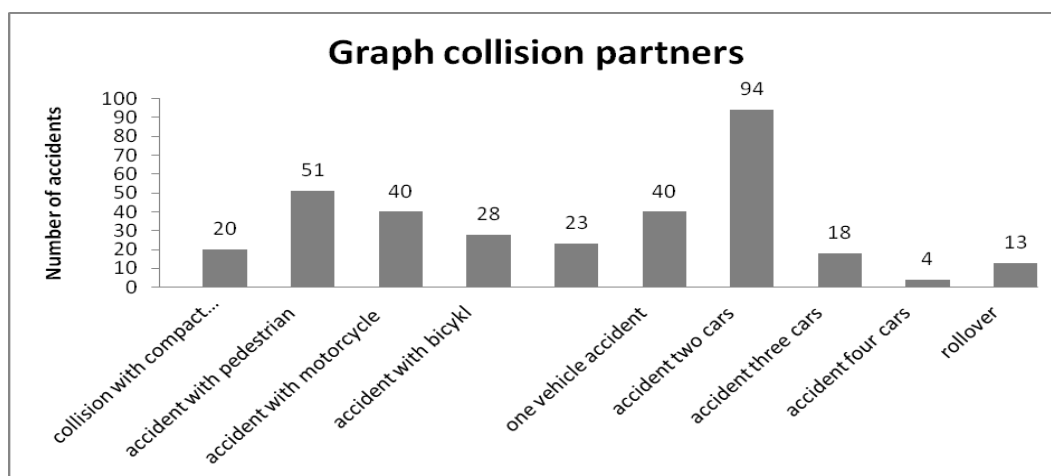

Figure 2: Distribution of the number of traffic accidents, depending on the type of a collision partner.

As regards the vehicles involved in the accidents investigated, it can generally be said that the condition and age of the tyres have a significant influence on the course and consequences of traffic accidents. Current findings suggest that drivers use tyres of the prescribed size although often of earlier production date, insufficient tread depth or underinflated. As regards tyre age, most often represented were 3 years old tyres, followed by the group of 4 and 5 years old tyres. As a matter of interest, even 18 to 24 year-old tyres were reported. During the period specified for the use of winter tyres (from 1 November to 31 March) it was found that this requirement was not met in only 6 out of 135 examined vehicles in the specified period.

As concerns the above mentioned issue of overlooking another road user it was found that the omission was due to their "hiding" behind the right front pillar or their location in a driver's blind spot.

A serious traffic accident also occurred because of the incorrect placement and securing of goods. In one case the transported goods intruded into the vehicle crew's compartment. In another accident (head-on collision) there was an explosion of a gasoline canister located in the storage compartment in the front part of the vehicle.

Last, but not least, when investigating accidents it was found that in many cases vehicle headlights were not turned on, a clear view from the vehicle in poor weather and light conditions was not secured, safety belts were not used (or were used improperly) or the technical check of the vehicle was not valid. In these cases it is only possible to appeal to drivers to adequately check the vehicle prior to driving. In 2012 it was registered at sites of accidents whether participants of accidents used reflective vests on accident sites. It was found that out of 322 traffic accident participants, only 70 of them put on their vests after an accident, which represents only 22% of the people involved. This number included only persons at the spot of an accident who were neither members of the rescue teams nor the research team. Among the participants, employees of towing services, undertakers' employees and employees of assistance services were also included. The data are shown in Figure 3.
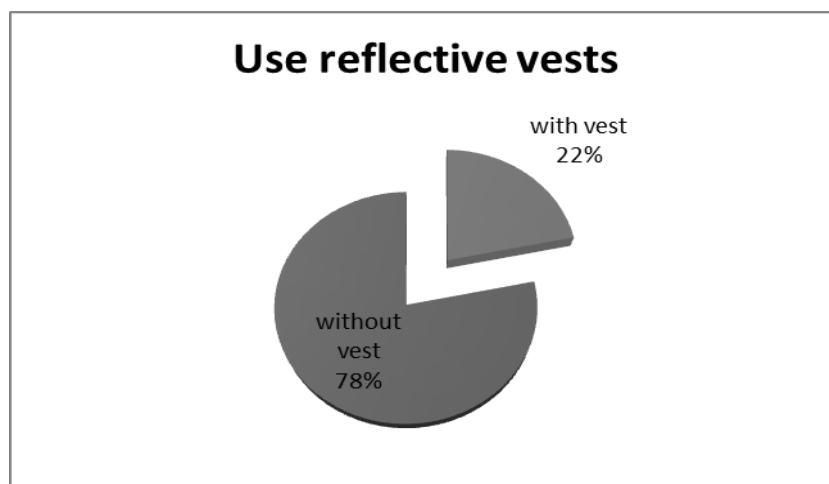
Figure 3: Dividing traffic accident participants present on the spot according to the use of reflective vests.

Figure 4 shows the age of the vehicles investigated within the analysis of traffic accidents. The largest group is represented by 11 years old vehicles, followed by vehicles of 6 and 10 years of age. Fifteen vehicles were older than 25 years. These were mainly public transport vehicles – trams.
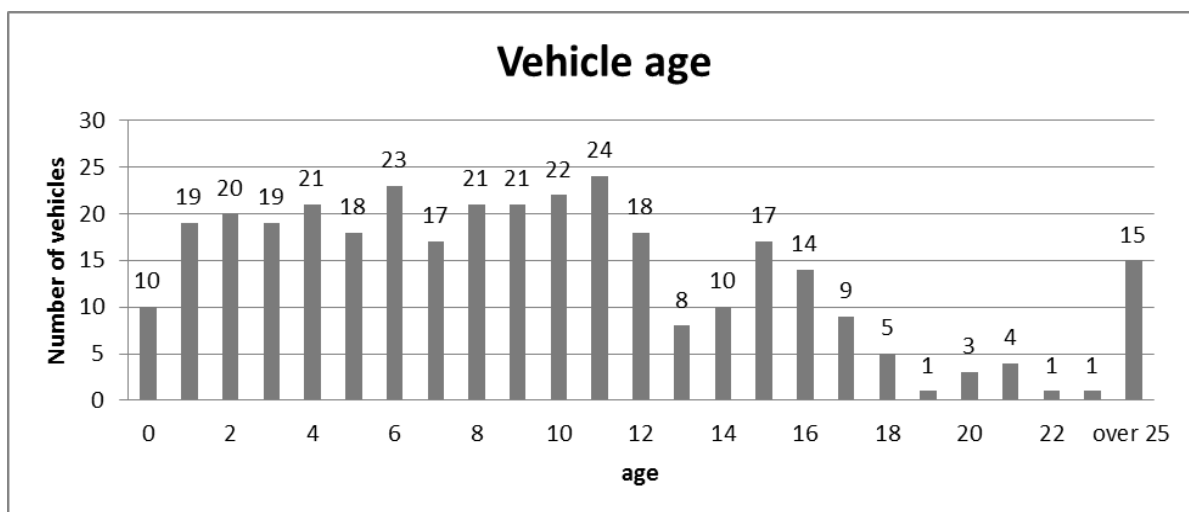
Figure 4: The age of vehicles investigated through an in-depth analysis of traffic accidents.

2.3 Psychological aspects of transport

From the perspective of the human factor the following findings have been achieved than can be seen from Figure 5. Due to the low number of data obtained so far they must be seen as descriptive statistical data. Inattention has so far been found to be the most significant psychological phenomena involved in the occurrence of traffic accidents – in almost half of all cases. The decline in attention was mainly caused by the other activities of the participants of accidents (smoking, eating, handling a mobile phone or other objects, interaction with passengers). The attention of participants was increasingly exerted especially in unclear traffic situations, in case of changes on accident spots or when driving a vehicle in an unfamiliar place. In 26 cases attention decreased during routine rides. In 22 cases, accidents took place with the active participation of persons younger than 25 years or older than 65 years. Persons in the period of young adulthood are less experienced in driving. It can be expected that people over 65 years show a decline in cognitive functions, which is associated with prolongation of reaction time, constriction of visual field and slowing of thought processes (Havlík, 2005). These specificities could occur also in people surveyed in the project HADN. Driving under the influence of intoxicating and addictive substances, mainly alcohol, was reported in 21 cases. Fatigue and sleep were detected in 12 cases, particularly at night and early morning hours, with the common denominator of the absence of passengers or vehicle crew. The average sleep time of these drivers before the accident was 6 hours. In 7 cases, the culprits of accidents reported their negative emotional mood state caused by a disturbance before the drive or during it. Six people were experiencing health problems that had direct influence on the accident. In addition to chronic and acute diseases, suicide was accomplished in one case. As concerns the specific group of road accidents represented by accidents with pedestrians, we have dealt with fifty-one cases. In addition to inattention on both sides, i.e. vehicles and pedestrians, this type of accident is influenced, especially under low visibility conditions, by dark coloured clothes and the absence of reflective elements.

Causes of Traffic Accidents in Terms of Human Factor
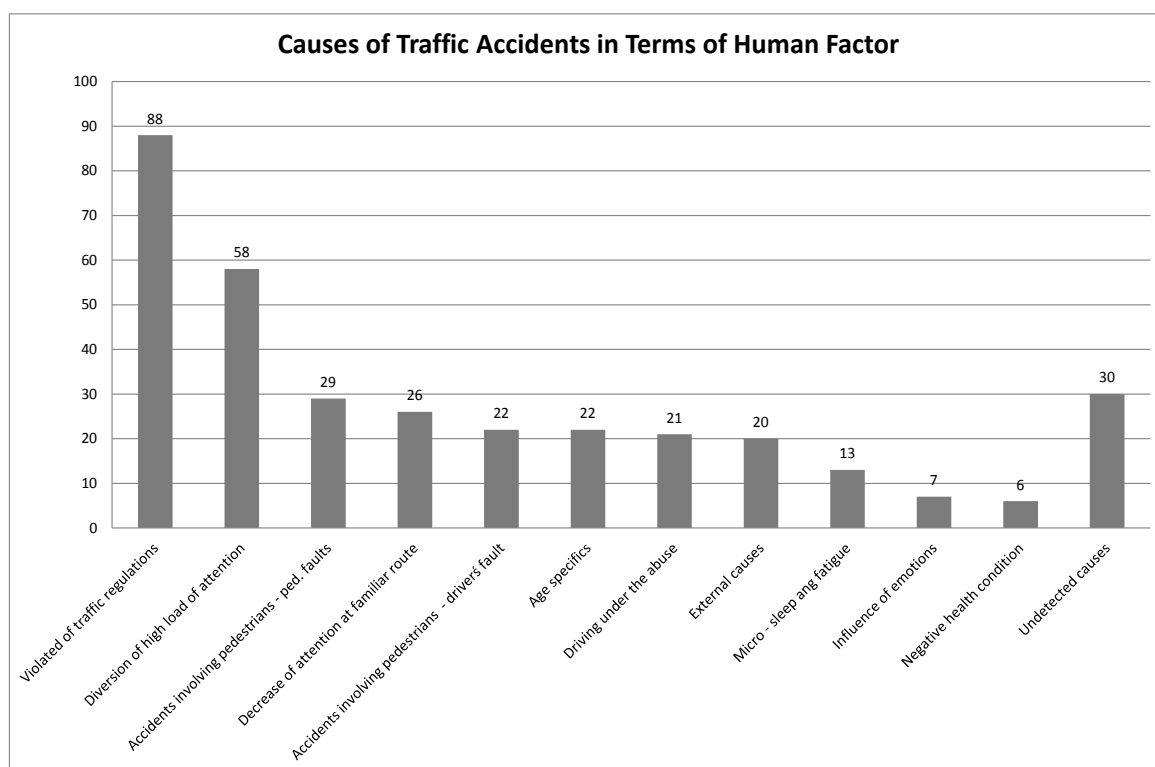
Figure 5: Causes of accidents from the perspective of the human factor.

2.4 Health consequences of traffic accidents

Among the injured in traffic accidents in the years 2011 and 2012, males dominated. The average age of patients at the time of hospitalization was 47 years. As in recent years, and also in the examined period, traffic accidents were a major cause of serious injuries, representing almost a half of all injuries. ISS (Injury Severity Score) is used for the evaluation of the severity of injuries, and its average distribution during the monitored period was as follows: among the injured, 83.1% of them attained ISS 16-30, 10.5% ISS 31-45 and 6.5% ISS ≥ 45. The average time patients spent in the emergency department with their primary examination and treatment was 105 minutes. Among the diagnoses of the patients, cranial traumas, injuries to the limbs and chest and spleen, and spinal injuries dominated. The average length of stay of patients was 18 days. Lethality of seriously injured patients in the year 2011 was 9.3%.

We have also examined the position of the injured persons in the vehicle or outside the vehicle at the time of the accident. Their number was determined according to the frequency of use of the vehicle and the total number of accidents. Most people were injured in cars, namely 53.2% of all injured persons. The injured drivers both of double-track vehicles and single-track vehicles formed the largest group. The results are shown in the following graph.
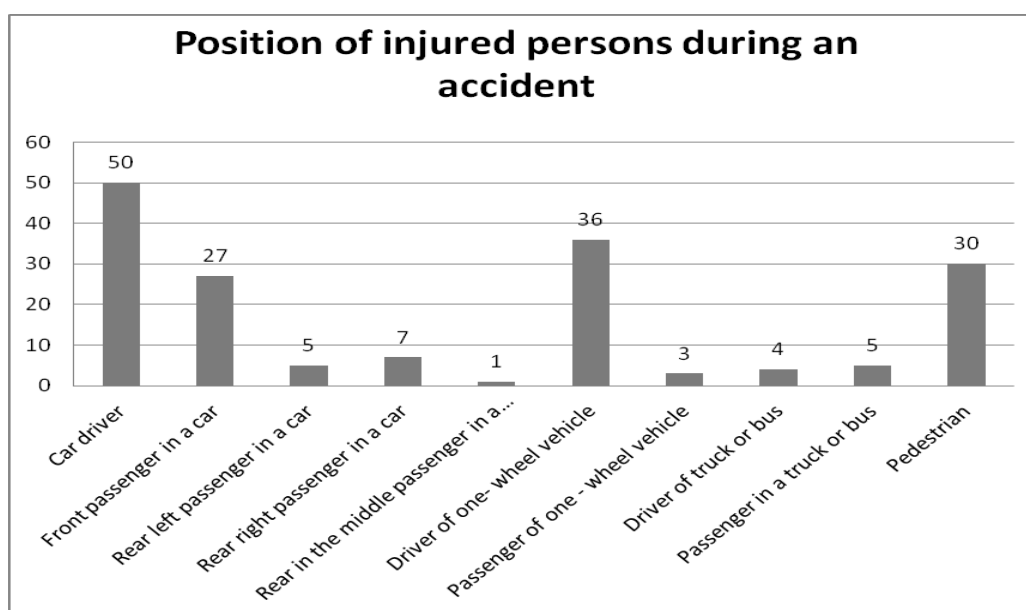
Figure 6: Position of injured participants of accidents.

3   CONCLUSION

The purpose of this article is to familiarize the professional community with the first experience obtained through an in-depth analysis of road traffic accidents, which represents one of the possibilities of a proactive approach to the solution of issues connected with traffic accidents. The analysis should be completely independent of the activities and achievements of organizations and institutions that are legally required to take part in solving and liquidation of traffic accidents (first aid services, investigating authorities of the Police of the CR, fire fighters). The aim of this in-depth analysis of traffic accidents is to obtain reliable and undistorted knowledge about the origin, cause and consequences of traffic accidents, with a special emphasis on finding the root causes and their formation (Andres, 2009; VALT, 2004).

The analysis was carried out comprehensively and with a consideration of transport infrastructure, vehicles involved and participants of accidents.

Although the duration of the project is proposed for 5 years, it is even now possible to trace some dependencies that affect both the emergence and cause of traffic accidents. The results of the current accident survey not only confirmed some "well-known findings" such as the fact that the non-use of helmets by cyclists is a risk, which reflects in a significant deterioration of the consequences of accidents, but it also detected many other factors connected with accidents, including the following points: Inadequate storage of luggage and, on numerous occasions, of dangerous loads in passenger cars, the lack of elimination of blind spots, particularly in older trucks and buses, and actual details about the (non-)activation of airbags in accidents, are also of interest.

It is also well known that the quality of road surfaces in our country is rather low. This fact is also reflected in accidents, where the unevenness of the road surface could lead to the loss of control of a vehicle and consequently to a skid. Road places with improper cross slopes, which contribute to a loss of vehicle stability were also detected (Andres, 2011).

Based on the investigated accidents, we can already see areas for recommending changes in legal and technical regulations in the transport infrastructure, as well as in vehicle engineering and the education of drivers. They are, however, not sufficiently supported so far by statistically significant results of the investigation of accidents and cannot therefore be administered yet, after less than 2 years of accident research.

In the area of transport infrastructure we can speak about confirmation of knowledge that is well-known among professionals, of what a safe traffic area should look like. Deficiencies lie rather in the implementation of that knowledge and assuring compliance with safety policies.

In the area of vehicle engineering, some suggestions can be made of making amendments to regulations on tyres, the elimination of blind spots in vehicles, airbags, etc. (Andres, 2011).

In the area of preparation of drivers for real traffic it seems that driving skills, especially of young motorcyclists, are insufficient, which deserves addressing. There are also deficiencies in the assessment of not only drivers' health, but also their psychological condition.

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Kinematic Analysis of Backward Falls of Pedestrian and Figurine in Relation to Head Injury

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ABSTRACT: Unexpected backward falls caused by a vehicle at a pedestrian crossing or at a supermarket parking space, by slipping on the road or by an external force acting against the chest followed by a backward fall is a very frequent phenomenon and can affect anyone. Especially the back and temporal part of the head come into contact with the ground during this uncontrolled motion and, depending on the impact strength and surface properties, it can cause serious injury. This study addresses a kinematic analysis of probands' backward fall (voluntary fall, chest impact fall, slipping fall) and correlates it with dummy-based data and subsequently with data from head-surface interaction. From the measured head acceleration we can therefore calculate head injury criteria related to individual kinematic analyses and values during the fall.

KEY WORDS: Backward fall, head injury, kinematic analysis, pedestrian, Qualisys.

1   INTRODUCTION

Falls can be grouped as standing falls, height falls and free falls. This study addresses standing falls, which are the most common, affecting a wide proportion of population. The standing falls is a threat especially to children, elderly people and alcohol-affected people. According to Deemer et al. (2005), falls are a major cause of morbidity and mortality in children, but are also reported falsely in child abuse. Therefore, it is of interest to understand those factors which may lead to a higher likelihood of injury in a feet-first freefall. Seniors are hospitalized twice as often as the general population for fall-related traumatic brain injury (TBI), while over half of all fall-related deaths in older adults are due to TBI. The risk for fall-related TBI increases substantially with age; persons over the age of 85 are hospitalized for fall-related TBI over twice as often as those aged 75–84, and over 6 times as often as those aged 65–74 (Manavais et al., 1991). In the conclusion of their findings, Kool et al. (2008) suggest that drinking in the previous 6 h has a strong and consistent relationship with the risk of unintentional falls.

Standing falls can be further grouped by direction into backward falls, forward falls, sideward falls and combined falls. Injuries due to backward falls, apart from sideways fall, are a major health problem, particularly among the aged populations (Majumder et al., 2009). A total of 327 injuries were identified in 259 patients. Back injury was the most common (19.3%) (Smith & Nelson, 1998).

The next category of falls are falls after car impact. The impact speed of the striking car is widely accepted as a prime factor for the injury risk in car-to-pedestrian collisions. However, people's opinions differ as to the exact relationship between car impact speed and pedestrian fatality risk (Rosén et al., 2011). According to Rosén and Sander (2009) a strong dependence on impact speed is present, with the risk at 50 km/h being more than twice as high as the risk at 40 km/h and more than five times higher than the risk at 30 km/h. A lot of studies are concentrated on the reconstruction and modeling of pedestrian crashes at speeds higher than 20 km/h, but 12.1% of pedestrian injuries are caused by car speeds less than 10 km/h (Peng et al., 2012).

Slip and fall accidents have been recognized as a major threat to the safety of individuals, not only in industry, but also in daily life. According to the 2002 annual report of science activity, "same level fall" and "fall to lower level" were cited as two of the five leading injury causes accounting for 5 or more days away from work (Yoon & Lockhart, 2006). Mechanical impact is the leading cause of injury, death and disability in people aged under 45 in the USA, Europe, and, increasingly so, in Third World countries (Jennett, 1996). In Ireland, falls are the single greatest cause of hospital admissions for both males and females across most age groups, with head injuries occurring in approximately a quarter of fall admissions.

After contact between the head and a surface multiple injuries take place. From an injury mechanics point of view both direct injury, caused by the impact of the head on a surface, and indirect injury are concerned. The brain can therefore be injured locally - acceleration-based injury (so called translation injury). The primary injury damage of the brain usually corresponds to a point of impact, but can also take place contra-laterally by means of par contre-coup mechanism. Apart from lacerations of head skin the bony part is injured too - neurocranium fractures can be divided into fissures, comminuted fractures and traumatic brain injuries (TBI). Traumatic brain injury (TBI) is an important cause of injury-related hospitalization, disability, and death worldwide. It is of particular concern in the older population as functional recovery following an acute injury to the brain is often limited and can signal the end of independent living (Harvey & Close, 2012). The tolerance of the head to skull fractures is much easier to determine than its tolerance to intracranial injury. This is because of the definite relationship between force applied to the skull, and failure of cranial bone (Wright & Laing, 2012). In cases of severe head injury caused by a fall, coup contusions are either absent or very minor, in contrast to the presence of extensive contre-coup damage. In cases of a severe blow to the head, however, the reverse occurs, with contre-coup lesions a rarity and coup damage extensive (Yanagida et al., 1989). A study examining the pattern of brain injuries in falls resulting in death found skull fractures in 66% of cases. Acute subdural haematoma (ASDH) have been found in between 78% and 85% of fatal falls (Manavais et al., 1991).

There are three most common approaches to biomechanical analyses. Experiments involving human participants, dummies and computer simulations. Analyses of falls with human probands were carried out by Klenk et al. (2011) using two measurement protocols:

- Fall simulation was conducted onto protective layers of mattresses. Participants stood at a distance of 1.5 times the lengths of their foot apart from the mattresses with their back to the mattress and were instructed to "fall backwards as if you were a frail old person".
- The participants now were instructed not to fall onto the mattresses, if possible, when released from a backward lean. The instruction was "when we release you, try as hard as you can not to fall". The participants were held by a staff member in a backward lean of about 30–40°. The inclination of the body position was adjusted so a fall was unavoidable.

Computational simulation of real life head injury accidents has been used for various purposes. Some have compared AIS (abbreviated injury scale) scores for real life injuries to HIC scores or other indices of injury calculated from the reconstruction (O'Riordain et al., 2003). Evaluation of head impact dynamics is commonly accomplished using mechanical impact simulators. Such tests have found widespread use in the development of safety standards for devices including helmets, airbags, and playground surfaces (Wright & Laing, 2012).

An optimal approach turns out to be a combination of human probands and dummies. The conditions are set among the probands and measurements are done within the limits of human tolerance. Dummy measurements follow along with a validation of input data and a simulation of extreme values. This data can then be implemented in computer models.

2   MATERIAL AND METHODS

Klenk et al. (2011) used only the accelerometer data that had been affected by mattress impacts. In our study we used a Qualisys system for both probands and dummies for a comprehensive kinematic analysis of the fall onto a mattress, but for assessment of possible head injuries the Manikin dummy, equipped with a three-axis accelerometer in the head, was made to fall on a flat, dry surface of asphalt concrete (ACO 11). We speculate two possibilities for the cause of the fall. The first one, that cars on the pedestrian crossing are not able to stop and hit the pedestrian with a small velocity (up to 10 km/h) or a car pulls away just at the moment when pedestrian enters its path and hit him by a small velocity (up to 10 km/h) (Fig. 1). In the second case, the person falls after an impact to the chest (Fig. 2).

Figure 1: Backward fall of dummy after car impact.

Figure 2: Backward fall of dummy after chest impact.

As the methodics of probands falls we analyzed three ways of performance. Voluntary backward fall with an instruction to the proband to fall as erect as possible, an impact to the chest without the possibility to step backwards and finally a fall after pulling the legs forward (Fig 3).

Figure 3: Tree types of backward falls.

To assess the severity of head injury a maximum acceleration, 3-ms criterion a HIC_{36} were chosen as comparison criteria. 3-ms criterion is applicable not only to head injury. The limiting value is 80g and it means that an acceleration higher than 80g must not last over 3 ms. The formula for the HIC is defined as:

$$HIC = \left\{ (t_2 - t_1) \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right)^{2,5} \right\}_{max}$$

where t_1 and t_2 are, respectively, the start and finish times of the acceleration spike, and $a(t)$ is the resultant linear head acceleration with respect to time. HIC values were calculated over 36 ms (HIC_{36}) durations to allow comparisons of results with existing injury criteria. Head injury criterion HIC use is based on a proposal of the National Highway Traffic Safety Administration (NHTSA), 1972 (Marjoux et al., 2008). For the effects of direct impact

it has been demonstrated that HIC is an acceptable discriminator between severe and less severe injuries (Tarriere, 1981). It also correlates with the risk of fractures to the skull. According to EHK 94 regulation (First, 2008) the threshold is then determined as HIC = 1000 and acceleration that is greater than 80 g for no longer than 3 ms. HIC $_{36}$ was designed to protect the head against injuries, such as fractures of the skull with a longer exposure when there is no contact with the hard parts of the interior.

The dummy Manikin and three healthy men in their middle ages (age 29 ± 3 and 75 ± 7 kg) were tested. Multi-analyzer system Dewetron, 3 measuring channels and one output channel and accelerometer MMF KS 943 with a sampling frequency 5000 Hz were used for the measurement of acceleration. The motion capture system Qualisys with 6 cameras and 400 Hz sampling frequency was used for scenery capturing and Qualisys Track Manager was used for the motion capture process. The software package HyperWorks (application HyperView and HyperGraph) was used for evaluating the measured data. The data were filtered after import according to the EuroNCAP methodology (EuroNCAP, 2011).

3 RESULTS

The kinematic data were evaluated using a Qualysis Track Manager. Overall results can be seen in Table 1. The following parameters were analyzed: maximum speed (impact speed) on the top of the head - in Os Parietale area, on the front of the head on Os Frontale, on both shoulders, furthermore the travelling distance of the Os Parietale spot and, thereby, the overall change of head rotation against the shoulders. There were 8 measurements of the figure – three were after chest impact, five were after car impact. There were no statistical differences between chest and car impacts.

Table 1: Kinematic data.

		Max. velocity Head_ Parietale (mm/s)	Max. velocity Head_ Frontale (mm/s)	Max. velocity Shoulder_R (mm/s)	Max. velocity Shoulder_L (mm/s)	Distance Head Parietale (mm)	Difference of angle ($^{\circ}$)
Dummy	Mean	6018,6	5078,0	4755,0	5328,8	3003,0	5,1
	SD	140,0	175,5	99,8	91,3	117,9	0,1
Backward Fall	Mean	5 126,4	4 542,8	4 102,7	4 953,9	2 973,8	5,4
	SD	511,8	376,9	185,2	796,9	79,5	0,1
Backward Fall - chest force	Mean	5 716,5	4 965,3	4 812,9	5 071,9	3 072,8	5,7
	SD	290,3	202,6	512,7	630,1	48,7	0,3
Backward Fall - leg slide	Mean	5 289,1	4 596,9	4 748,2	4 753,8	2 708,4	18,7
	SD	481,5	336,8	551,5	484,2	63,2	1,8
T-Test Dummy vs. Backward Fall		0,10	0,07	0,08	0,61	0,85	0,05
T-Test Dummy vs. Backward Fall - chest force		0,17	0,10	0,88	0,57	0,61	0,05

The data from the accelerometers were imported into the software HyperGraph and filtered according to the method of Euro NCAP – filter CFC 1000. CFC 1000 is characterized by the following parameters: 3 dB limit frequency is 1650 Hz, stop damping is -40 dB, and sampling frequency is at least 10 kHz. The values of recorded accelerations in three axes were converted to the resultant acceleration of the head and the values of the HIC, 3ms criterion, and the maximum acceleration were computed. Results are shown in Table 2.

Table 2: Data from accelerometers.

	Max. a (g)	3-ms (g)	HIC 36	Max.velocity Head_Parietale (mm/s)	Max.velocity Head_Frontale (mm/s)
Dummy 1	120	45	794	6 427,1	6 130,0
Dummy 2	265	47	816	6 608,8	6 328,2
Dummy 3	225	56	911	6 734,2	6 259,7
Dummy 4	314	52	895	6 724,8	6 430,5
Dummy 5	198	51	843	6 879,0	6 425,0
Dummy 6	212	52	899	6 898,0	6 489,0
Dummy 7	112	41	698	6 245,0	5 890,0
Dummy 8	324	61	935	6 987,0	6 423,0

4   DISCUSSION

The gathered data were imported into the STATISTICA CZ 10 software, where they were statistically evaluated.

It can be stated that the dummy and the probands can be compared on a significance level 0.05. It is therefore possible to consider the dummy's behavior during the backward fall comparable to a human body. The closest to a dummy are the values of a fall after chest impact (see Fig. 4). This is because the dummy does not bend during the fall, while the conscious human reflexively bends the torso and dampens the fall, resp. decreases the impact speed.
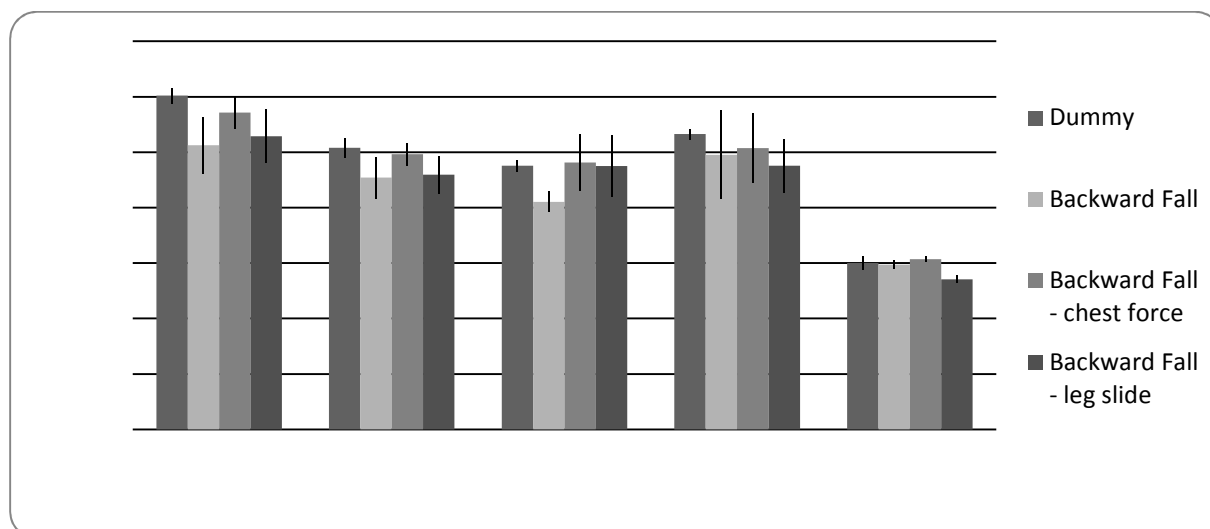
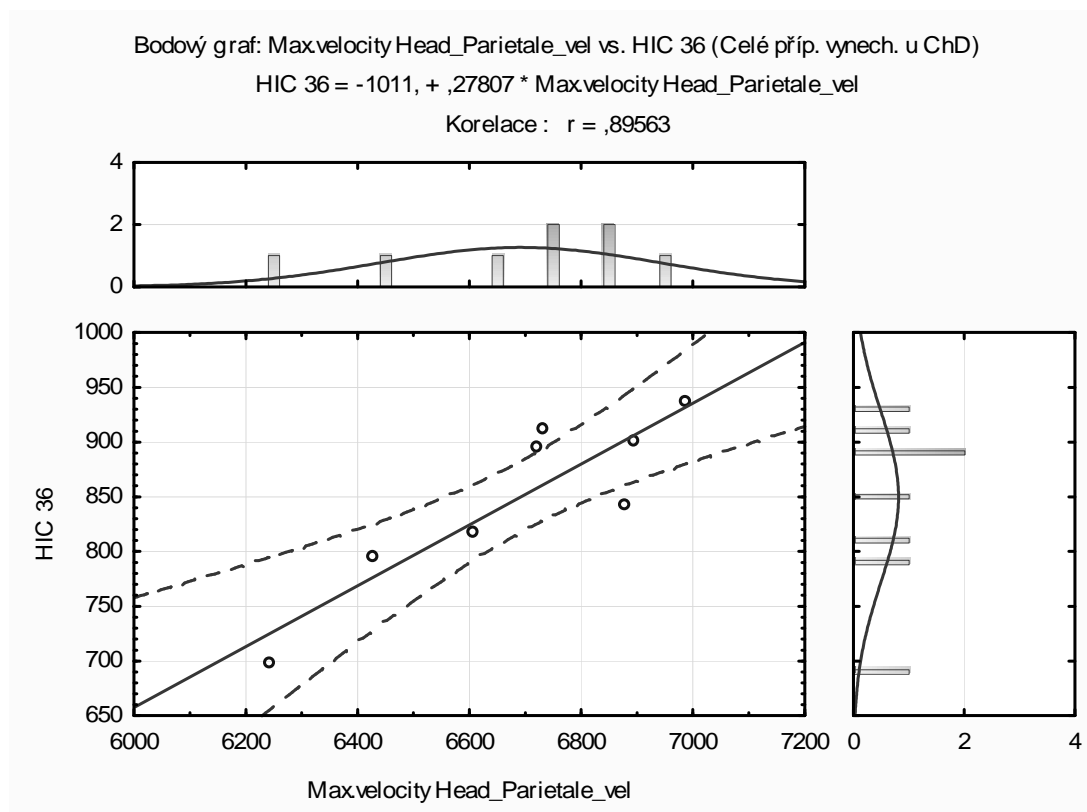**Figure 4: Kinematic data in Graph.**

During the voluntary backward fall there was a strong correlation found between top speeds of Os Frontale and Os Parietale (r=.998), which is understandable. What is interesting is no proven correlation between the rest of the body segments. Only the distance travelled was close to the top speed on the Os Parietale (r=.0,942).

If we look at the correlations of individual head injury criteria with impact speeds (Table 4), we can find interesting data for projecting a possible head injury from the fall type and the impact speed (Fig. 5).

Table 3: Injury correlations.

	Max. a	3-ms	HIC 36	Max.velocity Head_Parietale	Max.velocity Head_Frontale
Max. a	1,00	0,86	0,85	0,77	0,72
3-ms	0,86	1,00	0,94	0,88	0,72
HIC 36	0,85	0,94	1,00	0,90	0,85
Max.velocity Head_Parietale	0,77	0,88	0,90	1,00	0,92
Max.velocity Head_Frontale	0,72	0,72	0,85	0,92	1,00

Bodový graf: Max.velocity Head_Parietale_vel vs. HIC 36 (Celé příp. vynech. u ChD)

HIC 36 = -1011, + ,27807 * Max.velocity Head_Parietale_vel

Korelace : r = ,89563

Figure 5: Max. velocity and HIC 36 correlation.

Impact surface significantly affected injuries. Since harder surfaces deform less during an impact they result in a more rapid deceleration when compared with a softer surface. Consequently, the fall energy must be absorbed over a shorter period of time for harder surfaces than softer surfaces. This allows the body less time to distribute and dissipate the energy, potentially resulting in a higher injury risk. The friction of the impact surface may also affect injury risk. Surface friction is typically reported using the coefficient of friction (COF). The higher the COF, the greater the surface friction. Whenever shear forces exceed the COF of the shoe-floor interface, a slip can result (Deemer et al., 2005).

Results of studies about pedestrian fatality risk as a function of car impact speed (Anderson et al., 1997; Tefft, 2012) say that there is a very small probability of severe injuries or death. But reality could be different. When a car hits a pedestrian at a minimal speed and the pedestrian does not expect the impact, he then falls with uncontrolled motion and, depending on the impact strength and surface properties, this can cause serious injury. This is the reason why we must analyze isolated falls as well.

If we look at a reconstruction of real world head injury accidents resulting from falls using multibody dynamic (O'Riordain et al., 2003), there is an input speed unknown variable which can change results very dramatically. Klenk et al. (2011) presented the acceleration pattern of a real-world fall and simulated fall. But acceleration is only from the centre of gravity (of the whole body) and only during the fall phase, not during impact. The influence of headform orientation and flooring systems on impact dynamics during simulated fall-related head impacts was measured by Wright and Laing (2012). He used a mechanical head impact simulator at 1.5, 2.5, and 3.5 m/s impact velocities, which are too low according to our study. Our results, especially for head impact velocity, could be very useful for simulations in the future.

ACKNOWLEDGEMENTS

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Lowering the Impact of Aviation on Global Earth´s Radiation Balance

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ABSTRACT: This paper discusses the possible involvement of contrail radiation in the scheme of the EU ETS to decrease aviation impact on the global Earth´s radiation balance. The main goal of this involvement should be the lowering of aviation radiation balance without any further costs for aviation operators. This fact should encourage further research of this possibility due to this being a "win - win" scenario. Lowering the aviation impact on the radiation balance with lower costs than only the charges dependent on the EU ETS scheme, which nowadays covers only emissions of CO_2.

KEY WORDS: aviation, radiative balance, contrails, EU ETS.

1   AVIATION AND CLIMATE CHANGES

The goals of the Kyoto protocol were taken on by the EU in 1998. Although the Kyoto protocol tackles only the emissions of greenhouse gases, it is important to stress that lowering the emissions of greenhouse gases is not the main purpose of the Kyoto Protocol. Lowering emissions of greenhouse gases is only a tool with which to achieve the real goal. The real goal should be the minimization of the impact of human activities on the radiative balance of the Earth´s atmosphere.

Today´s level of scientific understanding of aviation's impact on global atmosphere is very low. We are able to estimate the impact of greenhouse gas emission from engines quite well. However, the area which is still necessary to explore is the problem of induced cloudiness and contrails.

Aviation has a negative impact on global Earth´s radiation balance. One part of this negative impact is the production of greenhouse gases, mainly CO_2. This part of negative impact is directly dependant on fuel consumption, and, as such, is only very slightly susceptible. However, there is second component of the whole aviation on global Earth´s radiation balance impact. Radiative forcing is a commonly used indicator of how much an activity influences the total energy balance of the Earth. RF is an indicator which shows to what extent each component of aviation emission influences the global warming. The relation between radiative forcing and the equilibrium Earth surface temperature change (ΔTs) can be simply represented by the equation:

$$\Delta Ts = \lambda \, RF$$

where λ represents the climate sensitivity parameter ($K/(W/m^2)$).

The addition, on which we will focus in this paper, are contrails and induced cloudiness. The danger of contrails and induced cloudiness work on the assumption that the flight of jets or turbofan aircraft may sometimes produce contrails. Contrails can be the building blocks of more massive cloudiness which may occur on some occasions (Schumann, 2005; Mannstein & Schumann, 2005). Cloud coverage works very similarly as greenhouse gases do. Clouds let through radiation from the upper atmosphere and from the Sun, but reflect radiation which is coming from Earth. As such it is conserving energy in the Earth´s atmosphere, and, through this, its increasing the volume of energy on one side of the global Earth´s radiation balance equation (Haywood et al., 2009). This is the reason why aviation's contribution to the global Earth´s radiation misbalance is more important than any other emission which would be of an equal amount. Aviation contributes to atmosphere energy twice; once, as every fossil burning engine, and, second, from creating contrails and clouds which have a surplus negative effect. Estimates of the negative impacts of aviation are burdened with a high level of scientific uncertainty and they vary between 15% and 350% of negative addition of aviation greenhouse gases production. For more details see Blockley (2010), Chapter 304.

2   AVOIDING CONTRAILS AND INDUCED CLOUDINESS

The avoidance of negative effects from contrails and induced cloudiness is quite simple; we have to avoid producing contrails. Avoiding contrail production is possible via different methods, but one of the most practical ones is by changing the flight levels. The change of flight level can be either through descending or climbing. However, due to the fact that modern jet aircrafts are flying as high as possible, for the reason of better engine effectiveness at higher flight levels, the only applicable change is descending. It is here that the first issue is to be solved, as flight at lower flight levels means engine operation would be less effective and would consume surplus fuel and produce surplus emissions. These surplus emissions of greenhouse gases would have an additional negative impact on the global Earth´s radiation balance. Therefore should there be any decision-making mechanism, a formula or table to decide on a change of flight level would be advantageous. This is the key decision, and the goal of our future research.

The problem connected with this key decision is the level of scientific understanding of all incorporated aspects. The LOSU of aspects is variable between full understanding of specific incorporated problems and a low level of LOSU of others. We are able very precisely to estimate the amount of emissions which would be produced during flight. We are also able to summarize with a rule for which situations contrails will occur. The precise probability of developing cloudiness from contrails is a less studied area. The lowest LOSU is connected with the direct estimation of cloudiness and contrails' impact on global Earth´s radiation balance. Another unknown aspect is the price of EU ETS allowances, which may change rapidly in future. The EU ETS connection with this issue will be discussed later.

3   AVOIDING CONTRAILS LEADS TO SURPLUS FUEL CONSUMPTION

The first issue is the estimation of the negative impact of induced cloudiness and contrails in comparison with the negative impact of changed flight level/fuel consumption. The estimate of the negative impact of induced cloudiness and contrails is burdened with a high level of uncertainty. Lowering this level of uncertainty will be long term issue,

which will not disappear in next few years. We think that a responsible approach should not have to waitfor the results of long term research on the impact of cloudiness on the Earth´s atmosphere, but instead to find a solution from a different angle. We would like to define how important the negative impact of cloudiness and contrails would have to be in order to justify the needs of level changing during flight planning. This means we would like to start detail research of this issue now and when there will be more precise results on the impact of cloudiness on atmosphere balance we will be able within a short time to decide which flights should be implemented in some kind of contrails avoiding procedures, and which flights need not.

Despite the fact that we theoretically know in which atmosphere the contrails will occur we cannot forecast them as today's weather forecasting is not aimed at forecasting humidity and filled up of air in flight levels where most of airliners fly, which is necessary for contrail prediction. Additionally, prediction models of how contrails will form in cloudiness is today again fraught with many uncertainties. However, prediction models of contrails are dependent on atmospheric pressure, temperature, and humidity and have very good tools in mode S of secondary radar. Especially information from BDS registers 44 Routine meteorological data, and 45 hazardous meteorological data are very important. Data from these registers shall be sufficient for models similar to "Contrail Cirrus Prediction Tool" (CoCiP), or MM5T (Schumann, 2012; Steufer et al., 2005) which shall be sufficient for a new kind of forecast for aviation. Unfortunately, information involved in these clusters are nowadays transmitted by only a negligible percentage of aircraft and so it is insufficient for forecasting. A change will only come about by equipping more aircraft with humidity measuring equipment.

4   LEGISLATIVE FRAME

An important step in decreasing the impact of aviation on the atmosphere radiative balance is to prepare legislation on how a voluntary change of flight level would be made in practice, because in controlled air space airplanes cannot change their level however they like. There are two main problems connected with this level change to avoid contrail production.

The first are regulations and procedures of air traffic management which shall enable the changing of flight levels depending on contrail forecast. This procedure preparation should work on a basis which is adopted for avoiding thunderstorms and weather hazards during flight.

The second area is developing such a program which would motivate aviation operators to change their flight level. The motivation program which may be used for this purpose has been in operation in aviation since 2012. The program is called the EU ETS.

The EU ETS, European trading scheme for trading allowances to emit CO_2. From the year 2012 aviation has been implemented in this scheme. The EU ETS is a trading scheme based on a cap and trade basis. It is one of the policies introduced across the European Union (EU) to help it meet its greenhouse gas emissions reduction target under the Kyoto Protocol. Very simply put, the EU ETS allows the producer to emit only as much greenhouse gas as the producer has allowances for. Allowances are partially distributed free of charge according to emission background and are partially accessible on the free market where they can be sold and purchased by anyone.

This market instrument allows the contributors who spare some of their allowances to sell them for profit. Theoretically, this system should be used for every greenhouse gas.

In practice, only the emissions of CO_2 are taken into account. More about the EU ETS can be found in EU Directive 87/2003.

As mentioned before the EU ETS is obligatory and aviation operators are now getting used to working within this legislative framework. Although today's contrails production is not part of the EU ETS, this system could very easily be changed to fulfill this new role. The EU ETS has been working since 2005 and covers more than 10 000 industry installations. Starting from 1[st]January 2012 all aircraft operators attaining the limits of transport performance and performing flights arriving at or departing from any airport situated in the territory of the European Union or an EEA-EFTA1 country (Iceland, Liechtenstein and Norway) will be included in the EU Emissions Trading System. Aviation is included in the system by EU Directive 101/2008. This is going to be implemented in several gradual steps to help businesses to become established within the EU ETS. For the first year there will be allowances for 97% of historical aviation emissions. Historical emissions represent the average of the estimated annual emissions for the years 2004, 2005, and 2006. For each of the next years there will be allowances only for 95% of historical emissions. But only 15% of all allowances are auctioned. The rest, more than 80 %, is allocated freely to airlines according their historical emissions. The number of needed allowances is counted according to the equation (2), where fuel consumption is in tonnes, and the emission factor should be taken from 2006 IPCC Inventory Guidelines or subsequent updates of these Guidelines, for each type of fuel; for the most commonly used aviation fuel the emission factor 3.15 is used.

Fuel consumption × emission factor (2)

Emission factor 3.15 covers only the production of carbon dioxide, for the inclusion of emissions of other greenhouse gases which are produced during the combustion of aviation fuel we would have to raise the emission factor. The inclusion of aviation in the EU ETS gives rise to a few issues which have been obvious even before aviation really starts to work within the EU ETS. A crucial problem is that the EU ETS takes into account only the production of CO_2 and its RF addition. The EU ETS doesn´t take into account any other sources of RF from aviation, even though the RF from CO_2 emissions may only be 1/3 of all RF. Aviation companies are forced to obtain allowances to emit CO_2. There is a big opportunity for the implementation of a new development scheme for decreasing the impact of aviation on global Earth´s radiation balance.

Nevertheless, the EU ETS is appropriate and suitable for incorporating contrail avoidance. A possible way may be a change in equation (2). Depending on the situation there should be another constituent which would decrease emission factors dependent on how much the aircraft would have to fly at a lower flight level, compared to the flight level stated in the flight plan, to avoid airspace where there is a risk of contrails. The value this constituent shall be the subject of expert debate.

The EU ETS is the only program suitable for use with contrails airspace avoidance. Without any stimulus there is no chance that aviation companies would voluntarily change their flight levels only to avoid contrails. It is absolutely essential to prepare changes in the EU ETS to be ready to involve this scheme as soon as the impact of induced cloudiness and controls will be proved.
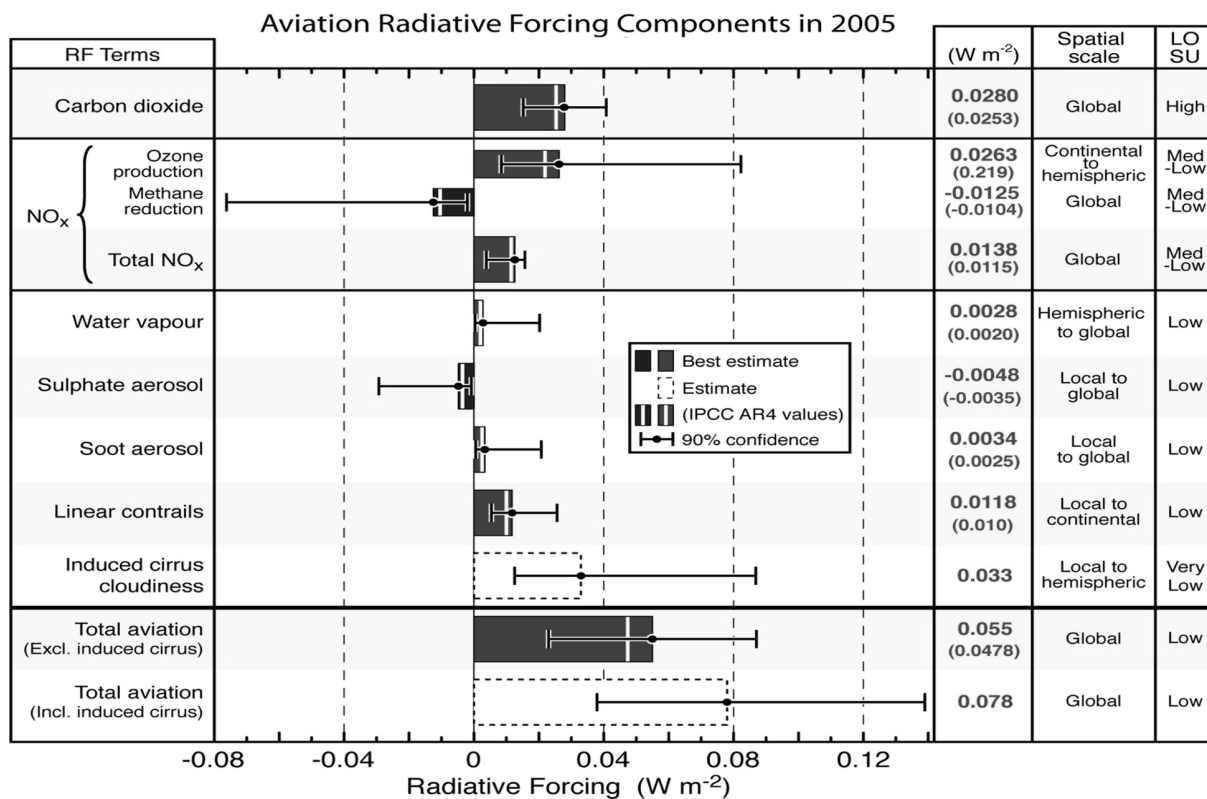
Figure 1: Aviation Radiative Forcing estimates (Lee et al., 2010).

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Monitoring of the Damage Evolution in Reinforced Concrete Girder by Means of Nonlinear Elastic Wave Spectroscopy

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ABSTRACT: Nonlinear elastic wave spectroscopy (NEWS) is a package of advanced methods of ultrasonic spectroscopy which make it possible to capture with a high level of sensitivity the formation and development of structure damage even in materially, as well as geometrically, highly complicated specimens. Concrete and reinforced concrete are classical examples of materials to which the application of conventional ultrasonic methods is very complicated. This is why they make an ideal medium for the application of non-linear ultrasonic methods. The object of this experimental study consists of the application of nonlinear ultrasonic testing to assess the structural integrity of a reinforced concrete girder which was extracted from a bridge structure during the reconstruction of the bridge. The girder was tested in three stages: prior to loading, in the course of loading, and when the loading had been completed, with the aim of identifying the parameters correlating with the girder structure integrity damage. Two nonlinear ultrasonic spectroscopy methods were applied, namely, employing one and two harmonic signals. Frequency spectra of the transmission responses were analyzed. Defects occurring in the structure under investigation give rise to heavy nonlinear effects accompanying the propagation of elastic waves, which, in the single-signal excitement case took effect in emphasizing the odd-numbered harmonic components among the newly generated frequencies. Therefore, the amplitudes of the latter were evaluated. In the other case, two ultrasonic signals of close frequencies were applied and their difference components were evaluated. Structure integrity damage was identified in the girder by means of the frequency spectrum analysis.

KEY WORDS: Nonlinear ultrasonic spectroscopy, harmonic analysis, reinforced concrete testing.

1   INTRODUCTION

Most of today's non-destructive ultrasonic testing methods are based on the application of linear ultrasound excitation and on the assumption of a linear elastic continuum. These conventional ultrasonic testing methods provide an efficient and reliable tool for a variety of applications. However, there are applications where these methods encounter heavy limitations and become impracticable, for example in the cases

of complicated material composition or defects which are undetectable by current ultrasound wavelength signals. This is why nonlinear ultrasonic testing methods started to be developed in the last two decades, spreading into the areas which are inaccessible for classical methods (Shuia et al., 2008; Aleshin & Van Den Abeele, 2007). The principle of these methods consists of anharmonic oscillations of atoms at the defect or crack faces. The reason is that the oscillating atom energy versus displacement plot does not exactly follow the quadratic law (Claytor et al., 2009). Consequently, odd-numbered harmonics of the fundamental frequency are prevailingly generated. This phenomenon provides us with an efficient tool to discriminate between damaged and undamaged specimens (Haupert et al., 2011).

The ultrasonic defectoscopy is therefore a powerful tool to study defects and cracks in solids. In some cases, provided the method has been calibrated, the extent and type of the damage can be determined. As most of the nonlinear effects are amplitude-dependent, taking effect only after sufficiently high-amplitude exciting signals are applied, it is evident that the exciting signal amplitude plays a crucial role in the nonlinear ultrasonic testing methods. The threshold exciting amplitude, which is capable of bringing about a recordable nonlinear response, depends, above all, on the type of the material under test, the damage nature and the excitement type.

Thanks to its composition, concrete is a heavily hysteretic material, which shows a certain degree of nonlinearity even under no-load conditions (Nazarov et al., 2003; Bentahar et al., 2006; Antonaci et al., 2010). If there are defect regions in the concrete specimen under test, these regions will make additional sources of nonlinearity which exceed, by several orders of magnitude, the specimen's own nonlinearity. Under ultrasonic tests, the nonlinear behaviour of the material takes effect in a deformation of the ultrasonic waves propagating through the specimen, thus resulting in nonlinear effects in the frequency spectra of the specimen under investigation. The nonlinear effects consist of an amplitude-dependent occurrence of higher harmonic components (f_2, f_3,...) when a single-frequency excitation with a frequency f_1 is used, and a marked growth of odd-numbered harmonics and the formation of side bands ($f_1 \pm f_2$, $f_1 \pm 2f_2$,...) when simultaneous excitation by two frequencies f_1 and f_2 is used (Hajek et al., 2003). Another option of time-dependent excitation is the application of an impulse signal. In this case, the application of a mechanical impulse signal may result in a substantially higher output response. Besides the generation of new harmonic components, the defect induced nonlinearity also results in a change of the specimen transfer characteristics and both of these phenomena can be analysed at a time.

Thanks to its robustness and relative simplicity, the nonlinear ultrasonic spectroscopy, NEWS, as a method based on evaluating the higher harmonic component amplitude ratios, has proved to be suitable for concrete and reinforced concrete testing. As all of the phenomena employed in the NEWS methods are amplitude dependent, we focused our attention on amplitude characteristics of higher harmonics (f_2, f_3) and their ratio, f_n / f_1. When applying the impulse excitation, we focused on the frequency analysis of the response versus the exciting impulse intensity function.

2   TESTED OBJECT AND EXPERIMENTAL ARRANGEMENT

The object of our experiment was a reinforced concrete girder which had been extracted from a bridge structure in the course of its reconstruction. The girder was of KA type, its dimensions being 0.5 m x 0.6 m x 11.5 m. It was brought to CDV laboratories at Tisnov to be placed on an elastic cushion, which in turn was seated on two concrete guard rails.

A special frame had been assembled for the purpose of loading. For safety reasons, it was designed so as to allow the loading process to take place beneath the girder itself. The girder was measured in three stages: prior to loading, in the course of loading and when the loading had been completed. The objective of these measurements consisted of monitoring the structure integrity damage. The r.h.s. part of the specimen was measured at 4 points, henceforth denoted as measurement positions.

Figure 1: The girder with the loading frame (left), dynamic girder loading (right).

3   MEASUREMENT RESULTS

Measurement results obtained from two measurement positions differing from each other in the steel armature pattern are presented here. First, we used the single exciting signal method which is described in detail, together with the measuring apparatus, in (Korenska & Manychova, 2010; Manychova, 2009; Korenska et al., 2008). A harmonic exciting signal of a frequency of f = 29 kHz was applied, transmission responses of the girder, as picked up by the sensor, were analyzed (Zumpano & Meo, 2008). The orientation of the exciter E and the sensor S is diagrammatically shown in Fig. 2.
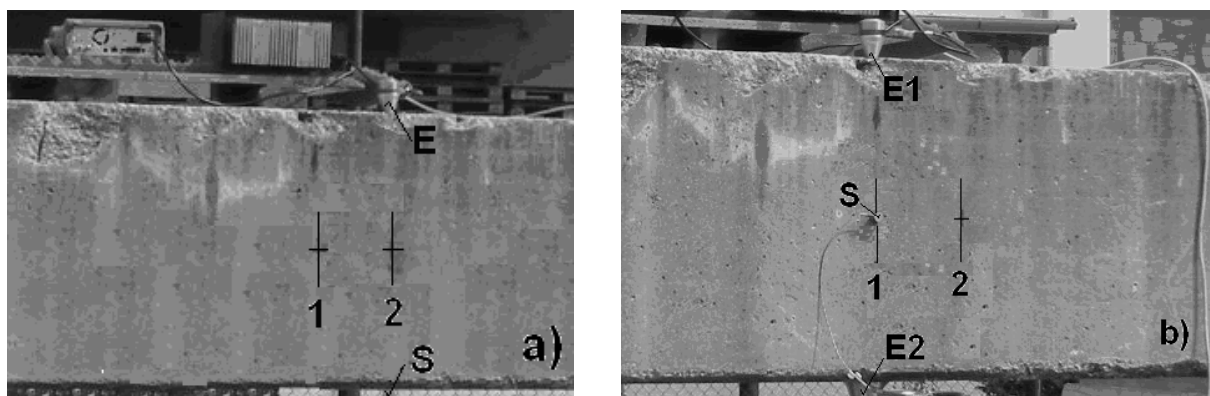
Figure 2: Schematic illustration of the measurement positions:
a) measurement on position No. 2 (single exciting signal method),
**b) measurement on position No. 1 (double exciting signal method).**

During the measurement on position No. 1 (Fig. 2a) the exciter E and sensor S were placed above and under the measurement position, similarly to the situation with the measurement on position No. 2. During the measurement on position No. 2 (Fig. 2b) the exciters E1, E2 and sensor S were placed similarly to the situation with the measurement on position No. 1.

The measurements resulted in the transmission response frequency spectra. By way of illustration, Fig. 3 shows this frequency spectrum for No. 2 measurement position. The diagram illustrates an abrupt fall of amplitudes of even-numbered harmonic frequencies (f_2 and f_4), the amplitude of the fifth harmonic (f_5) exceeding that of the amplitude of the fourth harmonic (f_4), providing us with information on the occurrence of structure-defect-induced nonlinear effects. This is in accordance with cited foreign sources and our knowledge from results of extensive laboratory measurements.
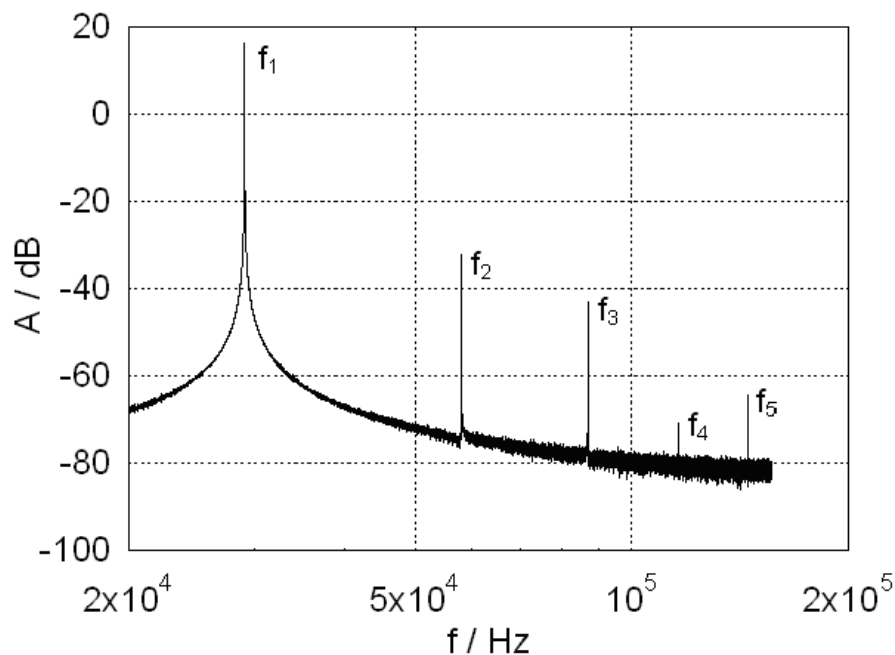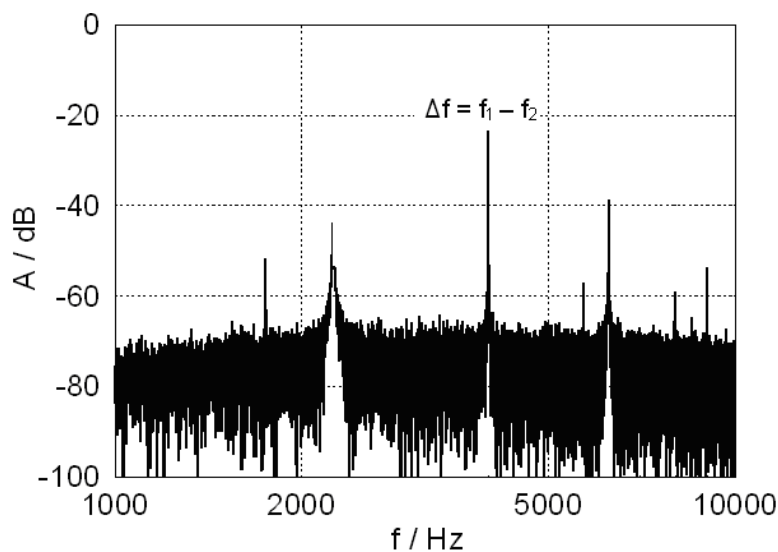

Figure 3: Frequency spectrum for No. 2 measurement position and excitation signal frequencies 29 kHz.

Fig. 4 shows the values of higher harmonic frequencies db-amplitudes relative to the 1st harmonic (exciting frequency f_1) db-amplitude for No. 1 and 2 measuring positions. From the comparison of the curves we may infer that better structure quality corresponds to No. 1 measuring position. In this case, the relative amplitudes are decreasing uniformly with the harmonic frequency order number, with no nonlinear effects.
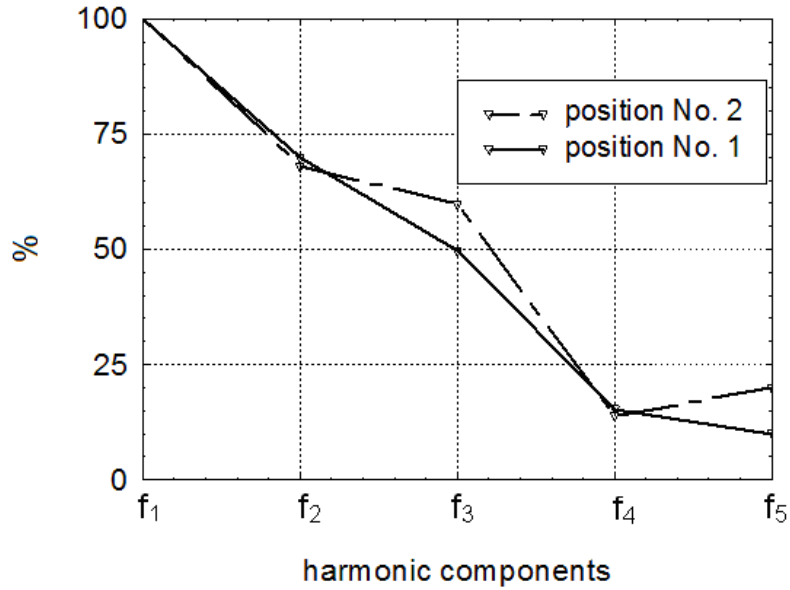
Figure 4: Higher harmonic frequency amplitudes expressed as a percentage of the first harmonic amplitude.

Furthermore, the correlation coefficient square, r^2, was evaluated. This quantity serves to evaluate the linearity of the harmonic frequency amplitude decrease curve. The correlation coefficient square nears unity if the amplitude vs. frequency plot decrease shows no nonlinear effects, which is the case of an intact structure. The more the amplitude decrease plot shape differs from the straight line, the more r^2 tends to zero. The correlation coefficient squared shows a decrease in value ($r^2 = 0.9216$) for the second position compared to the first position ($r^2 = 0.9728$). This parameter also exhibits higher-quality structure in the case of position No. 1. Secondly, two harmonic ultrasonic signals whose frequencies neared each other ($f_1 = 29$ kHz and $f_2 = 25$ kHz), were applied, see Fig. 2 b). In the frequency spectrum, which corresponds to No. 2 position, Fig. 5, there occurs, beside some parasitic components, the excitation frequency difference component, $\Delta f = 4$ kHz. This difference component did not occur in the case of the measurement position No. 1.


Figure 5: Frequency spectrum for No. 2 position and excitation signal frequencies 29 and 25 kHz.

After the no-load girder measurement had been completed, the girder was loaded dynamically by means of steel plates of a mass of 320 kg each. By means of a UNC loader, three plates were made to fall down in succession from a height of 15 cm on a wooden pad, see Fig. 1 (on the right). The frame loaded the girder over the total of its length by means of two I-shaped joists, placed at a distance of 17 cm from each other on a NAIP cardboard of a thickness of 1.5 cm. The response to the mechanical impulse was simultaneously recorded by two sensors placed on both measurement positions (see Fig. 2b).

Figure 6 shows the frequency spectra of the response to the mechanical impulses resulting from the impacts of two and three plates as recorded by the sensors at No. 1 and No. 2 measurement positions. In order to make the comparison more apposite, the amplitudes are not in dB units. The comparison of the frequency spectra of Fig. 6 a) – No. 1 measurement position – gives evidence of a shift of the dominant frequency from 2.5 kHz (two plate impact) to 3.5 kHz in the case of the three plate impact. In the latter case, a much larger spread of the frequency spectrum values is seen when compared with the two-plate-impact.

Fig. 6 b) shows similar results for No. 2 measurement position. In this case again the high intensity of the exciting signal brought about an upward shift of the dominant frequency (from 2.5 kHz to 4.7 kHz), the value spread of the frequency spectrum having become larger.

The loading process having been completed, the two harmonic exciting signals methods were applied. The results of the single harmonic ultrasonic signal excitation method application are shown in Fig. 7.
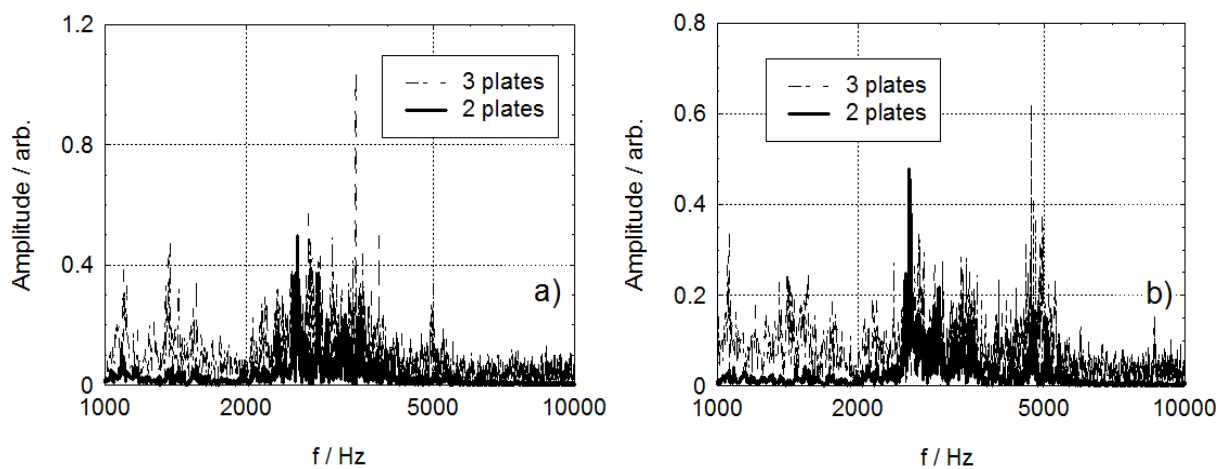

**Figure 6: Frequency spectra of the response to the mechanical impulses:
a) No. 1 measurement position, b) No. 2 measurement position.**
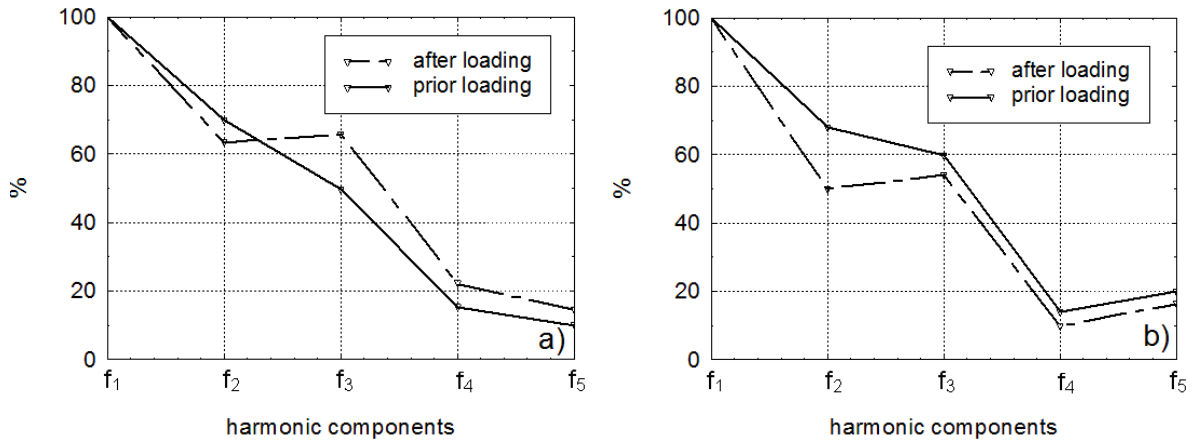
**Figure 7: Higher harmonic frequency amplitudes expressed as a percentage
of the first harmonic amplitude:
a) measurement position No. 1, b) position No. 2.**

Relative values of the higher harmonics obtained from No. 1 position prior to and after the girder loading are shown in Fig. 7 a). Nonlinear effects are evident to occur in the post-loading curve. The amplitude of the third harmonic (frequency f_3) exceeds that of the second one (frequency f_2). Fig. 7 b) shows similar results for No. 2 measurement position. Both curves exhibit nonlinear effects. Similarly, the correlation coefficient squared shows a decrease in values compared to the pre-loading results, see Fig. 8.
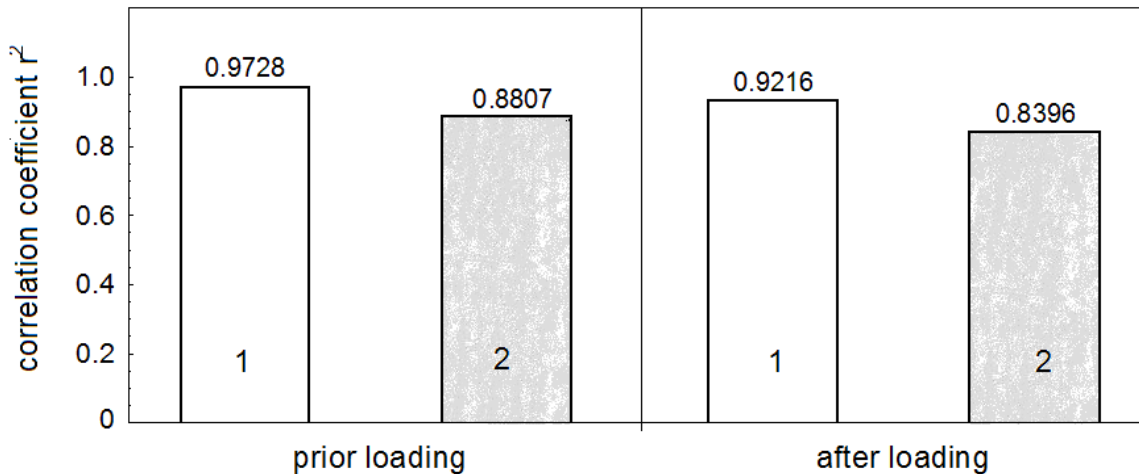
**Figure 8: Variation of the correlation coefficient square for the first three harmonic
frequency amplitudes.**

Fig. 8 compares graphically the correlation coefficient squared values for both measurement positions (1, 2).

When applying the double harmonic exciting signal method, the measurement results are analogous. In both frequency spectra (measurement position No. 1 and 2), difference components $\Delta f = 4$ kHz and their second harmonic component of a frequency of 8 kHz can be identified, among more numerous parasitic components, see Fig. 9.
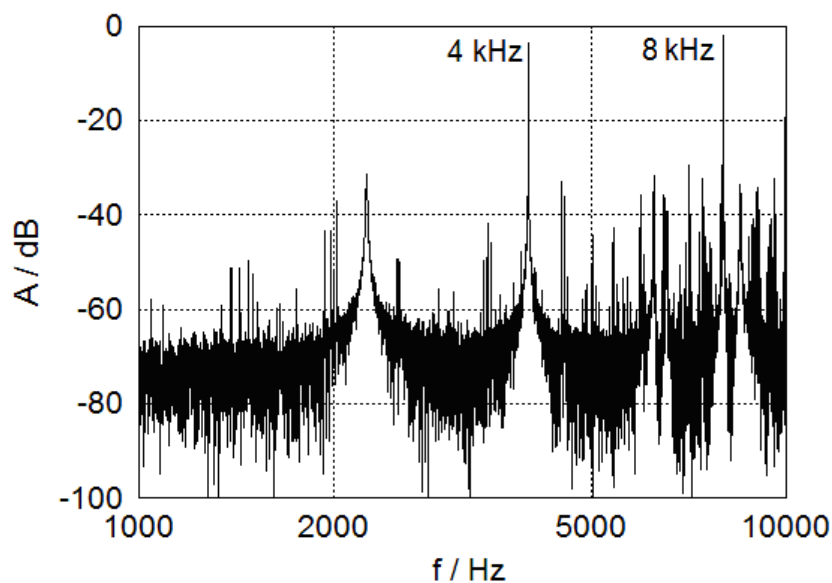
Figure 9: Frequency spectrum for No. 2 position and excitation signal frequencies 29 and 25 kHz, after loading.

4　CONCLUSION

The objective of these experiments was to verify the applicability of the nonlinear ultrasonic spectroscopy to monitoring the damage development in bulkier building elements in situ. A reinforced concrete KA girder, which had been extracted from the bridge structure in the course of the bridge reconstruction, was tested.
Measurement results are presented for two measurement positions which differ from each other in the steel armature pattern. Two nonlinear ultrasonic spectroscopy methods were applied to test the structure quality, namely, the single and the double harmonic ultrasonic signal methods. The measurement was carried out prior to the girder loading, the response was picked up during the girder dynamic loading and finally, the measurement was carried out after the girder loading was completed.

When analyzing the measurement results obtained from the single exciting harmonic ultrasonic signal method, we found that the damaged structure caused the amplitudes of odd-numbered harmonic components to increase in comparison with even harmonic components and the values of the square of the correlation coefficient to decrease. The occurrence of a new component whose frequency equalled the difference of the exciting frequencies in the frequency spectra obtained when using two exciting signals served as a nonlinearity and structure damage indicator. The above nonlinear effects were observed while measuring at the second measurement position prior to loading and at the both measurement positions after the load application. Steel plates falling down onto the girder were employed to implement dynamic loading of the girder. The girder response was picked up simultaneously at both measurement positions. The response frequency analysis as recorded for two different excitation intensities gave evidence of frequency changes at both measurement positions, which was due to the structure integrity defects.

The experiments were a continuation of the large laboratory measurements. The existing measuring set-up, which was assembled for laboratory testing, was supplemented and optimized; a high-frequency power amplifier was added for more extensive usage. The novelty of the experiments is the use of nonlinear ultrasonic spectroscopy methods to monitor structure integrity damage in bulkier structural elements in situ. Based on our

analyses, we may state that the application of the nonlinear ultrasonic spectroscopy methods appears to be a promising approach to assessing the reinforced concrete structure integrity. Continual or repeated monitoring in specified time intervals and subsequent analysis of selected parameter variations will provide information on structure changes taking place in the building object under investigation.

ACKNOWLEDGMENTS

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Groundwater Contamination Caused by Road Construction Materials

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ABSTRACT: Materials used for the construction of roads can represent one of the sources of environmental pollution. In this respect, especially the water migrating in the road body can be contaminated by pollutants released from these materials. This paper presents the results of a study focused on the leaching of compounds from materials used for road construction. At localities with older pavement surfaces, concentrations of polyaromatic hydrocarbons (PAHs) detected in samples from different body layers were highest in the layer subjacent to the asphalt pavement surface and decreased in the direction to underlying layers. The highest concentrations of PAHs were found in the pavement surface at the locality with the newest pavement surface. Toxicity tests showed adverse effects on test organisms at all localities in the first layer, i.e. the asphalt pavement surface, as well as in the third or fourth layer. On the contrary, samples with the highest concentrations of PAHs were classified as non-toxic, with zero mortality of test organisms. In samples of infiltration water the same PAHs as in soils were identified, with the highest concentrations detected for pyrene, benzo(a)pyrene, and fluoranthene. Water filtration through the road bodies can be classified as slightly toxic to test organisms.

KEY WORDS: water; road; PAH; metals; leaching.

1   INTRODUCTION

Alternative materials have been used for the construction of road pavements between the 60s and 80s of the last century. At that time it was crucial to meet the technical requirements for construction, but these materials could have a negative impact on some components of the environment. Particularly the water migrating on the road body, carried away by drainage systems, may be contaminated by pollutants released from these materials. A number of organic and inorganic pollutants were identified in the water leaving a road body (Krein & Schorer, 2000; Legret & Pagotto, 1999; Stotz & Krauth, 1994) that may accumulate in the vicinity of roads and can thus lead to significant pollution of the environment (Legret et al., 1996). Potential pollutant occurrence in water in road bodies can originate from bitumen leaching as organic material derived from petroleum containing different types of hydrocarbons and from the content of many chemicals generated from road traffic during the use of the pavement, including vehicle exhausts, gasoline, lubricating oils, tires and brake lining wear (Legret et al., 2005). The major chemicals typically investigated in relation

to asphalt pavement are heavy metals like Cd, Cr, Cu, Ni, Pb and Zn and polycyclic aromatic hydrocarbons (PAHs) (Lindgren, 1996; Brantley & Townsend, 1999, Legret et al., 2005). Legret et al. (2005) described leaching of selected heavy metals and polyaromatic hydrocarbons (PAHs) from samples containing 10 % and 20 % of reclaimed asphalt pavement surface. Leaching of PAHs from samples of commonly used commercial bituminous mixtures and asphalts at low concentrations was also documented by other studies (Brandt & de Grooth 2001; Pagotto et al., 2000). Pollution of surface water and groundwater by selected risk elements from pavements that were constructed with the use of crushed ash is considered insignificant, except for potassium (K), sodium (Na) and sulphates that were detected in high concentrations and may originate from this material (Arnold et al., 2002). The leachability of selected pollutants from various agglutinated and non-agglutinated materials – both conventional and alternative – used for the construction of road bases - is significantly dependent on the pH of the environment (Hill et al., 2001). The pavement surface layer may also be a source of pollution of surface water that if not captured and specifically drained can infiltrate into the soil and rock environment in the vicinity of roads. This infiltration inevitably leads to pollution of verges. However, this pollution remains localised in the top layer of soil, where as much as 90 % of pollutants remain effectively captured (Berbee et al., 2004). However, pollutants bound on colloidal particles that may pass even through filter devices in settling tanks are an issue (Sansalone & Buchberger, 1995). Runoff water from road surfaces is more contaminated by emissions from motor vehicles than water infiltrating through porous asphalt into the road body from where it is drained (Legret et al., 1996).

2   METHODOLOGICAL PROCEDURES

Boreholes were drilled at three localities with a different age of the pavement; at all localities samples were taken of individual structural layers and at one locality a seeping waters sampler was installed. The core drilling method was applied to drill the boreholes, using a mobile drilling rig and a drill bit with an inside diameter of 25 cm. The borehole was drilled step by step, with each step of approximately 30 cm, and the particular core section was put at a pre-prepared stacking place. The borehole depth was measured on reaching the subgrade. From each layer of the road body profile, approximately 500 g of soil were collected in a polyethylene sample container for the determination of inorganic substances, and 500 g in a glass sample container for the determination of organic substances and toxicity tests.

To determine the concentrations of inorganic substances in particular layers, samples were dried, homogenized and transferred to a solution by dissolving them in a mixture of acids. Subsequently, analyses were conducted on devices ICP – OES (iCAP 6500, Thermo Scientific, USA) and FAAS (AA 280 FS, VARIAN, Australia). Prior to the determination of concentrations of organic substances, samples were transferred to hexane, using supercritical fluid extraction (Lizard 2000, Seko-K s.r.o., Czech Republic). Subsequently, the extract was purified with the use of column chromatography on a silica gel sorbent. The eluates obtained were then preconcentrated to the required volume and the determination of selected organic pollutants contents was carried out using GS-MS (QP 2010, Shimadzu, Japan).

Water extracts from soil samples were also prepared, according to the methodology defined by the standard ČSN EN 12457-4 (2002). After 24 hour shaking (KS 130 basic, IKA, Germany) the extract was centrifuged at 3900 g for 10 minutes (Universal 32, Hettlich, Germany), filtered if necessary (coarse material) and its pH was determined. The water extract was tested to assess the possible effects on living organisms with a commercially produced test Thamnotoxkit FTM (SOP, Thamnotoxkit F, 1995), using *Thamnocephalus platyurus* as a test organism.

A seeping waters sampler was installed into the borehole at locality 1 to describe the pollution of the environment by substances released from material used for road construction. After completion of the borehole and having taken the samples, the device was put on the borehole bottom. Then the borehole was carefully filled with corresponding layers of soil in the exact order in which the layers had been uncovered by drilling. The scheme and location of the sampler within the pavement, the device's main parts, and the principles of operation are described in detail in Leitão et al. (2008).

3   RESULTS AND DISCUSSION

3.1 Road layers

The individual layers found in the borehole drilled in the road on a particular locality were described macroscopically and a profile through the road – the sequence of layers – was made (Figure 1). Separate layer characteristics are summarized in table 1. Layers were described in accordance with specific standards ČSN EN 13108-1 (2008), ČSN EN 13108-5 (2008) and ČSN 73 6133 (2010). Tag AC 20; 50 mm means a surface course made of Asphalt Concrete with aggregates of 20 mm in diameter and a 50 mm thickness of the layer.

Table 1: Summary of separate layers characteristics.

Layer No.	Locality 1	Locality 2	Locality 3
1	surface layer – AC 20;50 mm.	surface layer – AC 20; 70 mm.	surface layer – AC 12, 250 mm.
2	G-C - gravel mixed with clay soil - brown-gray colour, gravel component (max. 40 mm) of deep igneous and metamorphic rocks with irregular shapes thickness 200 mm	G-M - gravel mixed with fine grained soil - black-gray colour, gravel component (max. 30 mm) of deep igneous and metamorphic rocks with irregular shapes, occasionally slag thickness 150 mm	G-M - gravel mixed with fine grained soil - black-gray colour, gravel component (max. 50 mm) of deep igneous and metamorphic rocks with irregular shapes, occasionally slag thickness 100 mm
3	G - gravel - gray-black colour, gravel and sand component (max 3cm) of slag and cinder thickness 100 mm	G-M - gravel mixed with fine grained soil - brown colour, gravel component (max. 30 mm) of deep igneous and metamorphic rocks with irregular shapes, thickness 150 mm	S - sand – yellow - brown colour, gravel component (max. 10 mm) thickness 600 mm
4	G-F - gravel mixed with fine grained soil - dark brown to gray colour, gravel component (max. 50 mm) of deep igneous and metamorphic rocks with irregular shapes thickness 200 mm	G-F - gravel mixed with fine grained soil - brown - red colour, rock component (more than 200 mm) of metamorphic rocks with irregular shapes thickness 400 mm	S – sand – brown colour, gravel component (max. 40 mm) of metamorphic rocks with irregular shapes thickness – remains to the end of the bore hole

Layer No.	Locality 1	Locality 2	Locality 3
5	G-F - gravel mixed with fine grained soil - dark brown to gray colour, stony component (max 10 cm) of deep igneous and metamorphic rocks with irregular shapes thickness 35 cm	S – sand – gray - black colour, sand component (max 2 mm) thickness 200 mm,	
6	F – fine grained soil – brown - gray colour, gravel component (max 40 mm) thickness 150 mm	F – fine grained soil – gray – brown colour, thickness – remains to the end of the bore hole	
7	S – C sand mixed with clay soil – brown colour, thickness – remains to the end of the bore hole		

Concentrations of EPA's 16 priority pollutant polyaromatic hydrocarbons (PAHs) including coronene were determined in samples taken from individual layers of the road body. The obtained results indicate that concentrations of substances decrease with increasing depth, which is well evident from graphs in Figure 2, where concentrations of selected individual substances are plotted in logarithmic scale versus layer number, i.e. the depth of sampling. Graphs contain the most important substances in relation to human health classified by Monographs on the Evaluation of Carcinogenic Risks to Humans by the International Agency for the Research of Cancer (IARC, 2010) as carcinogenic to humans (Benzo[a]pyrene), probably carcinogenic to humans (Dibenz[a,h]anthracene, Cyclopenta[c,d]parene) and possibly carcinogenic to humans (Benz[a]anthracene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Chrysene).
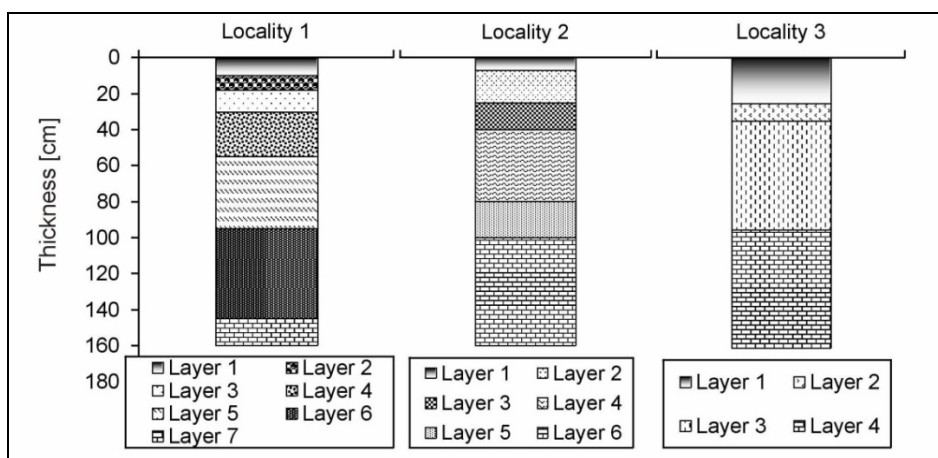

Figure 1: Cross sections of roads at particular localities.

The highest concentrations of PAHs at localities with an older pavement surface from the nineteen fifties (locality 1) or nineteen sixties (locality 2) were found in the layer below the asphalt pavement surface. At locality 1, the total concentration of PAHs in this layer was 195.9 mg.kg^{-1}, which may already pose a significant pollution risk to the environment, especially because of high concentrations of benzo(a)pyrene (57.6 mg.kg^{-1}), benzo(k)fluorantene (37.2 mg.kg^{-1}), benzo(a)antracene (22.7 mg.kg^{-1}) and indeno(1,2,3-cd)pyrene (22.1 mg.kg^{-1}). This may be caused by the leaching of these substances out of the asphalt pavement and their re-sorption in soil grains in the lower layer. This notion is supported by the results of analyses made on samples from individual layers at the locality with the newest road surface from the second half of the nineteen eighties (locality 3), where the highest concentrations of PAHs were found in the surface layer of the pavement. Because of the lower age, the leaching of PAHs from the asphalt pavement may have not taken place to such a large extent and thus that layer still represents a dominant source of these pollutants.
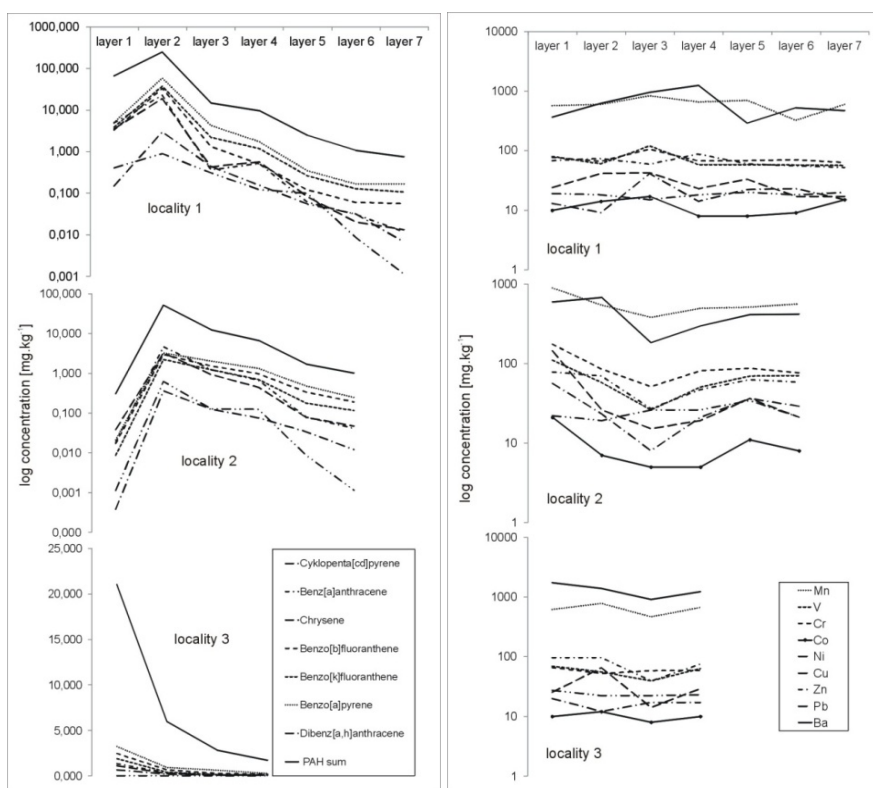

Figure 2: PAHs concentrations and selected metals concentrations in individual road layers.

Table 2: Toxicity tests results.

Locality	Layer	pH of extract	Mortality	Result
	1	**8.34**	**33.30 %**	**Positive**
	2	7.84	0.00 %	Negative
	3	7.33	3.45 %	Negative
Locality 1	4	7.56	3.22 %	Negative
	5	7.18	0.00 %	Negative
	6	7.24	0.00 %	Negative
	7	7.64	0.00 %	Negative

Locality	Layer	pH of extract	Mortality	Result
Locality 2	1	7.13	10.00 %	Negative
	2	7.20	0.00 %	Negative
	3	6.89	3.12 %	Negative
	4	**6.88**	**16.12 %**	**Positive**
	5	6.65	0.00 %	Negative
	6	6.63	6.45 %	Negative
Locality 3	**1**	**6.41**	**12.90 %**	**Positive**
	2	6.60	3.22 %	Negative
	3	**6.81**	**100.00 %**	**Positive** ($LC_{50} = 80.6$)
	4	6.79	6.45 %	Negative

The highest PAHs concentrations in the layer subsequent to asphalt surface were also found by Sadler et al. (1999) but were lower by the order of 1–10 mg.kg^{-1}.

Samples from individual layers were also analyzed for the concentration of selected metals. Iron was found to be the most frequent element that was present in concentrations by two orders higher than Ba (182 - 1733 mg.kg^{-1}) and Mn (380 - 880 mg.kg^{-1}) and by three orders higher than other analyzed elements. Concentrations of Mo and Cd were at all localities and in all samples below the limit of detection, which was 5 mg.kg^{-1} for Mo and 0.8 mg.kg^{-1} for Cd. These results do not indicate any dependence of the concentration of analyzed elements on depth, as is the case with PAHs. This fact is evident from the graphs in Figure 2, where concentrations of individual elements are plotted in logarithmic scale versus the depth of sampling.

The water extracts of soil samples were tested for toxicity at one trophic level. The tests were conducted using the freshwater crustacean *Thamnocephalus platyurus* as the indicator. The highest toxicity was found at locality 3, where the test classified two of the four layers as positive (Table 2). By testing the third layer from this locality, even 100% mortality of crustaceans was detected. This layer is formed by sandy material (grain size up to 1 cm). Similar composition cannot be found in other layers. So in comparison with all the other layers, this is probably the layer with the minimum sorption capacity for toxic substances.

To assess the reason for the increased toxicity of extracts from locality 3, concentrations of individual pollutants at all localities were compared using the statistical method ANOVA. With the exception of Ba and Pb, the results of the comparison of individual localities are statistically insignificant. Concerning Pb, only the difference between localities 1 and 2 was statistically significant. For Ba, concentrations at locality 3 were statistically significantly higher than those at localities 1 and 2. It therefore appears that the most likely reason for the higher toxicity of extracts from locality 3 is the increased concentration of Ba, which is most likely present in a soluble form in layer 3. Slight toxicity was detected for layer 1 at locality 1, i.e. asphalt pavement surface – with 33% mortality of organisms – and layer 4 at locality 2. This layer consists of gravel and a binder composed of loamy clay, and therefore re-sorption of pollutants migrating along with water from the upper layers (especially from the asphalt surface) down to the soil base might have occurred. The other layers at individual localities were classified by the test as non-toxic. The results show that the mortality of organisms was detected at all localities in the first layer – i.e. the asphalt pavement surface – and in the third or fourth layer. Although at localities 1 and 2 the highest concentrations of PAHs were detected in the second layer, the samples were classified as non-toxic, with zero mortality of the test organism. The most likely reason is the toxicity caused by heavy metals (particularly of Ba), as described above.

3.2 Percolation water

When sampling percolation water it is necessary to consider the time of the delay between the infiltration of water at the surface and its accumulation in the sampler. This interval cannot be precisely predicted because it depends on the water filtration rate, resistance of particular layers of the road body and on the length of filtration trajectory. The final volume of the sample is also influenced by the volume of water entering the environment. For these reasons, only two samples of percolation water were taken. We managed to eject 150 ml (sample 1) and 920 ml (sample 2) of groundwater from the sampler placed in the road body into the prepared glass sampling bottle. This volume was in both cases divided into three parts for the determination of organic and inorganic pollutants and for toxicity tests. In the samples the same PAHs as in soils were detected (Figure 3). The results of analyses indicate that the highest concentrations in groundwater were found for pyrene, benzo(a)pyrene and fluoranthene. With the exception of the last mentioned, these are the same compounds that were also present in the highest concentrations in road layers. Sample 2 also contained considerable concentrations of naphthalene and chrysene. However, in general, concentrations of PAHs in this sample were lower by an order of magnitude. This fact may probably be caused by the relatively quick infiltration of larger amounts of water from the surface that lasted until the spring months as the snow at this locality melted. Large quantities of infiltrating water passed through the rock environment faster and therefore there was not a prolonged contact of water with rock grains and minerals in pores. In this way a smaller amount of compounds from the surface of grains is released into the water during the contact. Determined PAHs concentrations are in accordance with Legret et al. (2005), Kriech (1990) and Kriech (1991) who found most of PAHs below the detection limit and the highest concentrations were found in all cases for fluoranthene. Detection limits were in referenced studies substantially higher than those used in this study, e.g. 0.25 mg.l^{-1} for anthracene vs. 0.005 mg.l^{-1}. Concentrations of metals were also determined in groundwater (Figure 4). Concentrations of alkali metals are relatively high, particularly of sodium and potassium. This may be caused particularly by the interaction of the percolation water with rubble and a binder, by which these compounds are released into the water. There is probably also a significant contribution of spreadings used for road maintenance in winter. For sample 1, the highest concentrations were determined for Mo, Ni, Cr, As and Be, and for sample 2 it was Ni, Cr and additionally, also Ba. Unfortunately, determined concentrations of the selected elements differ among Legret et al. (2005) and Kriech (1991) and this study, although the pH of the leachate wasnearly the same.

Concentrations of PAHs in the 2nd sample amounted to approximately 3 % of their values obtained for sample 1. This is most probably caused by the dilution of percolation water during the spring snowmelt, which is also indicated by the detected Na/K ratio caused probably by doping waters with sodium from winter maintenance.
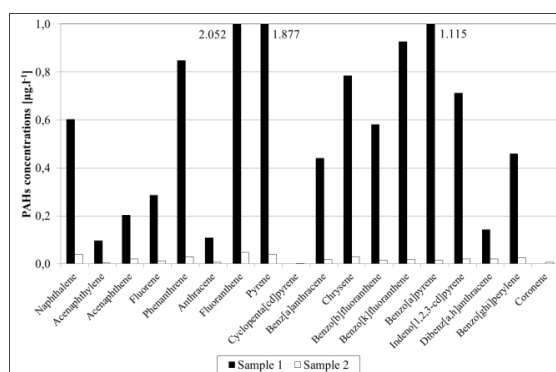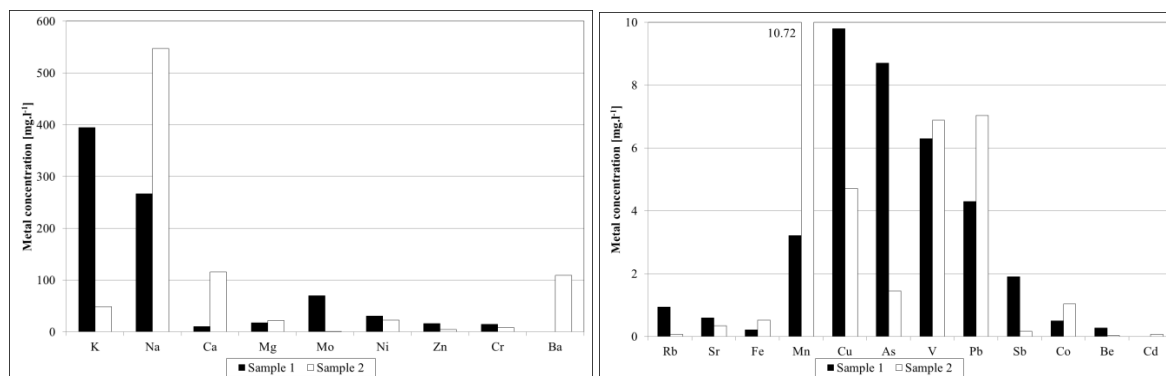

Figure 3: PAHs concentrations in percolation water samples.

Figure 4: Metals concentrations in percolation water samples.

The samples of water were tested for toxicity using the test Thamnotox kit and the freshwater crustacean *Thamnocephalus platyurus* as the indicator. Both samples of groundwater can be classified as slightly toxic, as 32.2 % and 36.6 % mortality of organisms were detected for samples 1 and 2, respectively. Given that at comparable toxicity levels of both samples of water, concentration of PAHs in sample 2 is approximately 3 % that of sample 1, it can be almost certainly said that the toxicity of these samples is not caused by PAHs. We can speculate here about the toxicity caused by the leaching of inorganic pollutants or by combining their effects with the effect of compounds that were not analyzed.

4   CONCLUSION

Concentrations of PAHs determined in samples taken from individual layers of a road body decrease with increasing depth. At localities with an older pavement surface the highest concentrations of PAHs were identified in the layer underneath the asphalt pavement surface. This may be caused by the leaching of these compounds from the asphalt pavement and their re-sorption into soil particles in a lower layer. On the other hand, at localities with the newest road pavement the highest concentrations of PAHs were found in the surface layer of the pavement where – because of a shorter time of exposure – PAHs may not have leached out from the asphalt road pavement to such a large extent. Toxicity tests showed the negative effects on tests organisms at all localities in the first layer, i.e. the asphalt pavement surface, and in the third or fourth layer. On the other hand, samples with the highest concentrations of PAHs were classified as non-toxic. The probable reason for this is that PAHs have strongly re-adsorbed onto the surface of soil grains and that they were not released into the water extract prepared in the process of sample preparation for the test. The opposite effect may take place with metals, particularly Ba, which probably exists in a soluble form. In samples of percolation water the same PAHs were identified as in the soils, with the highest concentrations found for pyrene, benzo(a)pyrene and fluoranthene. With the exception of fluoranthene, these are the same as those identified in highest concentrations in road construction layers. Concentrations of alkali metals, particularly of Na and K, are relatively high. Their source can be seen particularly in the interactions of percolating water with rubble and a binder, or in spreadings used for road maintenance in winter. Water percolating through the road body can be classified as slightly toxic.

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Value of Travel Time Savings in the Context of Leisure Travel in the Czech Republic

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ABSTRACT: This paper presents the results of a study focused on the estimation of the value of travel time savings in the context of long distance leisure travel by car. The study refers to the concept of willingness-to-pay for the reduction of travel time. Data on choice behavior were collected by means of a stated preference survey on a representative sample of the population in the Czech Republic and analyzed using methods of discrete choice analysis.

Results of the study suggest that, in case of the most common type of long distance leisure trips – weekend trips, estimated values of travel time savings obtained by the above mentioned methods are consistent with values recommended by literature, i.e. within the range of 25 % and 50 % of the average hourly wage. The study also confirms that the value of travel time increases together with trip length.

KEY WORDS: Value of travel time savings, conditional logit model, stated preference survey, willingness-to-pay.

1   INTRODUCTION

Value of travel time savings (VTTS) is one of the key inputs to transport planning models and tools for the management and appraisal of road investments decisions. Information on VTTS is essential for parameterization of destination, mode, route and departure time choice components of complex travel demand models. This paper describes the methodology and results of a study aimed at the valuation of travel time in the Czech Republic in the context of leisure travel by car.

Literature on the estimation of VTTS refers to two main approaches whose adequacy differs according to the purpose of travel (Bickel et al., 2006). The so-called cost saving approach is being used in the case of business trips, during which the travel time of employees is viewed as unproductive. For such types of trips the VTTS is equal to the monetary valuation of the employees' productive output. Cost saving approach is recommended also in the case of commercial goods traffic, where the main trip characteristics (for example, destination, route, and departure time) are given by the business policy of the employer. On the other hand, non-work trips, including commuting, shopping or leisure trips, are to a large extent determined by the driver himself. Is such cases it is appropriate to focus directly on the preferences of drivers and their willingness-to-pay for a reduction in travel time.

Section 2 presents in details the method of willingness-to-pay that combines the stated preference method for data collection and the discrete choice modeling for data analysis. Section 3 provides a description of the data collection method and key descriptive statistics of the working dataset. Section 4 presents resulting values of travel time savings and section 5 a discussion of the results.

2 METHODOLOGY

2.1 Discrete choice model

In the study, the valuation of travel time savings refers to the basic economical concepts of utility theory and the theory of rational choice. According to these theories consumers (in our case drivers as the user of transport infrastructure) choose from a finite set of all available options that bring him or her the highest utility. Utility is understood as a linear combination of attributes assigned to each option (travel time, comfort, fuel consumption, etc.) and individual preference weights that individuals assign to each attribute.

Regarding the fact that neither analyst nor the consumer (driver) himself or herself is not able to reliably identify all attributes influencing the value of the perceived utility, the utility function is complemented with an error term that aggregates all factors unrecognized by the analyst. The general form of the utility function has the form

$$U_i = V_i + \varepsilon_i$$

where U_i represents utility of option i; V_i represents factors influencing decision making that are known to the analyst; and ε_i represents all remaining "unknown" factors.

The theory of rational choice suggests that the consumer (car driver) who faces alternatives i and j with utilities $U_i > U_j$ always chooses alternative i. However, if the utility function consists of the unknown component ε_i, as is also in our case, the result of choice becomes more difficult to predict. The presence of a random component in the utility function requires that the choice behavior has to be viewed as a stochastic process, in which the given consumer (driver) chooses the alternative i with probability $Prob_i$ that complies with the equation

$$Prob_i = Prob\big(U_i > U_j\big).$$

The decomposition of utility function to partial components leads to the equation

$$Prob_i = Prob\big[(V_i + \varepsilon_i) > (V_j + \varepsilon_j)\big]$$

this is due to the presence of random components called the rule of random utility maximization. Further adjustment leads to the equation

$$Prob_i = Prob\big[(\varepsilon_j - \varepsilon_i) > (V_i - V_j)\big]$$

which shows that the probability of choosing alternative i is equal to the probability that the difference between unknown sources of the utility of alternatives j and i is higher than the difference between known sources of utility of alternatives i and j.

Further, it may be shown that if random components ε_i and ε_j are drawn from type I extreme value distribution with probability function

$$Prob(\varepsilon_j \leq \varepsilon) = e^{-e^{-\varepsilon}}$$

after certain arrangements made under certain conditions (for details see e.g. Maddala, 1983) it is possible to derive that the alternative i is chosen over alternative j with probability

$$Prob_i = \frac{e^{V_i}}{e^{V_i} + e^{V_j}}$$

The equation above is a specific form of a discrete choice model for two alternatives – binary logit model.

2.2 Implementation of a binary logit model in the willingness-to-pay method

The method of willingness-to-pay consists of the estimation of a maximum sum of money people are willing to sacrifice in order to a gain certain merit, product or, conversely, eliminate negative consequences of their choice. In simple linear models, the willingness-to-pay may be derived as the proportion of parameter estimates related to one non-monetary attribute (in our case *time*) and one monetary attribute (in our case *travel costs*). Linearity of utility functions in discrete choice models thus enables the implementation of such kind of models in the willingness-to-pay method.

　　In our specific case, the value of travel time during trips to leisure activities is formulated as the maximum amount of money that are people are willing to sacrifice in order to save one unit of time, provided that all other trip related attributes remain constant. In our study we consider two hypothetical alternatives that differ in the following attributes:

- Fuel related costs X_{costs} [in CZK];
- Travel time X_{time} [in *hours*];

The utility function of alternatives i and j has the form:

$$V_i = \beta_{costs}X_{costs} + \beta_{time}X_{time}$$

resp.

$$V_j = \beta_{costs}X_{costs} + \beta_{time}X_{time},$$

where β_{costs} and β_{time} represent respective parameters that are going to be estimated from empirical data.

Regarding the survey design (described in section 3), in which both alternatives are depicted only using the values of attributes and abstract names (e.g. route G), the utility functions are free of alternative specific constants.

Parameters β_{costs} and β_{time} of the conditional logit model were estimated by the maximum-likelihood method using the *survival* package of statistical software R (R Development Core Team, 2008), namely the function *clogit()*. The final value of travel time savings $VTTS$ was obtained by the substitution of the estimated values of β_{costs} and β_{time} to the formula

$$VTTS = \frac{\beta_{time}}{\beta_{costs}} \cdot 60 \quad \left[in\ CZK/_h \right].$$

3   DATA

3.1 Stated preference survey

The aim of the stated preference survey is to estimate weights that consumers assign to particular attributes of available alternatives. Respondents of the survey are introduced to hypothetical scenarios, and provided with hypothetical choice alternatives that differ in the values of particular attributes and asked to choose one alternative based on their preferences.

The survey design consisted of the specification of a hypothetical situation with respect to the objective of the study, i.e. the estimation of the value of travel time in the case of leisure trips. In the study we focused on two basic scenarios: weekend leisure trips (two to three days) and holiday leisure trips (1 week and more). In the following text we will describe in detail the survey design.

In the stated preference experiment we assumed several hypothetical destinations (scenarios) that can be accessed by two alternative routes i a j that differ in the values of attributes X_{costs} and X_{time}. In order to reduce alternative specific bias, routes were labeled by randomly generated letters (e.g. route D and route B). Further, a range of plausible values of attributes were calculated based on the assumption that a one way trip in the case of a weekend leisure travel resp. holiday travel takes about 1 hour 40 minutes, resp. 4 hours 30 minutes, which, in the case of an average speed of 70 km/hour, resp. 100 km/hour, corresponds to 117 km, resp. 450 km. The adequacy of the assumption was later confirmed by the results of the survey, in which respondents provided answers to the question "In the case of weekend leisure trip/holiday travel by car, what is the average distance traveled (return trip in km)?". The average distance provided by respondents was 126.5 km, resp. 430.5 km. Travel time values were set within ∓ 30 minutes range around the average travel time, resp. within ∓ 60 minutes range in the case of holiday travel; travel costs ranging from 270 CZK for the shortest route and 390 CZK for the longest route, resp. from 650 CZK to 875 CZK.

With respect to the fact that variables X_{costs} and X_{time} are continuous, it was necessary to select a limited number of values so that we would be able to cover in sufficient detail the maximum range of travel time values, while keeping the number of decision problems as low as possible. The range of travel time values was set within the range of 10 CZK/h to 360 CZK/h in the case of weekend leisure travel and of 38 CZK to 675 CZK in the case of holiday travel, with respect to literature (Litman & Doherty, 2009) that recommends values covering the range of 25% to 50% of average hourly wage (143 CZK/h in second quarter

of 2011) (MPSV, 2011). Finally fractional factorial design was used in order to generate a minimum number of value levels. For details on the procedure please refer to Hensher et al. (2005). Table 1 shows selected values of attributes.

Table 1: Attribute values in stated preference survey.

Weekend leisure trips		Holiday travel	
X_{time}	X_{costs}	X_{time}	X_{costs}
1 h 10 min	270 CZK	3 h 30 min	650 CZK
1 h 35 min	310 CZK	4 h 20 min	725 CZK
1 h 45 min	350 CZK	4 h 40 min	800 CZK
2 h 10 min	390 CZK	5 h 30 min	875 CZK

Each respondent of the survey was provided with 9 decision problems in each scenario that, according to fractional factorial design, systematically combined values in Table 1 and asked to choose his/her preferred route. Table 2 shows an example of the card with the decision problem.

Table 2: Example of card with decision problem used in the survey.

Scenario 1	Route G	Route D
Costs related to fuel consumption	70 CZK	130 CZK
Travel time	1h 45min	1h 35min

3.2 Dataset

The survey sample was selected from the population of residents in the Czech Republic using a stratified random sampling based on the register of addresses. 557 out of the total of 835 selected respondents agreed to participate in the survey, which corresponds to a 67% response rate. Sample representativeness was confirmed by the comparison of socio-demographical characteristics of the sample with characteristics of the population.

The survey was executed using the CAPI method. Each respondent was asked for his/her socio-demographic characteristics and basic characteristics of travel behavior in the context of leisure travel. Only respondents who indicated the use of car for a given type of leisure travel participated in the stated preference survey. The final dataset consists of 2502 choices from 278 respondents in the case of "weekend trip" scenario and 2061 choices from 229 respondents in the case of "holiday travel" scenario.

4   RESULTS

Tables 3 and 4 show final values of parameters β_costs and β_time estimated on the above described samples.

Table 3: Estimated parameters of conditional logit model in the case of "weekend trip" scenario.

Attribute	Parameter estimate β	SE	z-score	Pr (>|z|)
X_{costs}	-0,041527	0,002048	-20,27	< 0,001
X_{time}	-0,038672	0,002428	-15,93	< 0,001
R-square = 0,11				

Table 4: Estimated parameters of conditional logit model in the case of "holiday travel" scenario.

Attribute	Parameter estimate β	SE	z-score	Pr (>|z|)
X_{costs}	-0, 012147	0, 000604	-20,11	< 0,001
X_{time}	-0, 023407	0, 001402	-16,69	< 0,001
R-square = 0,13				

Negative values of parameters correctly suggest that higher travel costs, respectively higher travel time, have a negative impact on utility. Low p-values suggest that estimated values of both parameters are different from zero at a fairly low significance level. Low values of R-square are associated with a high level of variability unexplained by the model. The analysis of relations between the value of travel time and socio-demographic characteristics of respondents was out of the scope of the study.

The value of travel time savings in the case of weekend leisure trips is

$$VTTS_{weekend} = \frac{\beta_{time}}{\beta_{costs}} \cdot 60 = \frac{-0,038672}{-0,041527} \cdot 60 = 55,87 \ \left[CZK/h\right],$$

and in the case of holiday travel

$$VTTS_{hlidays} = \frac{\beta_{time}}{\beta_{costs}} \cdot 60 = \frac{-0,023407}{-0,012147} \cdot 60 = 115,62 \ \left[CZK/h\right].$$

The estimated value of travel time savings in the context of weekend leisure trips is within the range referred in literature (Litman & Doherty, 2009), i.e. 25% - 50%

of the average hourly wage in the Czech Republic. A higher value of travel time in the context of holiday travel is in accordance with findings in other studies (Wardman, 1998). The reason may consist of the increase of marginal disutility of travel time with trip length due to fatigue, boredom and discomfort (Mackie et al., 2003).

5   SUMMARY AND DISCUSSION

This study presented an estimation of the value of travel time savings in the case of weekend leisure travel using the willingness-to-pay method that combined the stated preference survey and conditional logit model. It was shown that the estimated values of travel time savings are consistent with the values found in other countries.

However, it has to be noted that the study leaves several important issues unanswered, particularly due to the small sample size and limited scope of the study. Further study should focus on the influence of socio-demographic characteristics and detailed characteristics of the trip (e.g. trip length or other types of leisure travel) on the perceived value of travel time savings.

ACKNOWLEDGEMENT

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Use of Accident Prediction Models in Identifying Hazardous Road Locations

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ABSTRACT: The paper introduces the possibility of using accident prediction models for the identification of hazardous road locations. The application of this method is presented with an example of secondary rural roads in the South Moravian region which are classified into road segments homogeneous in terms of basic geometric and traffic characteristics. The prediction model is represented by a generalized linear model which, on the basis of the available data, determines the expected number of accidents for individual types of road segments. A critical road segment is defined as a segment where the reported number of accidents significantly exceeds the number of expected accidents on roads with similar geometric and traffic characteristics. This method can be used as an effective tool for road network safety management.

KEY WORDS: road safety inspection, hazardous road location, accident prediction model.

1 STUDY BACKGROUND AND OBJECTIVES

The first stage of road network safety management is to identify hazardous road locations. The research of literature shows that the majority of EU countries use the system of identification of hazardous road locations (so-called black spots, hot spots, high risk sites, etc.) and an analysis of accidents occurring there (Elvik, 2008). However, none of these systems succeeds in coming closer to the ideal theoretical approach which is described in e.g. Elvik's (2007) work, who claims that critical spots identification and treatment is to be performed as follows:

- Development of an accident prediction model which can be also used as the basis for the analysis of the road network when identifying critical spots;
- Production of an extensive list of road elements to which the analysis is applied, and their classification (road segments, junctions, curves, bridges, tunnels, etc.). This classification is important for several reasons, e.g. not to identify an excessive number of junctions as accident junctions simply due to the fact that usually more accidents occur at junctions than at road segments of a similar length (e.g. 100 m);
- Estimation of the expected number of accidents for each element;
- Application of an algorithm in order to identify road segments with a higher than common number of road accidents;
- Design of potentially effective measures leading to the improvement of safety of the elements.

This approach was used in the study which is introduced in the following text. The study is a part of IDEKO project ("Identification and solutions to critical spots and road segments on the road network which stimulate road users' illegal and improper behaviour, due to their arrangement") conducted by Centrum dopravního výzkumu, v.v.i. and funded by the Programme of Safety Research of the Czech Ministry of Interior. The study deals with the network of secondary rural roads in the South Moravian region since this category is, together with primary roads, the most hazardous road category in the Czech Republic.

The next part introduces the sources of data used in the study, methodological guidelines of designing the accident prediction model and the resulting model form. Subsequently, the use of the model for the identification of hazardous road locations is described. The final part contains the overview of the study results and a brief description of the work plan of the IDEKO project.

2   ACCIDENT PREDICTION MODEL

Accident prediction models have been extensively used in the domain of road infrastructure for the estimation of the expected number of accidents on road segments and junctions (Hauer et al., 1988; Mountain et al., 1996; Greibe, 2003; Daniels et al., 2009) as well as for the estimation of safety benefits (Kulmala, 1995; Carson & Mannering, 2001; Usman et al., 2010).

2.1 Data

Data on road traffic accidents

Data on road traffic accidents was obtained from the sources of the Czech Police. For the purpose of this study road traffic accidents which occurred on rural secondary roads in the South Moravian region in 2009 to 2011 were used. Furthermore, the accidents which occurred at junctions with tertiary and higher category roads were removed, so that the database only contained the accidents which occurred at non-junction road segments. The accidents at junctions with local and access roads (access to field and forest roads, access to car parks, petrol stations, etc.) were kept in the monitored road segments.

Manual checks of these accidents were performed and they found that some of the accidents which are reported at a junction with a local road actually occurred at a junction with a tertiary road or a road of higher category. These accidents were then removed. Furthermore, the accidents which were located further than 50 m off the nearest road were also removed – these accidents were probably incorrectly localized. The total number of accidents which were left in the database was 1408 (515 in 2009, 480 in 2010 and 413 in 2011).

Table 1 contains an overview of the values of attributes from road accident reports. Besides some exceptions, all registered accidents occurred at two-lane roads, most frequently on straight road segments (45 % of cases), on straight road segments up to 100 m off a horizontal curve (22 % of cases), and in horizontal curves (30 % of cases). Just 3 % of reports refer to accidents at junctions with local and access roads. The majority of accidents are the consequence of a collision, the crash of a vehicle with a solid obstacle, and a crash with another vehicle (84 % of cases). Collisions with animals represent 11 % of cases and collisions with pedestrians and other collisions represent 3 % or 2 % of cases respectively. Due to the high proportion of accidents with animals, the data on roads were complemented with an attribute of "road surroundings" which is used as a proxy variable for animal exposure. A closer look at the liability for collisions with animals reveals

that vehicle drivers are liable in the majority of cases (83 %), animals are liable in 11 %, and drivers of non-motor vehicles, pedestrians, and vehicle collisions in the remaining cases.

Table 1: Description statistics of road accident from 2009-2011.

Variable	*Frequency*
ACCIDENT LOCALITY	
urban areas	13
rural areas	1395
TYPE OF ACCIDENT	
crash with non-rail vehicle	562
crash with solid obstacle	294
crash with pedestrian	39
crash with animal	158
crash with train	2
crash with other objects	326
other type of accident	27
ACCIDENT CHARACTER	
accident with injury or fatal consequences	776
accident with property damage only	632
ACCIDENT LIABILITY	
motor vehicle driver	1173
non- motor vehicle driver	38
pedestrian	15
forest animals, domestic animals	158
road fault	3
vehicle technical breakdown	12
other liability	9
ROAD CLASSIFICATION	
two-lane	1390
other	18
ROAD ALIGNMENT	
straight segment	638
straight segment after curve	307
curve	418
junction	45

Data on infrastructure

Data on secondary roads in the South Moravian region were collected from the sources of the Road and Motorway Directorate (ŘSD) database. Regarding the objectives of the study, only rural road segments without junctions with primary, secondary and tertiary roads

were selected. Following the example of Cafiso et al. (2010), the selected road segments were further divided into segments, so that each segment would meet the following criteria:

- the length of segment of at least 50 m
- equal number of traffic lanes along the whole length of road segment
- same road category along the whole length of road segment
- existence/non-existence of paved verges along the whole length of road segment
- existence/non-existence of permanent speed limit reduction along the whole length of road segment
- existence/non-existence of continuous forest vegetation in the vicinity of road segment
- equal traffic volume along the whole length of road segment

After the road division into homogeneous segments, each of the segments was complemented with data on road segment length, curvature, proportion of heavy vehicles, and the number of junctions with local roads. Finally, each of the segments was assigned with information on the corresponding number of road traffic accidents. The resulting set includes 848 segments. Table 2 shows basic description statistics of the data file.

Table 2: Basic description statistics of road infrastructure data file.

Label	Description	Variable type	Source	Description statistics (mean value /standard deviation/ minimum/maximum or frequency)
KRAJNICE	Road with shoulder	Binary [1=yes]	ŘSD	1:170; 0: 678
KATPK	Road category	Categorical	ŘSD	S7,5: 642; S9,5: 142; S11,5: 64
KRIZENI	Number of junctions with local roads	Continuous	ŘSD	0,20 / 0,50 / 0 / 4
VYBAV	Road equipment	Continuous	ŘSD	0,47 / 0,94 / 0 / 13
CUMUL	Curvature	Continuous [gon/km]	ŘSD	116 / 174 / 0 / 1595
JPRUH	Number of traffic lanes	Categorical	ŘSD	1:1; 2:806; 3:39; 4:2
LES	Road vicinity (forest)	Binary [1=yes]	Cenia	1:199; 0: 649
RPDI	AADT	Continuous [veh./year]	ŘSD	3063 / 2931 / 91 / 18500
PODILTV	Proportion of heavy vehicles	Continuous	ŘSD	0,18 / 0,05 / 0,06 / 0,49
LEN	Segment length	Continuous [m]	ŘSD	1176 / 1120 / 51 / 6456
CRASH	Number of accidents	Continuous [acc./3 years]	PČR	1,66 / 2,9 / 0 / 20

Methodology part

When designing the accident model, we took into account the data specific features, specifically the Poisson division of the number of accidents per 1 km of road segment length (see Figure 1). The data of this type are modeled with the use of Poisson regression model or a negative binomial regression model in the case overdispersion is suspected. In this case, we selected a general version of negative binomial regression, which is reduced to the traditional Poisson regression in the case of non-significant overdispersion.
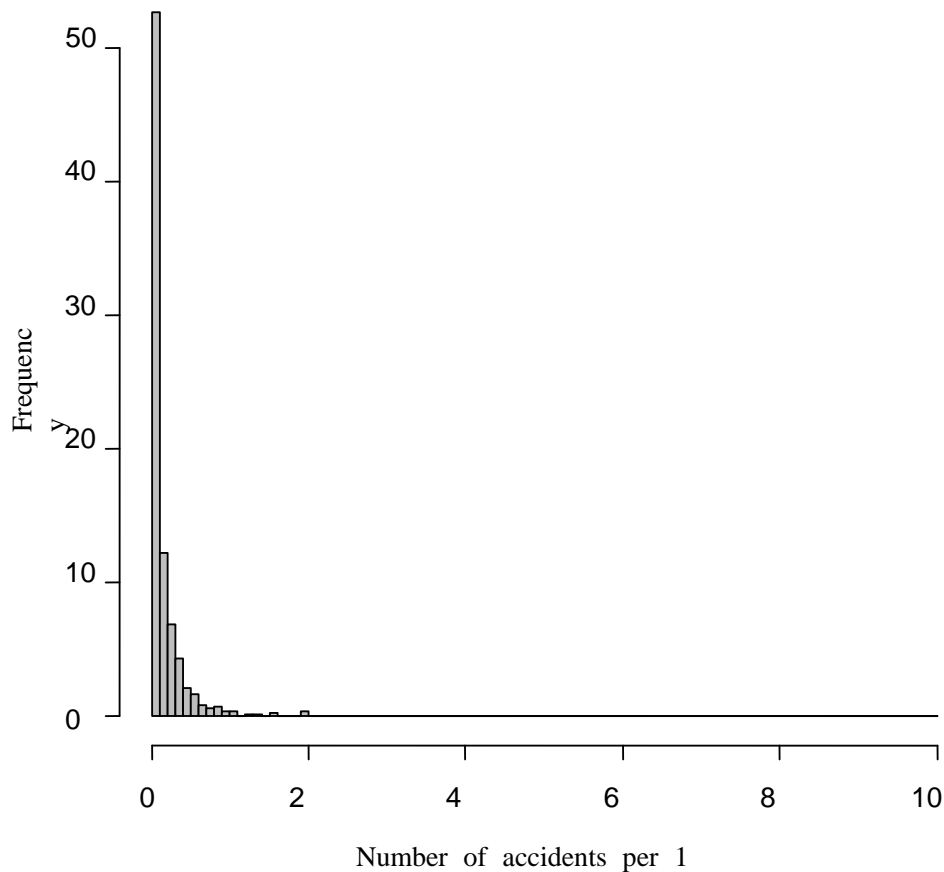
Figure 1: Histogram of the number of accidents per 1 km segment.

A detailed mathematical description of a negative regression model and its relationship to Poisson regression was published in a paper focused on the accident prediction model for roundabouts (Šenk & Ambros, 2011). It is to be noted that the negative binomial regression is a specific example of generalized linear regression, in which the model core is created by the following link function

$$\lambda = e^{(x\beta+\varepsilon)}$$

where e^{ε} is a random error with gamma distribution with the mean value of $E(e^{\varepsilon}) = 1$ and variance $Var(e^{\varepsilon}) = \alpha$. Integrating ε out of the above mentioned formula leads to negative binomial distribution of the described variable with the mean value of λ and variance $\lambda + \alpha\lambda^2$ Positive values of parameter α control for overdispersion of the response variable (number of accidents per road segment), while values close to zero reduce the model to the Poisson regression model. The estimation of parameters α and β is performed by the maximum-likelihood method.

$$E\ (CRASH) = e^{\beta_0+\beta_1\ ln(RPDI)+\beta_2\ ln(LEN)+\sum_{i=3}^{n}\beta_i\cdot x_i}$$

where *RPDI* represents AADT of vehicles passing through the road segment, *LEN* represents the length of segment in metres, x_i geometric-traffic characteristics of the segment and β_i represents the corresponding regression coefficient. The ability of the model to represent empirical data was evaluated by the combination of the Akaike information criterion (AIC) and the likelihood ratio test.

Resulting regression model

To estimate the parameters of the regression model the statistical software R, specifically its function *glm.nb()* for negative binomial regression from the extension package *MASS*, was used. The final model version is the result of the following process:

- Creation of the initial/updated model version with basic variables *RPDI* and *LEN* (number of variables in model *j = 2*);
- Creation of a set of models N formed of *n* models, by the extension of the updated model version with one of *n* variables which is not included in the updated model version *(j = j + 1);*
- The selection of a subset of models M out of N, so that for each model it is valid that coefficients of all variables are statistically different from zero at the significance level of 0.1. Furthermore, in comparison with the updated model version, the corresponding model version should explain the variability in a dependent variable better (assessed by likelihood ratio test). In case one of the conditions is not met, the modelling process is terminated and the updated model version is declared the final version.
- Model *m* out of a set M with the lowest AIC value is declared the updated model version.
- Return to point 2.

The final model version is shown in Table 3.

Table 3: Parameters of accident prediction model.

	β_i	*SEM*	*z-score*	*Pr(>|z|)*
γ	-13.64683914	0.632534442	-21.57485543	<0.001
ln(RPDI)	0.930655451	0.054874554	16.95969038	<0.001
ln(LEN)	0.949910152	0.052579181	18.0662791	<0.001
LES	0.419977676	0.095815101	4.383209652	<0.001
CUMUL	0.000417459	0.000233551	1.787444356	0.074
AIC	2357.3			
estimate α	2.08			
SEM α	0.28			
2 x log-likelihood	-2345.3			

A high positive value of dispersion parameter α and a low value of the standard error of the mean (SEM) confirm overdispersion of the response variable and the appropriateness to select the negative binomial model.

By substituting variables and corresponding values of parameters into the general function of the expected number of accidents, we receive the accident prediction model at road segments of secondary roads in the South Moravian region as follows

$$E(CRASH) = e^{-13,6468+0,9307\cdot ln(RPDI)+0,9499\cdot ln(LEN)+0,42\cdot LES+0,0004\cdot CUMUL}$$

3 MODEL APPLICATION

The previous chapter described the accident prediction model on the network of secondary rural roads in the South Moravian region. The following part introduces a potential application of the results of this model in the process of road network safety management, particularly from the viewpoint of road administrators. This process includes the identification of hazardous road locations (accident localities) and the determination of the priorities of their treatment.

3.1 Theoretical part

Pokorný and Striegler (2011) claim that there are currently a number of different definitions of an accident locality in the Czech Republic. There are more identification criteria for the determination of an accident locality. Within the literature research performed in the IDEKO project, a so-called *criterion of absolute difference* was selected in order to identify accident localities. This criterion focuses on localities with the highest potential for the reduction of the number of accidents. When using this criterion, it is necessary to determine what the absolute difference needs to be, so that a locality could be considered an accident locality. This depends on road safety policy, strategy, budget, and required accuracy level. Therefore, no single figure can be generally stated; however, two general rules can be used:

- The criterion for identification can be a determined figure which needs to exceed the potential (suitable for smaller territorial areas), or a certain percentage of the road network with the highest potential (suitable for larger territorial areas).
- Severity of accidents when identifying accident localities should not be taken into account.

Elvik (2007) defines hazardous road location as a location which has a higher expected number of accidents than other identical locations due to local risk factors under consideration that the local risk factors are particularly related to the road design.

3.2 Example of using the accident prediction model

Hazardous road locations are identified within the project on the road network of secondary roads in the South Moravian region (road segments without junctions only). These road segments are defined by their geometric and traffic characteristics which are represented by independent variables in the prediction model, described in part 2. The expected number of accidents, which is a result of prediction (and dependent variable as well), corresponds with the above mentioned definition. A suitable criterion to determine the severity (hazard rate) of road segments and priorities of their rehabilitation refers to the difference between the reported and expected number of accidents.

The risk being referred to by the number of accidents can be understood in two ways: individually or collectively. The individual risk represents a probability for drivers that a potential accident befalls a driver; it is expressed by accident rate. In contrast, the collective risk, expressed by the accident density, concerns all accidents. While, obviously, the individual risk is perceived by individual drivers, road administrators consider accident density a more suitable indicator (Ambros, 2012). In order to express the density, the mentioned difference between the reported (R) and expected number of accidents (E) was divided by the segment length:

X = (R – E) / L. Value X represents the above mentioned accident potential.

- Positive example: Two accidents occurred on a kilometre-long road segment, while three accidents were expected ⇒ X = 2 – 3 = -1.
- Negative example: Three accidents occurred on a kilometre-long road segment, while just two accidents were expected ⇒ X = 1 – 2 = -1.

Therefore, positive values of the accident potential indicate situations which should be targeted by subsequent treatment.

A demonstrative overview of the expected and real accident density of all segments on the network, which is the subject of this study, was created (see Table 4).

Table 4: Contingency table of the expected and real accident density.

expected and *real* accident density	0 – 0.5	0.5 – 1	1 – 1.5	1.5 – 2	2 – 2.5	2.5 – 3	3 – 3.5	3.5 – 4	4 – 4.5	4.5 – 5	5 – 5.5	5.5 – 6	6 – 6.5	6.5 – 7	7 – 7.5	7.5 – 8	8 – 8.5
0 – 0.5	100	120	83	56	33	14	12	7	5	7	0	3	3	2	3	1	1
0.5 – 1	8	21	28	13	1	1	2	1	0	0	0	0	0	0	0	0	0
1 – 1.5	2	25	16	12	3	3	2	0	1	0	0	0	0	0	0	0	0
1.5 – 2	7	16	15	8	6	2	2	2	0	0	0	0	0	0	0	0	0
2 – 2.5	3	9	13	8	3	1	0	2	1	0	0	0	0	0	0	0	0
2.5 – 3	0	6	6	7	4	2	2	0	2	0	0	0	0	0	0	0	0
3 – 3.5	0	2	8	8	3	2	2	0	2	1	0	0	0	1	0	0	1
3.5 – 4	0	1	1	3	3	3	0	0	1	0	1	0	0	0	0	0	0
4 – 4.5	0	1	2	1	5	2	2	0	0	0	1	0	0	0	0	0	0
4.5 – 5	0	1	0	1	3	0	0	0	1	0	0	0	0	1	0	0	0
5 – 5.5	0	0	0	3	1	2	0	0	2	0	0	0	0	1	0	0	0
5.5 – 6	0	0	0	2	1	0	1	0	1	0	1	1	1	0	0	0	0
6 – 6.5	0	1	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0
6.5 – 7	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
7 – 7.5	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0
7.5 – 8	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1
8 – 8.5	0	1	3	4	5	2	1	2	3	3	1	2	3	0	2	0	3

The rows are divided in intervals of the real accident density, and columns in intervals of the expected accident density. The number in each cell refers to the number of segments with the accident density in corresponding intervals.

The average real and expected accident density per 1 km of the analysed network is approximately 1.7. This is why the "below-the-average" road segments were highlighted, i.e. where the real, as well as the expected accident density, exceeded the value 2. This concerns 169 segments, i.e. approximately a fifth of the monitored network. It is obviously inconceivable to expect that such a large number of accidents can be treated. In the previous case, the criterion of "below-the-average" locality was applied. Another criterion can use a pre-determined proportion, e.g. upper 10 % of all values. According to this criterion, there are 83 hazardous segments occurring on the monitored network.

4 CONCLUSION

The article introduced the use of accident prediction models in order to identify hazardous road locations – both its theoretical background, and a specific example of its application on the network of secondary roads in the South Moravian region. Although the mentioned approach is recommended worldwide, it is the first known example of its application in the Czech Republic. The further project stage includes an accident analysis of selected spots and road safety inspection, in order to identify local risk factors. In this way the above mentioned theoretical definition of the critical segment will be met: it is a segment with a higher expected number of accidents than other similar segments, due to local risk factors. Subsequently, low-cost measures will be designed in order to remove these risk factors.

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