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Mature Vegetation along Roads

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ABSTRACT: The article deals with the issue of vegetation, particularly mature vegetation, along transport routes. Since rather heated discussions on this topic have recently appeared, particularly in relation to road safety, the authors of this article decided to present this issue in wider context and from various viewpoints. The starting point for this issue is mentioned in the introduction. The next part deals with the history of planting tree alleys in the Czech Republic. Subsequently, a brief summary of advantages and drawbacks of mature vegetation along transport routes is presented. The next part of the article discusses the environmental bases and, last but not least, the article deals with the impact of mature vegetation on road safety.

KEY WORDS: Vegetation, roads, safety.

1 INTRODUCTION

Planting mature vegetation along transport routes is becoming a centre of interest and an issue for discussion between staunch advocates and equally staunch opponents. In case an accident with fatal consequences occurs, whose cause is a collision with a solid obstacle – a tree, opinions appear that trees are dangerous and need to be completely removed. On the other hand, vegetation along transport routes has a wide range of benefits and inherently fits in the European landscape. The article aims to point out positive as well as negative effects of mature vegetation along transport routes and discuss possible bases. The results of the article do not and cannot provide unambiguous conclusions – mature vegetation yes or no, the given issue is too extensive for such conclusion.

2 HISTORY OF PLANTING MATURE VEGETATION ALONG ROADS

Great changes in landscape occurred in our country particularly during the medieval colonization in the 13th and 14th century. A large number of villages and towns were founded at that time and the road network was growing. The landscape was gradually becoming more and more civilized, and this process got even more intensive under the reign of Charles IV. This ruler was a founder of paved roads, since he realized their importance. The first planting of trees along those roads appeared at that time. On the other hand, at that time as well as later

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in the 17th century, trees were often removed not to provide a hiding place for robbers and other criminals. For example historical sources state that vegetation should be as distant from the road as a "stone throw encircled by fingers" (Bulíř, 1988). Planted tree alleys, which were established in open landscape, came only in the second half of the 17th century. Thus in the Baroque period the landscape, devastated by the Thirty Year's War, got gradually more civilized. Also, small architecture elements in the form of small chapels or wayside shrines started to appear in the landscape. These elements very often accompanied by solitary trees and follow-up tree alleys, which connected them to villages, hamlets, and to general surroundings.

Regarding mature vegetation planting along transport routes, an edict was published in 1752 which brought obligation to plant trees along all new roads. Therefore, most of the tree alleys were planted under the reigns of Maria Theresa and Joseph II, when fruit trees became popular as well. However, the reasons for planting were not only economic, but also focused on orientation, safety, and aesthetics.

The planting of tree alleys continued in the 19th century, when building of the secondary roads network began, and the law ordered to plant tree lines and alongside these roads, consisting especially of fruit trees. The planting also continued in the 20th century. When field boundaries were ploughed and non-forest vegetation was gradually removed in the 1950s, tree alleys along transport routes were often the only remaining sanctuaries for many animals and migration corridors for a large number of animal species. Therefore, the accompanying vegetation became the only planted vegetation apart from forests, and its popularity was also brought to urban areas.

3 TYPES OF ACCOMPANYING VEGETATION

The vegetation along transport routes can be divided into six groups (Cimbůrková & Šerá, 2011). The first type is a tree alley. Its advantage is a relatively low consumption of planting material and easy planting, the disadvantage particularly concerns over-aging, related to insufficient or unsuitable maintenance. The second type is an area-wide planting, which is particularly applied to newly built motorways and around grade-separated junctions. The third group is a forest vegetation, which is not specifically planted, but rather relates to transport routes cutting through the existing forest areas.

Another type is natural vegetation, i.e. vegetation grown by natural succession. This accompanying vegetation is particularly formed by fast growing woody plants and its advantage lies mostly in the cheap initial investment, which is however compensated by the need of corrective interventions. Another type of vegetation, bush stripes, is used for motorway central reserves. The last group of accompanying vegetation is grass vegetation, which is often used in combination with the previous types. Grass vegetation has a soil improvement and retention function and plays an important role for protecting soil from erosion.

When planting accompanying vegetation, apart from other features, it is necessary to consider the type of road. The accompanying vegetation should correspond to the surrounding landscape and respect the local conditions. Planting monotonous tree alleys, which make drivers tired, is not recommended for motorways, expressways and first-class roads. More suitable is to combine mature and low vegetation in irregular intervals, so that the monotonous character of the road is broken up and drivers' attention is maintained.

Regarding second-class roads, which are closely bound to local environment, the accompanying vegetation should be in accord with the character of the local landscape and support specific features of the given area. Therefore, on the one hand, the accompanying vegetation can underline views to the landscape and support important dominant features, and on the other hand, it can cover up undesirable views.

Regarding third-class roads, lower speeds allow drivers to notice more of a local environment, thus it is advisable to plant different groups of woody plants, while it is still necessary to take into account the local conditions and the surrounding landscape.

4 BENEFITS OF MATURE VEGETATION ALONG TRANSPORT ROUTES IN TERMS OF IMPACT ON THE ENVIRONMENT

The accompanying vegetation has a number of functions. Regarding its environmental function, it is a production of O_2, absorption of CO_2, interception of PM. The impact of tree and bush vegetation on PM reduction is based on a number of factors:

- absolute area of leaf surface,
- leaf surface quality,
- leaf position,
- movability of leaves,
- tree crown shape,
- sediment character.

In addition, vegetation plays an important role concerning hydrology, since it works as a protection of embankments and dykes, reinforcing them and protecting them from erosion. Vegetation also has a positive impact on water retention in landscape and thus reduces consequences of torrential rains.

Another advantage of mature vegetation along transport routes is its impact on reducing cross wind to vehicles and retention of snow, which prevents the creation of snowdrifts on roads.

The aesthetic function is also not negligible, since accompanying vegetation improves the road integration in landscape, and last but not least, it provides shade. In addition, trees significantly influence climate of the local environment.

As mentioned above, vegetation along roads often creates the only suitable biotope for a large number of animals in a certain area and provides connection to the surrounding environment, which greatly improves conditions for animal migration. For example, thanks to the accompanying vegetation, meadow vole was able to spread to the distance of 90 km.

The tree lines and alleys are also places where a large number of birds live, e.g. redwing and yellowhammer. This original inhabitant of forest-steppes found a sanctuary in the Czech agricultural landscape; in bushy field boundaries and in tree alleys along roads.

Another example of an animal bound to this environment is the hermit beetle. This beetle, just 25 mm long, develops in tree hollows. It is very rare in the Czech Republic and is listed among protected species and included in the protection system of NATURA 2000. Its protection is also supported by the European Union, which also supported a programme of the extensive planting of trees along roads in three Polish regions in 2010 and 2011.

5 IMPACT OF MATURE VEGETATION ON ROAD SAFETY

It is the issue of the relationship between mature vegetation along transport routes and safety that is discussed so much today. In the case of a collision of a vehicle with a solid obstacle, i.e. a tree, the consequences are often tragic. Nevertheless, the approach to “cut down everything and solve the problem” is over-simplifying it and the issue deserves a deeper analysis.

There is currently a lot of research in progress concerning the relationship between accidents and trees. This issue has two solutions. The first one is the care of the existing tree alleys. The other one concerns new planting along newly built roads, but here we deal with the issues of maintenance or financing. In addition, vegetation along transport routes is affected by traffic. Furthermore, there is an issue of planting indigenous species or introducing foreign species to the landscape.

The advantages of tree alleys along transport routes include easier anticipation of direction, when mature vegetation outlines the course of the road. Alleys also help to estimate distance and optically guide the driver. The advantages also include easier orientation in fog and in darkness, keeping drivers alert, and prevention of vehicle falling.

Some of the most serious drawbacks concern the danger of collision with a solid obstacle, and the increased risk of an accident due to leaves or fruit on the road surface. Inappropriately planted or maintained vegetation can also lead to limited visibility at junctions or inner sides of horizontal curves. Other negative effects include the risk of falling branches and dazzling of drivers due to changes of light and dark sections covered by tree crowns.

The following tables and graphs deal with the types of road accidents and their consequences in relation to trees along transport routes.

Table 1: Statistics of road accidents for last 5 years – total number of accidents.

Year	Total number of RAs on all roads	Total number of RAs – collision with solid obstacle	Total number of RAs - collision with solid obstacle (excl. trees)	Total number of RAs - collision with solid obstacle (collision with tree)	Total number of RAs – collision with solid obstacle (%)	Total number of RAs – collision with solid obstacle (excl. trees (%))	Total number of RAs - collision with solid obstacle (collision with tree (%))
2009	74 815	17 779	14 774	3 005	23.8	19.8	4.1
2010	75 522	16 894	14 429	2 465	22.4	19.1	3.3
2011	75 137	18 134	15 466	2 668	24.2	20.6	3.6
2012	81 404	19 261	16 427	2 834	23.7	20.2	3.5
2013	84 398	19 626	17 016	2 610	23.3	20.2	3.1

(Where RA .... road accident) (Source: authors; Policie ČR, 2014)

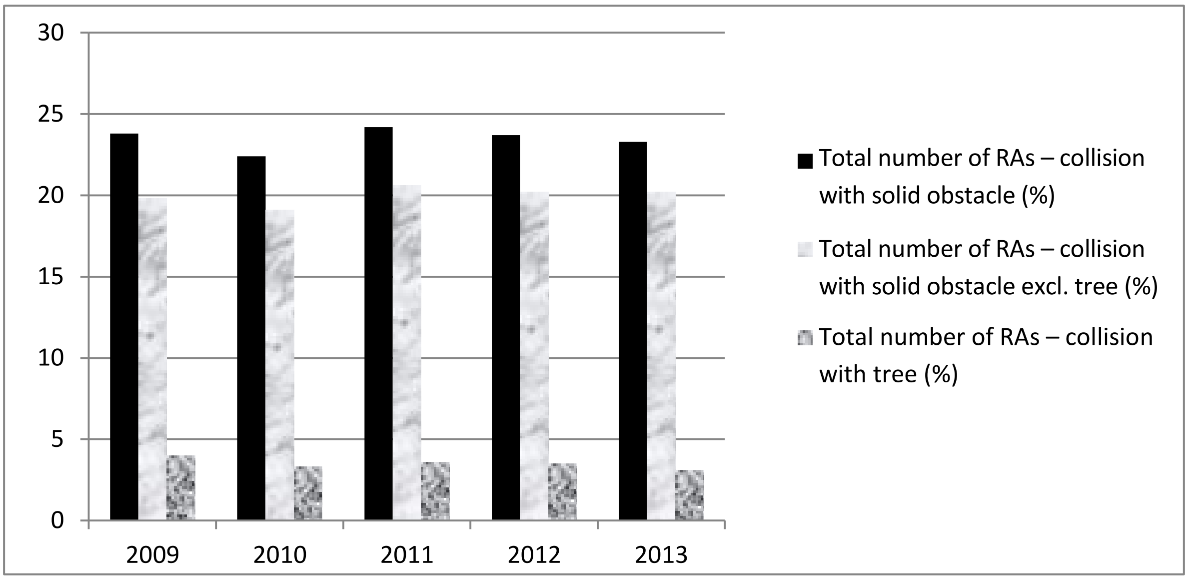

Figure 1: Statistics of road accidents for last 5 years – total number of accidents.
(Source: authors)

Table 1 shows the total number of road accidents on Czech roads and, for comparison, the total number of accidents with solid obstacles and the number of accidents with trees are shown. To be more illustrative the data are also shown in percentages and in graphic form (see Figure 1).

Table 2 shows data on mortality rate on Czech roads. Again, the data are shown in absolute values as well as in percentages and the Table is complemented with graphics (see Figure 2).

Table 2: Statistics of road accidents for last 5 years – total number of accidents.

Year	Total number of RAs on all roads	Total number of RAs – collision with solid obstacle	Total number of RAs – collision with tree	Total number of fatalities on all roads	Total number of fatalities – collision with solid obstacle (%)	Total number of fatalities – collision with solid obstacle excl. tree (%)	Total number of fatalities – collision with (%)
2009	74 815	17 779	3 005	832	27.2	11.3	15.9
2010	75 522	16 894	2 465	753	24.9	9.6	15.3
2011	75 137	18 134	2 668	707	22.5	7.6	14.9
2012	81 404	19 261	2 834	681	26	9.4	16.6
2013	84 398	19 626	2 610	583	26.4	11.7	14.7

(Where RA .... road accident) (Source: authors; Policie ČR, 2014)

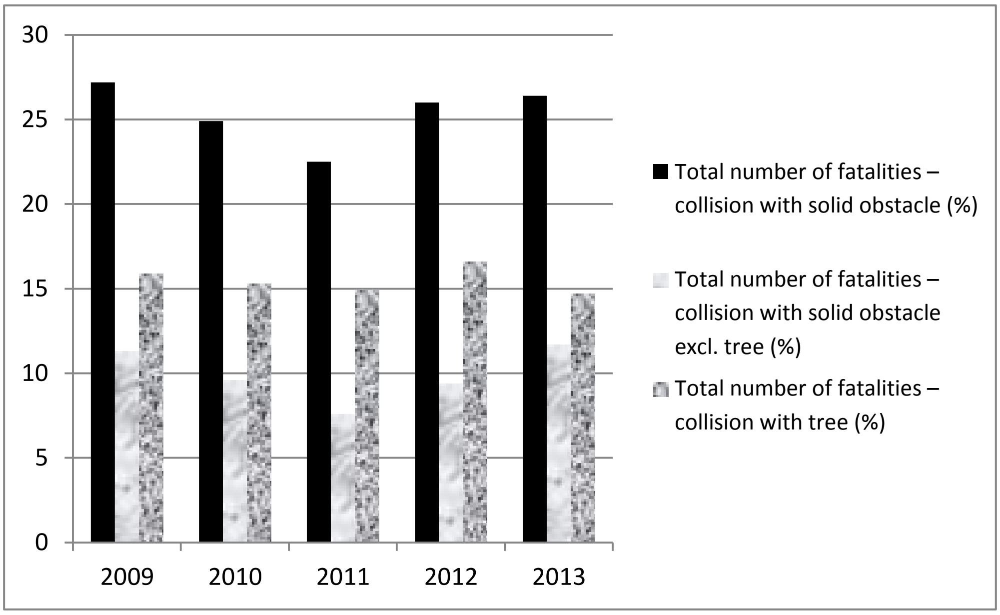

Figure 2: Statistics of road accidents for last 5 years – mortality rate.
(Source: authors)

The Tables and Graphs show the danger of trees along transport routes. Although the share of road accidents – collision with a tree only reaches 3 to 4% of all accidents, its share in mortality rate reaches from 14 to 17%. However, these numbers cover also collisions with solitary or inconveniently planted trees.

6 CONCLUSION

To conclude, the planting of bush vegetation along transport routes has a very positive impact on roads themselves, when the bush vegetation reduces the effects of cross wind and formation of snowdrifts, as well as on the surrounding environment, when the accompanying vegetation allows the road to fit better into the adjacent landscape. In addition, it creates in the Czech agriculture landscape a suitable and often the only biotope for a large number of animals.

Regarding mature vegetation, it is necessary to pay attention to road safety and particularly the distance of trees from the road. German research found that a 2-metre distance of trees from the road side does not make the accident consequences more severe than those on roads without trees. However, if we start making this distance smaller, the severity of accident consequences increases dramatically, and once the distance of trees from the road side reaches 0.5 m, the severity of consequences doubles. In the Czech Republic, the distance of trees from roads was already specified in standard ČSN 73 6101 Projektování silnic a dálnic (Design of highways and motorways) from 1957. The smallest permitted distance of a tree trunk from the road side was 2.5 m; later this distance was increased to 4.5 m (Švédová, 2010). Regarding the distance of mature vegetation planting along transport routes, the standard contains a graph specifying distance by road types. Furthermore, the standard includes the information that trees may not be planted on traffic islands, in sight fields, in protection zones of technical networks, at sites where it may obstruct visibility of road signs, etc.

The approaches to road safety vary in different European countries. For example, full-grown trees along transport routes were cut down in a massive scale for safety reasons in Germany in the 1950s. Approximately 50 000 kilometres of tree alleys had been removed by 1999 (Skalský, 2010). However, it became gradually clear that the landscape gets too monotonous and drivers are at risk of cross winds. Therefore, new planting started in 1990. This planting is accompanied by a campaign for better road safety with the emphasis on driving in tree alleys.

In Sweden tree alleys are a protected biotope (Skalský, 2010). And in Japan strips of vegetation are designed and planted 10 years before a road is put in operation, so that it would have its functions immediately (Oneyama et al., 1999). The research of relationships between road safety and accompanying mature vegetation is described in a large number of studies. Interesting results were brought by a study conducted in France (Pradines & Marmier, 2011), which, on the basis of surveys from 43 French departments, shows that there is no correlation between the data on road safety risks and the number of trees in alleys.

Mature vegetation along transport routes has formed the character of Czech landscape for centuries. As early as in 1632, Albrecht von Wallenstein had a four-row linden tree alley planted from the town of Jičín to Libosad. Thus it is necessary to make any interventions with great care. Tragic consequences of road accidents when a vehicle hits a tree are undeniable fact. The consequences of road accidents caused by a collision with a solid obstacle, particularly a tree, are described in Chapter 5, which summarizes statistics of road accidents for the last 5 years. The data in tabular and graphic form are obvious, but it is necessary to bear in mind that trees are not the ones that kill, but the driver's inattention or error is.

Collisions of motor vehicles with solid obstacles, e.g. trees, are a serious safety issue. As some research studies and experience show, in ideal cases roads should be designed without accompanying hazardous objects. However, this condition is difficult to meet and thus a compromise needs to be found. Regarding newly built transport routes, the situation is easier since mature vegetation can be planted in a sufficient distance from roads and grass and bush vegetation can be planted next to the road. Optimal distance of trees from roads is a subject of a large number of research studies, whose results vary. For example in Austria, the distances of trees at motorways are set to 4.75 m and at fist-class roads to 2.0 m (Simonová et al., 2007). The question is the distance of trees from each other. Historically, a patent from 1752 set the distance to 6 fathoms, which was 11 metres. Regarding safety, the optimum distance seems to be 40 m, but here we can hardly consider such distance a compact tree alley. Therefore planting is recommended with the distance of 25 m (Simonová et al., 2007), if possible, along a single side of the road and on the external side of horizontal curves. This recommendation correlates with other recommendations, when different sceneries do not have as tiring effect on drivers as a monotonous alley. On the other hand, driving through a tree alley makes drivers instinctively slow down. In Austria an increase in the number of road accidents occurred due to speeding on a monitored road section after the tree alley had been removed.

The situation is different with tree alleys along the existing roads. In these locations it is necessary to perform sufficient dendrological research and regular maintenance. Regarding safety, these tree alleys should always be accompanied with road safety measures, e.g. installation of suitable road signs, speed reduction, application of reflective marks and reflectors on trees, installation of crash barriers at horizontal curves. In addition, drivers' education cannot be neglected. In Germany drivers are taught as early as at driving schools to drive through tree alleys. In the Czech Republic, at least the tradition of reflective markings with a reflective paint on tree bark, which was common before 1989, becomes popular again.

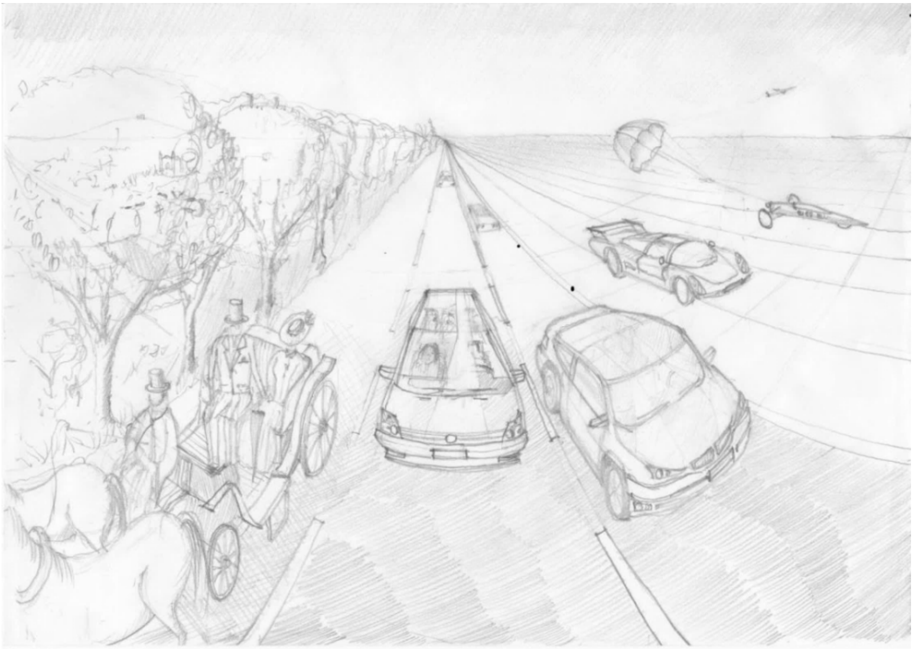

Figure 3: Vegetation along a transport route.
(Source: authors)

REFERENCES

Bulíř, P., 1988. *Vegetační doprovody silnic. Aktuality Výzkumného a šlechtitelského ústavu okrasného zahradnictví v Průhonicích*. Praha: Novinář. 198 p. (in Czech)

Cimbůrková, M., Šerá, B., 2011. Specifika vegetace kolem silnic a dálnic – problematika začlenění dřevin do volné krajiny. *Životní prostředí,* 45 (3) [online]. [cited 2014-10-31]. Retrieved from: http://147.213.211.222/sites/default/files/2011_3_162_165_cimburkova.pdf (in Czech)

Hykš, O., Neubergová, K., 2014. Vzrostlá zeleň podél dopravních cest [Mature Vegetation along Roads]. In Jandová, V., Mikulová, I., Ličbinský, R. (eds.). *VI Czech and Slovak Conference "Transport, Health and the Environment"*, Brno (Czech Republic), November 10-11, 2014. Brno: Transport Research Centre, pp. 177-184. ISBN 978-80-86502-85-4. (in Czech)

Neubergová, K., 2001. Funkce zeleně v našich městech. *Veřejná správa,* XII (16), pp. I – III. (in Czech)

Oneyama, H., Kawakami, A., Imai, R., Kosuge, T., 1999. A Possibility of Establishing the Ecologfical Network Using Road Space. Infrastructure and Transportation in the 21 Century. PIARC.

Policie ČR, 2014. Statistiky dopravních nehod [online]. © 2014 Policie ČR [cited 2014-10-31]. Retrieved from: http://www.policie.cz/clanek/statistika-nehodovosti-900835.aspx (in Czech)

Pradines, Ch., Marmier, F., 2011. Sécurité routière: véhicule-infrastructure-conducteur. *Revue générale des routes et des aérodromes* (RGRA), N. 891.

Simonová, E., Janata, M., Smělý, M., 2007. *Problematika pasivní bezpečnosti pozemních komunikací. Část 1 – pevné překážky (stromy) Rakousko, Německo*. Výstupy projektu Problematika pasivní bezpečnosti pozemních komunikací, VYPAB. Brno: CDV. (in Czech)

Skalský, M., 2010. Řidič v aleji intuitivně zpomalí. *Ekolist.cz* [online]. [cited 2014-10-31]. Retrieved from: http://ekolist.cz/cz/publicistika/nazory-a-komentare/martin-skalsky-ridic-v-aleji-intuitivne-zpomali (in Czech)

Šerá, B., 2005. Roadsite Greenery in the Open Landscape. *Životní prostředí* [online]. 39 (4), pp. 208-211. [cited 2014-10-31]. Retrieved from: http://147.213.211.222/sites/default/files/2005_4_208_211_sera.pdf (in Czech)

Švédová, D., 2010. Vegetační doprovod silnic, vliv na dopravní nehody a problémy s obnovou alejí. *Zahrada-park-krajina* [online]. (3) [cited 2014-10-31]. Retrieved from: http://www.zahrada-park-krajina.cz/ (in Czech)

Vysloužil, M., 2006. Historické aleje – cesty do historických zahrad. In *Historické zahrady Kroměříž 2006. Umění a společenská činnost v historických zahradách. Sborník vydaný u příležitosti konání odborného semináře*. Kroměříž: Agentura Bonus, pp. 41-43. (in Czech)

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Optimization of Measures to Prevent Collisions of Animals and Road Traffic

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ABSTRACT: The movement of animals on roads often causes a collision with vehicles. This not only results in the loss of animal population, but also in social losses – consequences of road accidents. This issue can be dealt with by restricting the movement of animals across roads – most commonly by fencing along roads in combination with construction of overpasses for safe crossing over roads. However, these measures also have their drawbacks – fragmentation of landscape, costs on construction and maintenance. These measures should be designed on the basis of an analysis of migration routes of animals, migration potential of an area (and thus increased movement of animals over a road), and on the basis of characteristics of the traffic flow on a given road. In 2011-2014, EDIP co. together with HBH Projekt have been working on a research project focused on the methodology for optimization of designing measures which should guide/regulate the movement of animals across the road. EVERNIA co. also participates in the project. The project is financially supported by the Technological Agency of the Czech Republic. The outcome will come in the form of a methodology which becomes a part of the regulations for designing roads.

KEY WORDS: Traffic collision, wildlife mitigation, landscape fragmentation.

1 INTRODUCTION

Migrations of animals at local, regional and higher than regional levels maintain balance between populations of animals, allow for the exchange of genetic information, even use of food sources and last, but not least they allow for the reactions of animals to changes in the environment and climate. Breaking a migration route by a construction of a road and the subsequent traffic causes stress to animals due to prevented freedom of movement, which may lead to two different situations. First, animals stop migrating and the local population losses contact among themselves. The other situation comes in the case of the migration habits of the animals being so strong that instinct overcomes the stress of road crossing. The success of crossing depends on the animal species, road category and traffic volume (EDIP, 2012).

Animals crossing roads cause collisions with vehicles and consequently losses in the population of migrating animals as well as social losses occurring due to road accidents. This issue can be dealt with by regulating animal movement over roads – most commonly by fencing the entire road section in combination with corridors for safe crossing of roads (ecoducts over roads, high capacity bridges, guiding stripes). Large financial resources are spent on the application of different measures to allow for animal migration over roads of different types.

The design of these measures should be realized on the basis of an analysis of animal migration routes and area migration potential.

So far no complex methodology has been developed that would take into account the following:

- real effect of these measures on individual animal populations,
- economic efficiency of these measures,
- necessity of these measures – fencing, ecoducts ("when to implement, and when not yet"),

in relation to traffic volume on roads.

All of the three aforementioned points are closely related to the probability of a potential conflict, which, apart from the frequency of occurrence of different animals, is directly influenced by another factor – character of traffic flow (particularly the gaps between vehicles) at sites of potential collision of vehicles with migrating animals (EDIP, 2007).

2 PRINCIPLE OF METHODOLOGY

The methodology is based on an expert evaluation of factors which influence the number of collisions with animals. These effects concern both the road, and the animals.

Regarding the road, particularly the technical road parameters are concerned:

- design road category, road arrangement (number of traffic lanes, their classification),
- horizontal and vertical road alignment,
- parameters and distances of bridges,
- design of areas under bridges,
- design of waterway diversions,
- other technical parameters (road fencing, extent of anti-noise screens, vegetation, alternative vegetation planting, etc.).

Regarding road traffic, traffic volumes are concerned (typically expressed as AADT [veh/day]).

Regarding animals, the following factors are concerned:

- Polygons of unfragmented area by traffic,
- Categorization of the Czech Republic in terms of occurrence and migration of large mammals,
- Long distance migration corridors for large mammals in the Czech Republic,
- Migration important areas,
- Territorial system of ecological stability,
- Biotopes CORINE,

- Quality category of involved hunting grounds,
- Migration activity of animals,
- Animal categories (according to TP180).

The methodology takes all of these factors into account and tries to quantify them. Since quantification is difficult concerning animals in most cases, the methodology works with point scales.

3 BASIC DATA ON ACCIDENTS WITH ANIMALS

Accidents with game (or generally called animals, we use both terms further on in the text as equivalents) make up approx. 5% of all accidents on the road network in the Czech Republic. 1 person dies with 3900 road accidents every year, 9 are severely injured and 85 are slightly injured. Material damage of these accidents amounts to CZK 155m per year (EDIP, 2012).

The evaluation concerned the road accidents recorded by Czech police in 2009-2012 which in their statistical forms contained “collision with game” in the item “Accident type” (see Table 1). Another group concerns accidents when the driver claims his/her behaviour was affected by animal(s) on the road. There are approx. 300 accidents of this type.

Table 1: Road accidents with animals, basic statistics.

Year	Number of accidents	Number of persons			Material damage in million CZK
		killed	severely injured	slightly injured	
2009	2 804	0	9	61	112
2010	3 219	1	3	56	127
2011	3 693	3	11	63	145
2012	5 953	0	13	157	234
Average	**3 918**	**1**	**9**	**84.3**	**154.5**

In order to present a more objective comparison, we calculate relative accident rate with animals on individual road categories (and classes) related to road lengths and traffic performance on them (see Table 2, Figure 1 and Figure 2).

Table 2: Road accidents with animals, relative accident rate.

	motorway	highways	secondary roads	tertiary roads
Average number of accidents with animals [accidents/year]	199	1 205	876	692
Network length (2010) [km]	734	6 255	14 635	34 129
Traffic performance (2010) [mil. vehkm/year]	7 381	19 337	12 351	7 447
Density of accidents with animals [accidents / km/year]	0.27	0.19	0.06	0.02
Relative accident rate with animals [accidents / mil. vehkm /year]	0.03	0.06	0.07	0.09

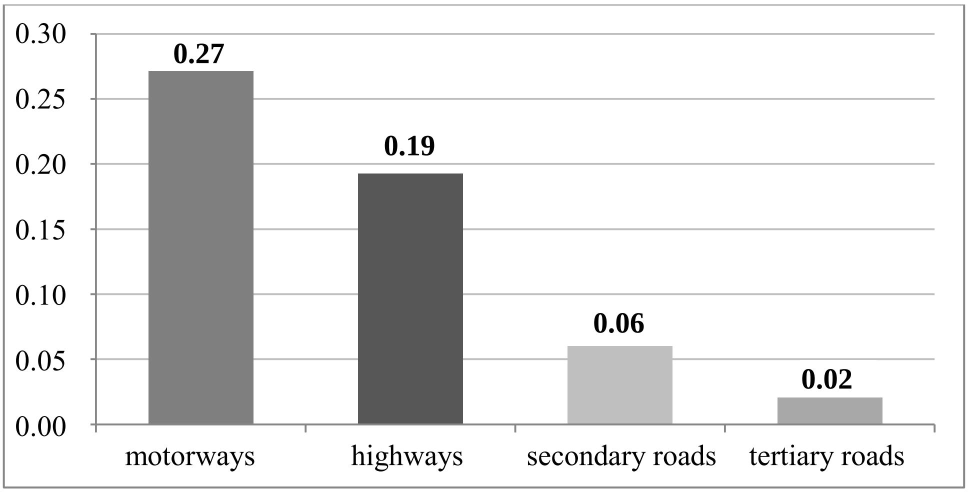

Figure 1: Density of accidents with animals [accidents/km/year].

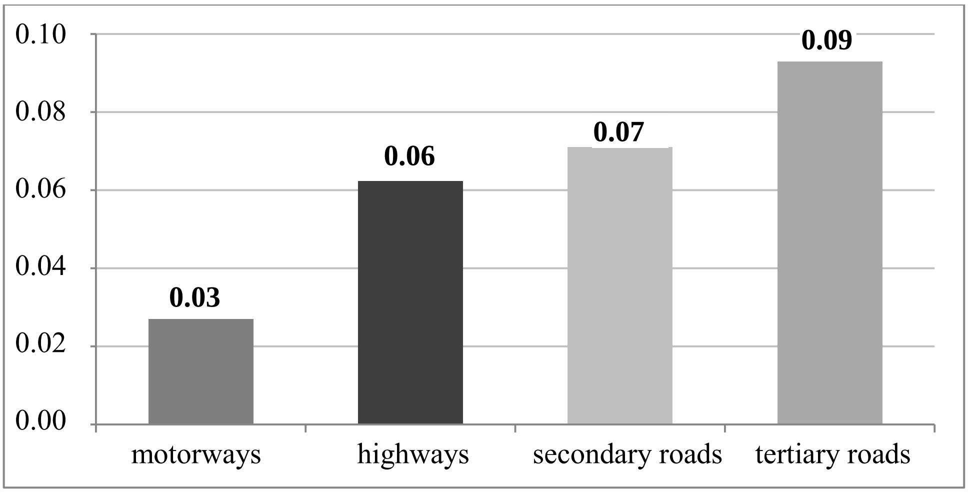

Figure 2: Relative accident rate with animals [accidents/mil.vehkm/year].

If we relate the number of accidents with animals to traffic performance (which is an objective indicator or relative accident rate), motorways are the most hazardous and the indicator of relative accident rate grows with decreasing category of road.

4 MIGRATION PRESSURE

The evaluation of local migration, or rather migration pressure modelling, is based on the evaluation of ecological migration potential evaluation (MPE), which is described in detail in “TP 180: Migrační objekty pro zajištění průchodnosti dálnic a silnic pro volně žijící živočichy” (Migration structures to provide permeability of roads and motorways for wild animals) (Anděl, 2006). These guidelines form basic frameworks for the designing of migration structures on roads and motorways in the Czech Republic. They define the terms, perform categorization of animals in terms of the requirements for migration structures, and describe recommendations as to technical solutions and dimensions of migration structures. The guidelines introduce the obligation to produce a so-called migration study – evaluation of migration routes of wild animals and design of measures to reduce the road barrier effect – at the stage of investment preparation for building roads. The migration study is a necessary prerequisite for ecological, technical and economic optimization of solutions (Anděl et al., 2011).

In the first stage, MPE is defined on the basis of an analysis of an area and expresses a probability of an area being used for migration (migration pressure before construction). Its evaluation is based on the current and prospective landscape situation. Long-term survey of an area in question is an inseparable part.

The value of MPE can be determined homogeneously for the whole length of a road in question or it can be determined separately for individual road segments and animal categories according to changing conditions of the local environment.

The evaluation of the total ecological migration potential is performed by an educated estimate – synthesis of individual factors which is used for the ratio between positive and negative properties for migration.

The following table shows an overview of possible levels which are defined for individual partial factors of migration pressure. Grey marked boxes indicate that the level is not defined for a given factor.

Table 3: Overview table of individual factor levels.

Individual factor	**Factor level**				
	Factor significantly increases migration pressure	**Factor increases migration pressure**	**Factor has no effect on migration pressure**	**Factor decreases migration pressure**	**Factor significantly decreases migration pressure**
1. Polygons of unfragmented area by traffic	++	+	0		
2. Categorization of the Czech Republic in terms of occurrence and migration of large mammals	++	+	0	-	--

3. Long distance migration corridors for large mammals in the Czech Republic		+	0		
4. Migration important areas		+	0		
5. Territorial system of ecological stability	++	+	0		
6. Biotopes CORINE	++	+	0	-	--
7. Quality of involved hunting grounds	++	+	0		
8. Migration activity of animals		+	0		
9. Horizontal alignment of road segment in question		+	0	-	--

The synthesis of individual factors can also be performed by the sum of their levels. The resulting value of the total ecological migration potential ranges between 0.0 and 1.0 according to the following table.

Table 4: Evaluation of MPE.

Sum of individual factors	MPE value	Ecological migration potential	Characteristics
10 – 14	1.0 – 0.8	Very high	Very important area in terms of migration with all-year or seasonal migration of animals
5 – 9	0.8 – 0.6	Above average	Important area in terms of migration with all-year or seasonal migration of animals
0 – 4	0.6 – 0.4	Average	Area with predominant changed biotopes with scattered (non-concentrated) migration of animals, which is particularly influenced by varieties of field crops
-1 – -3	0.4 – 0.2	Below average	Areas of low importance in terms of migration of animals, with low quality of biotopes or an area with obstacles complicating migration
-4 – -6	0.2 – 0.0	None	Unimportant area near urban development areas where the occurrence of wild animals is not expected

5 TRAFFIC VOLUME, PROBABILITY OF COLLISION

In order to determine the probability of a collision of a vehicle and animal, we need to know both the model of vehicle gaps on the road, and behaviour of animals crossing the road (Martolos & Anděl, 2007). Traffic flow consists of individual vehicles and gaps between them (Medelská et al., 1991). These gaps can be used by animals to cross the road. The frequency of gaps particularly depends on traffic volume. A simple exponential distribution is derived from the Poisson process of the number of vehicles which run through a given place on a road for a time interval t, under the assumption of random movement of vehicles on the road (i.e. it is not influenced by other factors, such as vicinity of junction, traffic restrictions, etc.) (Karlický & Slabý, 1983).

The density of probability of a simple offset exponential distribution of time gaps is in the form of:

$$f(t) = \frac{I}{3600} e^{-\frac{I}{3600}t} = ie^{-it} = \frac{1}{T} e^{-\frac{t}{T}}$$

where I stands for average hour traffic volume, i is average second traffic volume and T is average time interval expressed in seconds (Pistulka, 1970).

In order to determine the probability that the time interval W is higher than t [s], the summation function (summation line) is used. This is given by an equation for a simple non-offset exponential distribution:

$$P(W > t) = e^{-\frac{I}{3600}t}$$

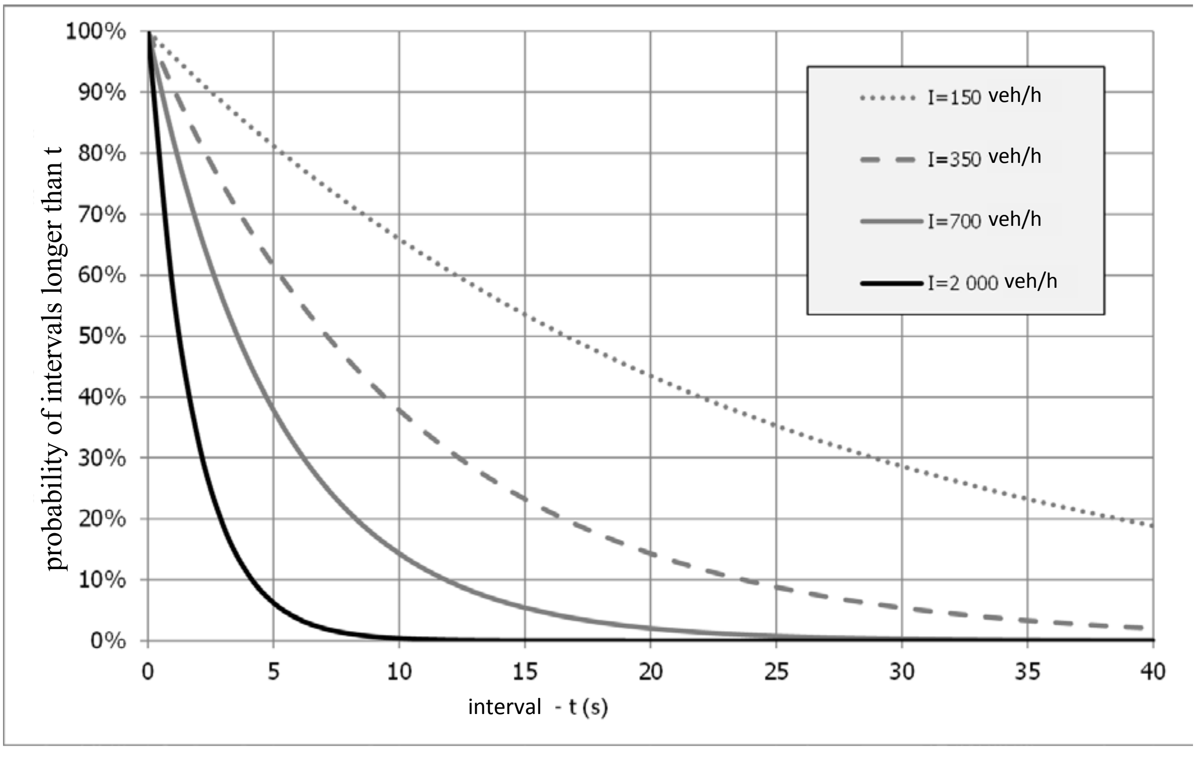

Figure 3: Probability of intervals longer than t (s) for different traffic volumes.

Figure 3 shows the so-called summation lines of the interval occurrence (i.e. probability of occurrence of an interval longer than the given time) for different traffic volumes.

Since the traffic volume fluctuates during the day (so-called daily variations of traffic volumes) (Martolos, 2012), graphs were created showing the probability of intervals shorter than t (s) for different hourly traffic volumes – see Figure 4.

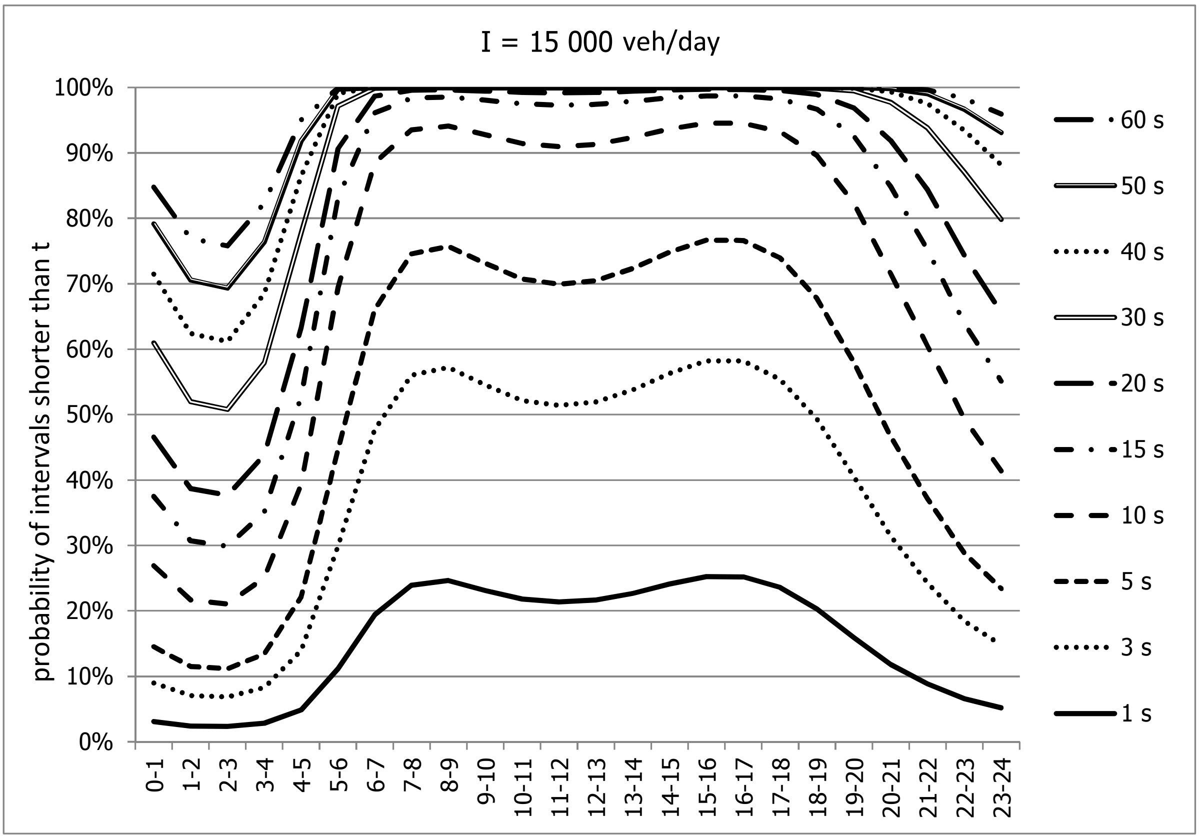

Figure 4: Probability of intervals shorter than t (s) during day.

If we know the time an animal moves for/on the road, which is not an easy task, we are able to calculate a probability of a collision with the given animal. In addition, if we know the distribution of the probability of occurrence of an animal on the road during the day (which can be guessed from the behaviour of individual species and from performed research by photo traps), we are able to calculate the probability of the number of collisions for a given time period (Martolos & Anděl, 2013).

If we know the migration pressure and collision probability, it is possible to guess the number of hit individuals on a given road segment and evaluate the effectiveness and character of measures for reducing collisions between vehicles and animals.

6 CONCLUSION

The answer to the question whether to use a fence or not, or what other measures to use, depends on many factors. Some of them can be clearly defined and specified, but some (as it is very common in the area of ecological issues) can be precisely determined with difficulties. Therefore, there will always be room for professional opinion and evaluation of experts on migration who design a solution after taking into account all impacts.

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REFERENCES

Anděl, P., 2006. TP 180: Migrační objekty pro zajištění průchodnosti dálnic a silnic pro volně žijící živočichy. Liberec: Evernia. (in Czech)

Anděl, P., Belková, H., Gorčicová, I., Hlaváč, V., Libosvár, T., Rozínek, R., Šikula, T., Vojar, J., 2011. *Průchodnost silnic a dálnic pro volně žijící živočichy*. Liberec: Evernia. 154 p. (in Czech)

EDIP, 2007. Projekt VaV č. 1F55A/065/120 - Využití dopravně inženýrských dat a metod pro kvantifikaci vlivů dopravy na životní prostředí (roční zpráva). (in Czech)

EDIP, 2012. Projekt TA01030107 - *Metodika optimalizace návrhu opatření k usměrnění pohybu živočichů přes pozemní komunikace*. Odborná zpráva o postupu jednotlivých prací a dosažených výsledcích 2011. (in Czech)

Karlický, K., Slabý, P., 1983. *Teorie dopravního proudu (Výběrový předmět 1).* Praha: ČVUT. (in Czech)

Martolos, J., Anděl, P., 2007. Odstupy mezi vozidly v dopravním proudu a pravděpodobnost srážky se zvěří. *Silniční obzor,* 68 (12), pp. 337-340. (in Czech)

Martolos, J., 2012. TP 189: Stanovení intenzit dopravy na pozemních komunikacích, 2. vydání, Plzeň: EDIP. (in Czech)

Martolos, J., Anděl, P., 2013. Distances between Vehicles in traffic Flow and the Probability of Collision with Animals. *Transactions on Transport Sciences*, 6 (2), pp. 97-106. ISSN 1802-971X.

Martolos, J., Šikula, T., Libosvár, T., Anděl, P., 2014. Optimalizace opatření k omezení střetu živočichů a dopravy na pozemních komunikacích [Optimization of Measures to Prevent Collisions of Animals and Road Traffic]. In Jandová, V., Mikulová, I., Ličbinský, R. (eds.). *VI Czech and Slovak Conference “Transport, Health and the Environment“*, Brno (Czech Republic), November 10-11, 2014. Brno: Transport Research Centre, pp. 55-62. ISBN 978-80-86502-85-4. (in Czech)

Medelská, M. et al., 1991. *Dopravné inženierstvo*. Bratislava: Alfa. (in Slovak)

Pistulka, B., 1970. Způsoby a výsledky analýzy rozdělení časových intervalů dopravního proudu. In *„Modernizace a rozvoj silnic, dálnic a místních komunikací“: seminář*, Havířov. (in Czech)

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Innovative Tools of Sustainable Mobility in European Urban Areas: Experience with Evaluation and Role of Political Barriers

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ABSTRACT: The presented article describes a European initiative for supporting innovative measures in sustainable transport in urban areas Civitas, particularly its latest completed edition Civitas Plus (2008-2012). The article presents the evaluation process of the performed measures and shows an overview of the main obstacles the Civitas Plus cities struggled with (with the emphasis on political barriers). In addition, it mentions drivers which helped to implement the sustainable mobility measures. It concludes with examples from European cities on how to avoid these barriers and prevent their occurrence.

KEY WORDS: Civitas initiative, political barriers, evaluation of sustainable mobility measures.

1 INTRODUCING THE CIVITAS INITIATIVE

It is mainly cities and urban areas which bear the negative effects of transport, such as traffic congestion, road accidents, emissions of pollutants and noise, while they can significantly contribute to their reduction. Cities play the major role in economic growth and development - they produce approx. 85% of EU GDP (Bosetti et al., 2014) -, are places where services, business, culture, industry and other functions are located, and furthermore they provide the transport infrastructure. Cities grow and develop, which relates to a large number of land-use problems on different levels, particularly regarding the relationships between cities and their peripheries, or between cities and higher administration units.

Transport and mobility reflect all these activities and the related duality of economic development and the environmental limits. The demand for mobility gradually increases and higher requirements are made of transport supply and deliveries. All these have an impact on the land use of urban areas for the transport infrastructure and also on the transport behaviour of inhabitants. It is clear that transport cannot only be dealt with by satisfying demand; the experience, not only from Czech cities, clearly shows that we are already limited in this respect. The cities do not have sufficient space for building new parking places, serious traffic congestions occur, etc. It is necessary to choose a balanced mixture of measures which should lead to sustainable use of transport with maximum emphasis on the use of alternatives to individual car transport, mobility and traffic flow management.

The European initiative Civitas (City-Vitality-Sustainability) has been supporting European cities for longer than ten years in the implementation of useful measures in all fields of sustainable transport. The European Commission uses this programme to support the spreading of innovative measures and the exchange of experience among EU cities. Since

2002, the EC has specifically provided financial and organizational support to more than 60 European cities to implement more than 800 measures for EUR 120m, within four consecutive editions (programmes). The latest completed edition took place from 2008 to 2013 with the title Civitas Plus (Brůhová-Foltýnová & Jordová, 2014a).

So far the funds from CIVITAS have supported transport solutions in three Czech cities – Prague, Ústí nad Labem and Brno. The latter two cities were supported by Civitas Plus.

This article describes the evaluation methods of measures of Civitas Plus in terms of their impact as well as the implementation process, and what were the most common barriers and drivers the cities encountered within the implementation of measures. We are to focus in more detail on political barriers and how it is possible to avoid / deal with these barriers on examples from European cities.

2 EVALUATION PROCESS OF CIVITAS PLUS PROJECTS

In total, 5 projects in 25 cities were implemented within the edition of Civitas Plus, which altogether made more than 300 measures to sustainable mobility. These measures were evaluated on the basis of their overall effectiveness. The following projects and cities were involved:

- ARCHIMEDES (Aalborg, Brighton & Hove, San Sebastian, Iasi, Monza, Usti nad Labem);
- ELAN (Ljubljana, Gent, Porto, Brno, Zagreb);
- MIMOSA (Bologna, Funchal, Utrecht, Gdansk, Tallinn);
- MODERN (Craiova, Brescia, Vitoria/Gasteiz, Coimbra);
- RENAISSANCE (Szczecinek, Perugia, Bath, Gorna Oryahovitsa, Skopje).

The implemented measures needed to be innovative and had to extend the existing knowledge and experience of the cities in the field of sustainable mobility. Some of their innovative features are mentioned as follows (Civitas Pointer, 2013a):

- Measures using new tools or methods: 48% of all measures;
- Measures using new technologies / ITS (real-time information on usage of vehicles, distribution of parking vehicles, intervals of buses and passenger flows or checks of signalling systems adapting to the existing traffic situation): 45% of all measures,
- Measures focused on specific groups of users (people living close to a bus line or travelling to a certain locality, or drivers of a certain type of vehicle): 39% of all measures.

The measures were divided into 8 thematic groups, which allowed for better comparison and evaluation. The following thematic groups were specifically involved: 1) Alternative fuels and clean and energy-efficient vehicles, 2) High quality energy-efficient Passenger Transport, 3) Economic based Demand Management strategies, 4) Mobility Management, Communication and Education, 5) Safety and Security, 6) Mobility services for energy-efficient vehicle use, 7) Energy efficient freight distribution, and 8) Innovative Transport Telematics Systems (Civitas Pointer, 2013b).

Within Civitas Plus, the monitoring and methodology of the evaluation of results of implemented innovative measures in cities, as well as harmonization of these processes among the above mentioned five projects / 25 cities was performed by another project called POINTER. The dissemination of outcomes and the presentation of experience were then coordinated by the project VANGUARD.

2.1 Evaluation process

The whole process of evaluation of Civitas Plus projects consisted of two parts – evaluation of impacts and evaluation of processes (Civitas Pointer, 2013a). The first of them was more quantitative and was based on monitoring and evaluation of relevant indicators of impacts of implemented measures. A template was created with 30 indicators from 5 fields (economy, energy, the environment, society, transport), from which the cities, or institutions which supplied them with expertise for the evaluation, chose the relevant indicators.

The evaluation of the process was then based on the description of barriers, drivers, and performed activities which the cities encountered with individual measures. In this was the data on the impact of measures concerning "talking of what is behind the numbers" were collected. The evaluation was performed at several levels – level of measures, package of measures, the city and the whole edition of CIVITAS Plus.

The evaluation of impacts showed that the measures in the Civitas Plus cities led to increased use of public transport (3 – 30% increase in the number of passengers in these cities), to reduced use of cars (between 4 and 15%), increased popularity of walking and cycling (between 1 and 4%; in some cities this increase meant doubled number of cyclists), reduced presence of heavy vehicles in urban areas by 60%, and reduced emissions of CO_2 by up to 55% (Civitas Pointer, 2013a).

3 ANALYSIS OF BARRIERS AND DRIVERS

The further text discusses the evaluation of processes, particularly barriers and drivers which influenced the process of the implementation of measures in the cities of Civitas Plus. The following table summarizes the most common barriers and drivers which the cities encountered in different stages of the Civitas projects realization (preparation, implementation, and operation).

Table 1: Overview of main barriers, drivers, and activities of cities under Civitas Plus projects.

	Preparatory stage	Implementation stage	Operation stage
Barrier	Political, planning	Cultural	Technological, spatial
Driver	Problem-related		Planning, spatial
Activity	Involvement of public	Involvement of public	Political, involvement of public, technological

(Source: Brůhová-Foltýnová & Jordová, 2014a)

3.1 Political barriers and drivers

One of the most often mentioned barriers and drivers are the political ones, i.e. related to the decision-making process, funding, production and quality of legislation environment, etc. The most commonly mentioned political barriers / drivers which occurred in European cities of Civitas Plus within the evaluation process are summarized by the following Table. It particularly concerns the lack of integrated long-term planning, but also the formulation of visions and involvement of stakeholders. Since this was mentioned as a barrier by 22 out of 25 cities, it may indicate that those are the problems encountered by both post-communist countries and also countries with a longer democratic tradition. Other barriers mentioned by the cities most often concerned a lack of funds for measures in sustainable mobility (Civitas Plus edition was a large part of the progress in the time of economic crisis) and legislation. These barriers are also closely related to political decision making.

Table 2: Overview of main political barriers and drivers for cities of Civitas Plus.

Barrier / driver	No. of cities: Barriers	No. of cities: Drivers
Process of tender – legislation, organization	17	6
Local elections, personnel changes in town council	6	6
Communication between relevant town council departments	8	8
Legislation	18	9
Integrated planning, production of visions and involvement of stakeholders	22	23
Finance	19	17
Cultural differences	16	12
Other	20	0

(Source: Brůhová-Foltýnová & Jordová, 2014a)

According to the cities of Civitas Plus, *the process of integrated planning and involvement of stakeholders* was complicated primarily due to low support of politicians, difficult coordination of different stakeholders, low awareness and knowledge of users and transport experts on new traffic measures, or due to the fact that their potential users failed to realize the benefits or even the existence of the measures (Aalborg, Donostia-San Sebastian, Iasi, Ljubljana, Monza, Vitoria-Gasteiz). Some barriers were caused by a missing common vision, strategy or political documents at the city level. A number of cities openly admitted that the measures were not accepted due to insufficient, cumbersome or exceedingly optimistic planning (Craiova, Gent, Monza, Perugia, Porto, Tallinn, Zagreb). Some problems with communication with key stakeholders were also caused by other reasons which could not be influenced (e.g. schools in Brescia and Utrecht had already been overloaded with other activates). In contrast, support of politicians, acceptance by public or even active demand for measures led to smoother and faster implementation of the measures.

Regarding the *financial barriers and drivers*, among the mentioned barriers by cities belong: different financial priorities of the cities (low importance for sustainable mobility measures), insufficient financial planning, and economic crisis and lastly the related cuts in city / national budgets. In contrast, drivers included savings of public transport operators / cities that were / were to be reached thanks to the implemented measures. Similarly, the economic crisis motivated people to use public transport, alternative fuels and P+R more often.

According to the cities of Civitas Plus, *legislation* often suffered because of the non-existence of specific measures and missing standardization (lack of national standards). For example, there was missing legislation for production of mobility plans in Aalborg and Coimbra, the implementation of measures in Donostia-San Sebastian and Zagreb was complicated by missing standards for biofuel quality. In addition, legislation limitations complicated and slowed down public procurement in Craiova and Tallinn or led to situations that the use of vehicles for biodiesel was economically disadvantageous (Craiova, Ljubljana). In contrast, the legislation drivers concerned new tools for regulation and integration of visions and measures from the regional level to national level.

Cultural differences include barriers, such as distrust in novelties, conservatism, misunderstanding, reluctance to give up the perception of a car as a status symbol, lack of awareness among users on a given measure and vandalism. A life style independent on cars and the perception of a car as a status symbol are other frequently mentioned cultural barriers of the cities of Civitas Plus (Bologna, Brescia, Donostia-San Sebastian, Gent, Iasi, Monza, Tallinn, Ústí nad Labem, Vitoria-Gasteiz). Italian Bologna struggled with a problem to persuade parents and schools to allow children to go to and leave school on their own. In contrast, the drivers included a positive approach of target groups, awareness of stakeholders, willingness to change and interest in the environment.

Signs of changes in mobility culture appeared in Donostia-San Sebastian, new culture and life style is also taking root in Brescia and traffic behaviour preferring sustainable transport is also catching up in Funchal. Inhabitants and experts in Utrecht clearly showed that congestion cannot be solely dealt with by building more road infrastructure and that the smart use of traffic management tools is a better solution.

3.2 Analysis of barriers and drivers: conclusions

The experience from the cities of Civitas Plus indicates that the number of barriers which appear in individual stages of the project performance significantly influences the implementation success of traffic measures and their impacts. However, they depend on the type of the measure and location (local/national cultural, legislation and economic context). The success of the measure in the preparatory stage is particularly influenced by political barriers. This stage is also important for technical or RTD traffic measures, since in this stage it is necessary to gain knowledge and expertise. The implementation and operation stages are influenced by organization and planning barriers and financial, technological and spatial barriers.

It was found that targeting the right stakeholders and involving suitable partners has a significantly greater impact on the successful measure implementation than its innovation. Some of the cities from Eastern Europe were confronted with barriers of accepting technological solutions that were locally innovative (but common in Western Europe). Furthermore, they faced technological barriers, e.g. unavailable national / local technology or sufficient number of qualified staff with knowledge of the particular technology.

Public acceptance may seem to be a barrier in the preparatory stage, but should not be an automatic reason to cancel a measure – a successful pilot stage can lead to better acceptance of such a measure and its subsequent implementation.

In the end, most of the barriers were successfully overcome by the cities of Civitas Plus; only 9 measures out of 300 were stopped or cancelled.

4 HOW TO PREVENT POLITICAL BARRIERS

The political environment (thus also the number and impacts of political barriers) influences the implementation process of sustainable mobility measures, although its impact is not fatal and consequently does not lead to measure cancellation. The project POINTER identified factors which influence the political environment, and thus indirectly the implementation of innovative traffic measures. The following factors (based on Dobranskyte-Niskota et al., (2007), Kelly et al., (2004), Litman (2011), Wefering et al. (2013)) are concerned:

- Number and structure of policies which are related to transport and their integration and harmonization;
- Existence of integrated transport policies (SUMP – Sustainable Urban Mobility Plan);
- Active use of traffic models;
- Effective long-term planning;
- Stability of local bodies (city councils) – organization of extraordinary community elections;
- Planning of financial resources;
- Planning of human resources;
- Active communication with (local) politicians/representatives;

- Approaches to public involvement;
- Regular revision of strategies and policies.

The role of these factors are shown in this chapter using examples from the following European cities of Civitas Plus: Aalborg, Gent, and Donostia – San Sebastian.

4.1 Integration of political documents and strategies in Aalborg

The Danish city of Aalborg has documents prepared which deal with all relevant aspects of sustainable transport (Civitas Pointer, 2013c). The city tries to harmonize and integrate these documents. Specifically, Aalborg has prepared an overall municipal strategy since 2009 and the land-use plan as well. The main sector document dealing with transport – General Transport Policy – was produced in 1990. It consists of general traffic plans for public transport, cycling and walking. The General Transport Policy is produced so that it would particularly support sustainable transport modes with the focus on mobility, the environment and public health, that it would create a balance between demand for growing mobility and environmental protection, that it would minimize negative impacts of transport and provide accessibility in the city and the whole region.

Aalborg has the Mobility Strategy prepared for 2013 – 2025. Furthermore, the city uses a number of action plans, e.g. action plan for parking, cycling support, road traffic safety, noise reduction, the infrastructure and use of information technologies in transport. In 1994 Aalborg adopted the first Action plan for Traffic and the Environment, which was supported by the Danish Ministry of the Environment.

Furthermore, the city uses a wide range of studies and expert analyses, e.g. a study of the infrastructure in the sea port, conditions for tenders and a new parking scheme. In addition, it reflects national policies and their goals, e.g. the Danish National Strategy on Alternative Fuels. Aalborg organizes campaigns, such as safe ways to schools, safety audits and others.

Transport issues are also included in other sectors and more general urban strategies, such as the Sustainability Strategy. The so-called Aalborg Charter was signed in 1994 in Aalborg (The Charter of European Sustainable Cities and Towns towards Sustainability), which bounds European towns and villages to responsibility in the area of producing sustainable and responsible communities (their higher involvement in Agenda 21). It deals with sustainable development and transport. The Charter was extended to Aalborg's commitments 10 years later.

4.2 Long-term planning and strategic visions in Gent

Gent adopted an ambitious urban development strategy called "Climate Plan Neutral Gent 2050". This strategy defines its vision – to become a climatically neutral city by 2050 – which focuses on all aspects of urban functions, not only of transport (Civitas Pointer, 2013c).

A number of different steps were made by the city to meet the objectives of these visions. The Climate Alliance was established in 2009. It associates several Climate Workgroups and supports the exchange of experience within the work groups as well as in between them. A Climate Plan Gent for 2008-2020 (it is an action plan with 105 activities) and an air quality plan were prepared. This plan designs a large number of specific steps, such as tools to support cycling as a non-emission transport mode, "greener" public transport, car-sharing, low-emission zones, traffic management systems, etc.

Furthermore, the city of Gent adopted a mobility plan for the whole city. The first mobility plan was adopted as early as 1997, and then it was followed by a new successful mobility plan in 2003, which significantly influenced mobility in the city.

4.3 Regular revision of strategies and policies: Donostia-San Sebastian

The Spanish city of Donostia-San Sebastian adopted a number of activities and campaigns for support of sustainable mobility, e.g. car-sharing and car-pooling systems, safe routes to school, personal mobility plans, commuting mobility plans, a Road Safety Charter, 30 km/h zones, etc.

The city's general strategy is always valid for 10 years, but it is continuously updated. Similarly, the transportation policy and its strategic plan are discussed with stakeholders every four years. The long-term financial plan of the city used to be regularly updated every four years, now it is every year.

5 CONCLUSION

The Civitas initiative continues with the current edition of Civitas Plus II, and other projects will be funded by the programme CIVITAS 2020. Therefore, there is an opportunity for Czech cities to get involved in some of the projects and receive support for the implementation of sustainable transport measures. Czech and Slovak cities can get in contact with Civitas through a newly established network of cities CIVINET, whose partial task is to support the exchange of experience of cities with the focus on sustainable mobility support.

The sustainable transport measures supported by the Civitas initiative are both "hard" (i.e. changes or construction of the infrastructure, purchase of vehicle fleet, etc.), and "soft" (particularly focused on informing and raising awareness of the public, better traffic management, car-sharing, car-pooling, and parking policy). Taking into account the innovation aspect of the supported measures, there can be pilot measures for alternative fuels or drives in passenger, personal and public transport and freight transport, or measures using modern information technologies.

In addition, Civitas provides cities with an opportunity to focus on the issue of planning, monitoring and evaluation. The cities can have a Sustainable urban mobility plan prepared, missing data collected, and an important study produced. The fact that the cities find the impacts of the introduced measures and analyse barriers and drivers brings potential for improvement of strategic and long-term urban planning and for a feedback on the functioning of the city and city organizations. Therefore, we can gain experience and prospective potential to reduce the risk of occurrence of barriers described in this text under the realization of the sustainable mobility measures.

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REFERENCES

Bosetti, S., Brůhová-Foltýnová, H., Jordová, R. et al., 2014. *Policy recommendations for EU Sustainable Mobility Concepts based on CIVITAS experience*. Freiburg (Germany): ICLEI, Brno (Czech Republic): Transport Research Centre. 68 p. ISBN 978-80-86502-77-9.

Brůhová-Foltýnová, H., Jordová, R., 2014a. The contribution of different policy elements to sustainable urban mobility. *Transportation Research Procedia*. **Accepted for publication.** ISSN 2352-1465.

Brůhová-Foltýnová, H., Jordová, R., 2014b. Inovativní nástroje udržitelné mobility v evropských městských oblastech: zkušenosti s evaluací a role politických bariér [Innovative Tools of Sustainable Mobility in European Urban Areas: Experience with Evaluation and Role of Political Barriers]. In Jandová, V., Mikulová, I., Ličbinský, R. (eds.). *VI Czech and Slovak Conference "Transport, Health and the Environment"*, Brno (Czech Republic), November 10-11, 2014. Brno: Transport Research Centre, pp. 167-174. ISBN 978-80-86502-85-4. (in Czech)

CIVITAS POINTER, 2013a. *Deliverable 2.6.1, Overview of Evaluation Findings*. Transportation Research Group. University of Southampton.

CIVITAS POINTER, 2013b. *Deliverable 2.5.1c, Final report on wider implementation of measures.* TRG - University of Southampton. Transport Research Centre.

CIVITAS POINTER, 2013c. *Deliverable 3.2.2, Final Report on Policy Assessment in the Civitas Plus Programme.* Transport Research Centre.

Dobranskyte-Niskota, A., Perujo Mateos Del Parque, A., Pregl, M., 2007. *Indicators to Assess Sustainability of Transport Activities - Part 1: Review of the Existing Transport Sustainability Indicator Initiatives and Development of an Indicator Set to Assess Transport Sustainability Performance* [online]. ISBN 978-92-79-07802-6 [cited 2014-10-31]. Retrieved from: http://publications.jrc.ec.europa.eu/repository/handle/111111111/10416

Kelly, J., Grosvenor, T., Jones, P., 2004. *Successful transport decision-making. A project management and stakeholder engagement handbook. VOLUME 1 - Concepts and Tools*. GUIDEMAPS consortium.

Litman, T., 2011. *Developing Indicators for Comprehensive and Sustainable Transport Planning* [online]. Victoria Transport Policy Institute [cited 2014-10-31]. Retrieved from: http://www.vtpi.org/sus_tran_ind.pdf

Wefering, F., Rupprecht, S., Bührmann, S., Böhler-Baedeker, S., 2013. *Guidelines. Developing and Implementing a Sustainable Urban Mobility Plan.* Rupprecht Consult.

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Air Pollution by Gases and PM in Rural Areas

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ABSTRACT: Pollution of the air by gases (nitric oxide, nitrogen dioxide, nitrogen oxides) and particulate matter is a matter of everyday life. Particulate matter (PM) is one of hazardous pollutants causing deterioration of the environment and thus quality of life of the population. Long-term exposure to effects of increased concentrations of gaseous pollutants can also cause deterioration of the environment and human health. Particulate matter and gases production by road transport is a burning issue, particularly for larger urban areas. However, pollution also occurs outside urban areas from different sources (road transport) that primarily affect vegetation and animals living in the given areas. The environment in urban areas can be affected secondarily by a long-range transfer of pollutants. Due to the dominant use of combustion engines, exhaust gases contain large amounts of gaseous pollutants as well as particulate matter. They particularly include a large amount of the finest PM fractions, which can remain in the air for a long time, easily enter respiratory tracks, and damage human health. The other part includes particulate matter produced by the friction of different parts of roads and vehicle fleets, which concerns matter of larger aerodynamic diameters. The aim of the presented part of the work is to monitor production of particulate matter and gaseous pollutants along roads in rural areas and evaluate their inter-relations, while taking into account the monitored meteorological characteristics and traffic volume.

KEY WORDS: Particulate matter, gaseous pollutants, meteorological characteristics, traffic volume, regression analysis.

1 NEGATIVE EFFECTS OF SELECTED POLLUTANTS ON THE ENVIRONMENT

Particulate matter (PM) can be produced by natural sources or by anthropogenic sources. The natural sources include sea salt, Earth's crust dust, pollen, and volcanic ash. The anthropogenic sources mainly include burning fuel in thermal power plants, local heating of households, and burning fuel in vehicles. Some of the major sources in urban areas include exhaust gas emissions, resuspension of road dust, and heating of households by wood or coal. These are the sources with low input of emissions to the air, under 20 m, which leads to a significant impact on the level of concentration in the human breathing zone (Jandačka, 2013; Huzlík et al., 2011; Pant & Harrison, 2013; Thorpe & Harrison, 2008; Vojtěšek et al., 2009).

The effects of PM on human health are caused after its inhalation and penetration to the lungs and the blood circulatory system, which leads to adverse effects to respiratory, cardiovascular, immunity and neural systems. The ultrafine particles (with diameters <0.1 micrometre) can even reach the brain through the nose (Breysse et al., 2013). The chemical and physical interaction between PM and lung tissue may cause irritation or damage. The smaller the particle, the deeper they reach in the lungs. The impact of PM on mortality rate is clearly related to the fraction $PM_{2.5}$, which makes 40 - 80% of weight concentration of PM_{10} in the ambient air in Europe (European Environment Agency, 2013; Jandačka, 2013). In addition, the “coarser” fraction 2.5-10 µm of the fraction PM_{10} has impact on human health and influences mortality rate.

Most of urban and rural inhabitants have experience with everyday exposure to increased concentrations of PM, which may have adverse effects on human health. Chronic exposure to PM contributes to the risk of cardiovascular diseases, respiratory track diseases, and lung cancer. The mortality rate related to air pollution is by 15 - 20% higher in urban areas with a high level of pollution in comparison with relatively cleaner areas. It is estimated that the average life expectancy in the European Union is shorter by 8.6 months due to the exposure to $PM_{2.5}$. Apart from the effects on human health, PM may also have a negative impact on climate changes and ecosystems. In addition, PM contributes to soiling of buildings and may even have corrosive effects on buildings and structures, depending on PM composition (European Environment Agency, 2013).

Nitrogen dioxide is a reactive gas which is mainly formed by oxidation of nitrogen monoxide (NO). The high temperature combustion processes (e.g. processes in car engines and power plants) are the main sources of NO and NO_2. These two gases are commonly known as NO_x. Nitrogen monoxide accounts for the major part NO_x emissions. A small part of NO_x emissions is directly emitted as NO_2, usually 5 - 10% for the majority of combustion sources. Vehicles burning diesel are an exception. They usually produce higher proportions of NO_2, up to 70% NO_x is NO_2, since their exhaust treatment systems increase the direct emission of NO_2 (Grice et al., 2009). There are clear signs that direct transport emissions of NO_2 increase dramatically as a result of the higher number of diesel vehicles, particularly new vehicles with diesel engines (Euro 4 and 5). This may lead to more frequent breaches of the limit values of NO_2 in peak hours.

Similarly to ozone, NO_2 is also one of the air pollutants which primarily affects the respiratory system. Short-term exposure to NO_2 may have adverse effects on human health, such as reduced function of the lungs for a sensitive part of the population, while long-term exposure may lead to adverse effects, such as higher vulnerability to respiratory system infections (Figure 1).

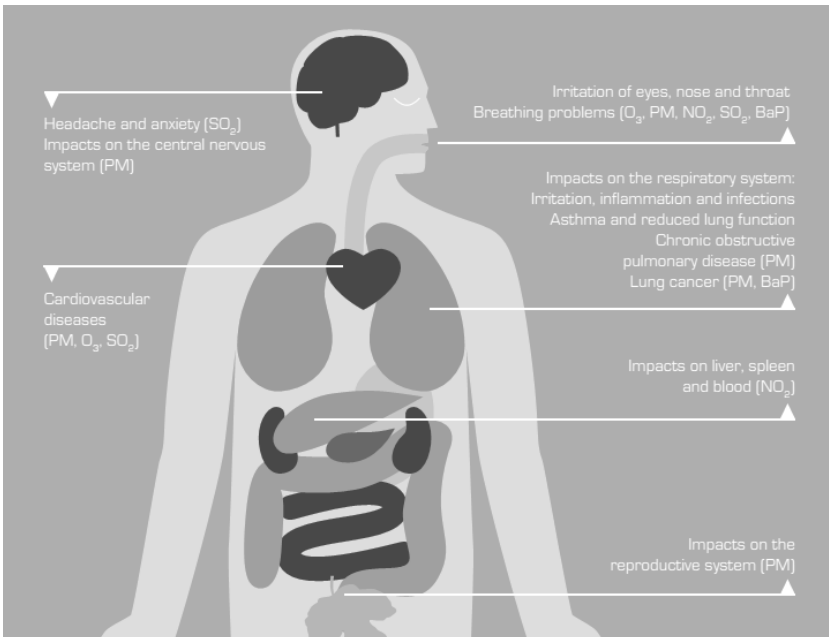

Figure 1: Impact of air pollution on human health (Breysse et al., 2013).

NO_2 is one of the reactive nitrogen compounds which may have undesirable effects on ecosystems, such as the acidifying effect. However, it is also a source of important nutrients. The excess of reactive nitrogen deposition may lead to the surplus of nitrogen nutrients in terrestrial and aquatic ecosystems, which causes eutrophication (nutrient oversupply). The excess of nitrogen may lead to changes in unique terrestrial and aquatic animal and plant communities and may cause a loss of biodiversity. Nitrogen oxides (NO_x) play an important role in the formation of O_3. They also contribute to the formation of secondary inorganic aerosols (SIAs) through the formation of nitrates thus contributing to the concentrations of PM_{10} and $PM_{2.5}$ (European Environment Agency, 2013; Jandačka, 2013).

2 MEASURING OF SELECTED POLLUTANTS

The measurements of selected pollutants (NO, NO_2, NO_x, PM_{10}) were performed at motorway D1 between Považská Bystrica and Žilina near the village of Predmier. The measuring devices were placed in the premises of the former Centre of Administration and Maintenance of Motorways (SSÚD). The measuring station at the former SSÚD is located approx. 500 m from the village of Predmier, which lies on the left bank of the river Váh in the middle of the Bytča basin. At the northwest it is enclosed by the Javorníky Mountains and at the southeast by the Strážovská hornatina. The motorway D1 runs through the valley of the river Váh and is oriented in the direction southwest ↔ northeast. The orientation of the valley implies the prevailing direction of winds, which blow predominantly from the southwest or the northeast (Figure 2).

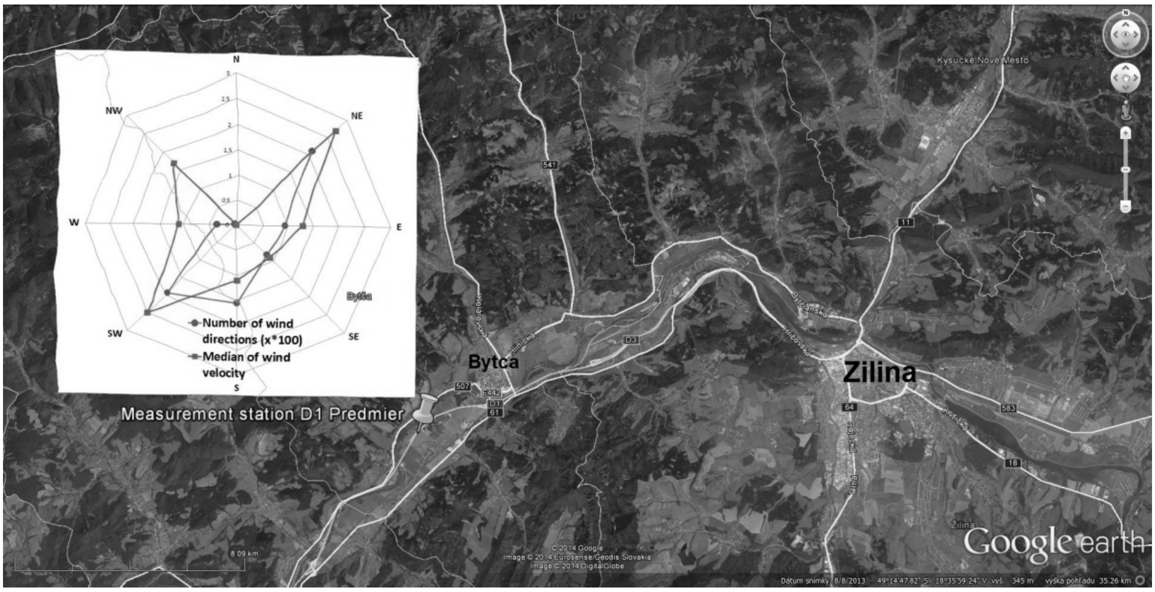

Figure 2: Measuring station and compass rose (source materials: Google Earth).

The measuring devices were placed approx. 7 m from the edge of the sealed part of the road. Different equipment (Figure 3) was used for the measurements. This article evaluates the data from the mobile monitoring station of air quality of the University of Žilina. The measured pollutants by the mobile monitoring stations included NO, NO_2, NO_x, PM, CO, SO_2, O_3. The following part evaluates mostly the pollutants of NO, NO_2, NO_x, PM_{10}, due to their potential origin from road traffic. The values of these pollutants were measured in May 2013, November 2013 and January 2014 (Figure 4).

Figure 3: Deployment of measuring equipment while measuring air pollution.

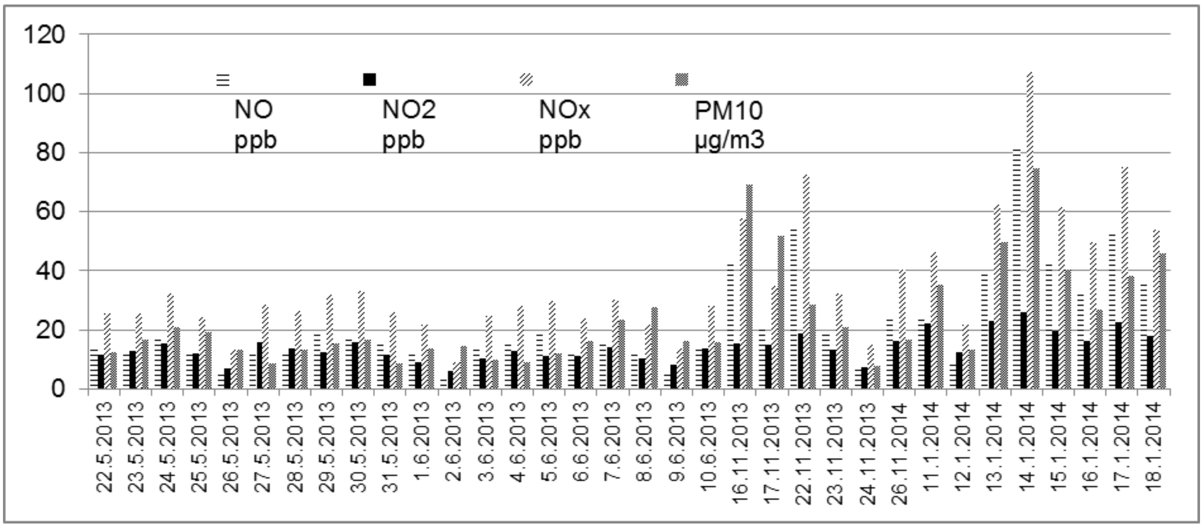

Figure 4: Average 24-hour concentrations of selected pollutants from performed measurements.

Together with the monitoring of air pollution, the meteorological parameters (temperature, humidity, speed and direction of wind) (Figure 5), and road traffic volume on motorway D1 were recorded (Figure 6).

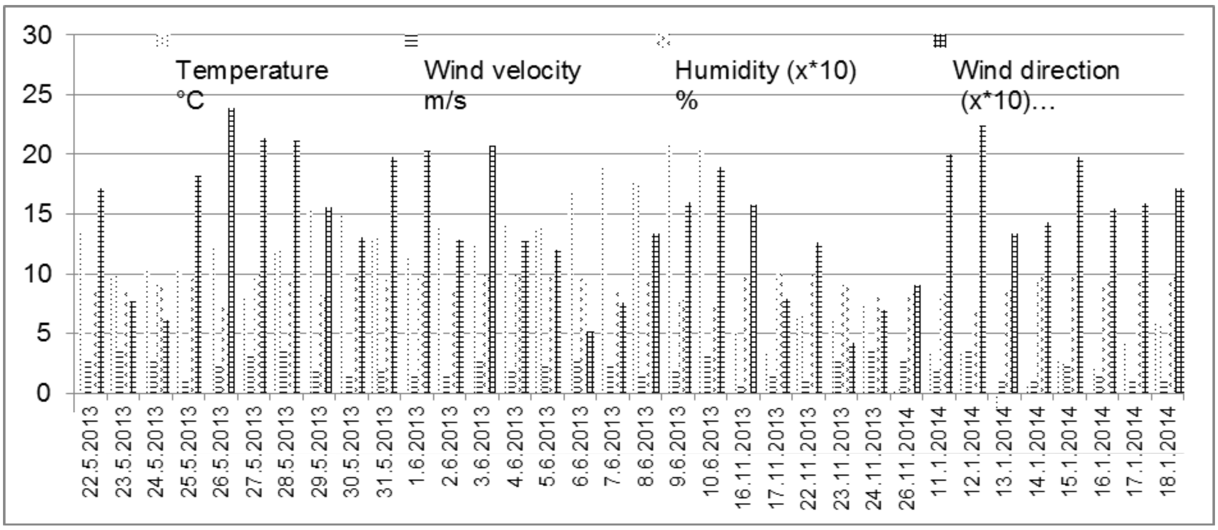

Figure 5: Average 24-hour values of meteorological parameters of selected pollutants from performed measurements.

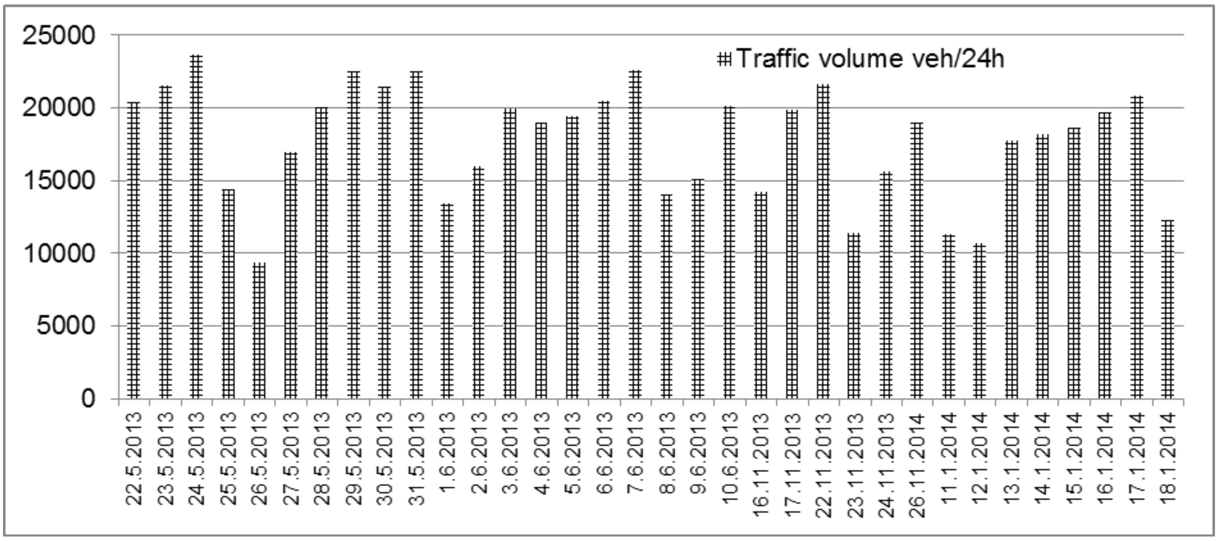

Figure 6: Average 24-hour traffic volumes of selected pollutants from performed measurements.

The wind direction in the given area is based on the surrounding terrain (flat terrain surrounded by a hilly relief forming the valley of the river Váh in direction southwest ↔ northeast) (Figure 2). The prevailing winds blow in the direction of the valley of the river Váh; the motorway D1 is oriented in the same direction. This fact also implies the pollution mass flow produced by road traffic on D1, in the direction of the motorway orientation. The level of air pollution by road traffic along both sides of the motorway can be affected by the assumed propagation of imissions in the direction of the motorway. Despite this fact, we tried to create a model of relations of selected pollutants on the local conditions.

3 EVALUATION OF AIR POLLUTION BY SELECTED POLLUTANTS

A matrix of hourly concentrations of pollutants, meteorological parameters and traffic volumes was created in order to evaluate relationships between the selected air pollution components (NO, NO_2, NO_x, PM_{10}) and the ambient conditions (meteorological parameters). The matrix consisted of separately selected dependent variables (NO, NO_2, NO_x, PM_{10}) and independent variables (temperature (TEMP), humidity (HUMI), wind speed (WS), traffic volume (ID)) and contained 775 items (measured values). Multiple regression analysis (MRA) was used for the evaluation. Further evaluations deal with the inter-correlation of dependent variables PM_{10} and NO, NO_2 and NO_x.

MRA concerns the group of techniques used for studying a linear dependence between two or more variables. It determines estimates of β parameters in a regression model

$$y_i = \beta_0 + \beta_1 x_{i,1} + \beta_2 x_{i,2} + \cdots + \beta_m x_{i,m} + \varepsilon_i, \quad (1)$$

where x are independent variables and y is a dependent variable. Index i stands for a serial measurement number, β are unknown regression parameters and b are their estimates of number m (Table 1). The absolute member β_0 is the intersection point of the hyperplane with axis y. ε_i are random errors. The estimates of parameters b_i are the directions of the regression hyperplane from the direction x_i and are called partial regression parameters (or partial regression coefficients for standardised variables) (Meloun & Militký, 2006).

Table 1: Significant included variables for models of PM_{10}, NO_x, NO_2, NO and results of MRA.

Dependent variable	Included independent variable	Estimate of parameter "b"	Significance of "p"	Correlation coefficient	Coefficient of determination of multiple R^2
PM_{10}	Abs. member	42.89	0.000000	-	0.32
	TEMP	-1.32	0.000000	**-0.49**	
	WS	-4.41	0.000104	-0.40	
	ID	0.005	0.002683	-0.14	
NO_x	Abs. member	51.71	0.000000	-	0.48
	TEMP	-2.14	0.000000	**-0.48**	
	WS	-7.53	0.000000	-0.40	
	ID	0.03	0.000000	0.17	
NO_2	Abs. member	16.68	0.000000	-	0.38
	TEMP	-0.50	0.000000	**-0.40**	
	WS	-1.52	0.000000	-0.30	
	ID	0.008	0.000000	0.22	
NO	Abs. member	35.03	0.000000	-	0.45
	TEMP	-1.64	0.000000	**-0.47**	
	WS	-6.01	0.000000	-0.41	
	ID	0.02	0.000000	0.14	

Temperature (TEMP), wind speed (WS), and traffic volume (ID) (Table 1) were found as the significant variables from the meteorological parameters and traffic volume for all dependent variables of PM_{10}, NO_x, NO_2 and NO. Humidity was not included in any model. Its high sensitiveness to the ambient air temperature was confirmed with PM_{10}. The air temperature has a significant impact on the process of formation, changes and condition of particulate matter in the air. Wind speed mainly influences the dispersion of particulate matter and long distance transfer of pollution by particulate matter. Both factors, temperature and wind speed, show a negative correlation with the concentrations of PM_{10}, which means that the concentrations of PM_{10} are higher under lower temperature and lower wind speed. Correlation coefficients PM_{10} vs. temperature -0.49 and PM_{10} vs. wind speed -0.40 are not relatively high, which may be caused by prevailing wind flow in the given area and by the fact that the monitoring station is hit by the pollutant mass flow only marginally. PM_{10} negatively correlates with traffic volume, which is a bit misleading since road traffic in the given location is considered the dominant source of pollution. However, the concentrations of PM_{10} are so much affected by the meteorological parameters that it is very difficult to prove the interconnection of road traffic and air pollution by particulate matter. The determination coefficient for the model with a dependent variable PM_{10} and independent variables temperature, wind speed, and traffic volume is just 0.32. Therefore, it only characterizes 32% of the original data dispersion, which can be caused by the absenting main flow of pollution by road traffic.

Regarding the dependent variables NO_x, NO_2, NO, the model characterized 48%, 38%, 45% of the original data dispersion. The values are a bit higher for these gaseous components of air pollution than for particulate matter. The correlation between NO_x, NO_2, NO and traffic volume was low (0.17, 0.22, 0.14) and positive, which usually means positive interconnection of these gaseous pollutants and traffic volume, and possibly lower sensitiveness to meteorological parameters as well as to particulate matter. In addition, these gases can probably more easily propagate into the local environment out of the prevailing air flow.

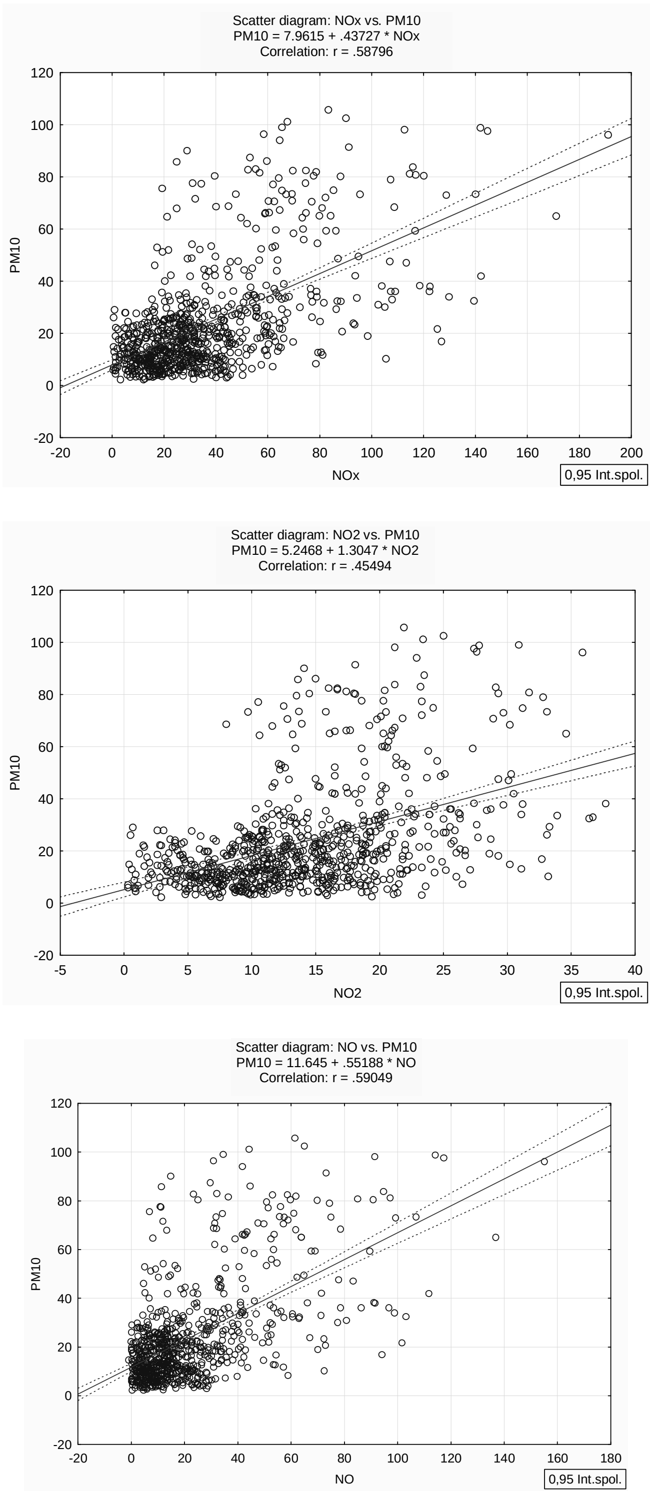

Figure 7: Correlation of PM_{10} and NO_x, NO_2, NO and their relationships.

The inter-correlation of PM_{10} expressed by correlation coefficients and significant markers of road traffic of nitrogen oxides NO_x r = 0.58, NO_2 r = 0.45, NO r = 0.59 is relatively high (Figure 7). The analysis of the relationship of PM_{10} and NO shows that nearly 35% variability of both variables is determined together, thus they are probably interconnected with road traffic.

Regarding the proportion of individual components of NO_x, NO_2 shows above average presence in the total air pollution by nitrogen oxides (Figure 8). This finding may lead to a theory on a large number of diesel vehicles in traffic flow and thus direct production of NO_2 to the air (Grice et al., 2009). In addition, the theory may be supported by the oxidation of NO formed by burning fuel in vehicle engines to NO_2 in the air.

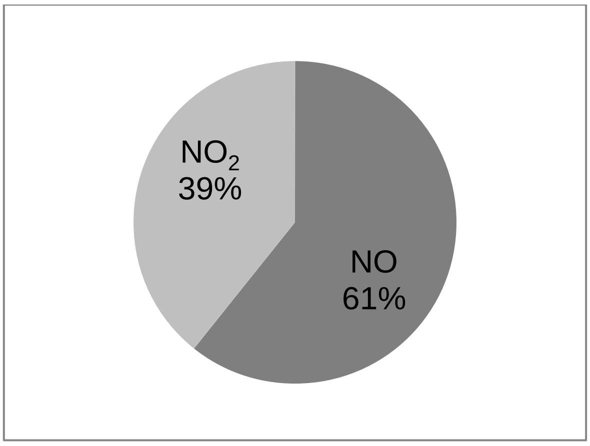

Figure 8: Proportion of NO_2 and NO in NO_x.

4 CONCLUSION

Research of air pollution by road traffic is a complicated process particularly in terms of the direct relationship of measuring pollution and road traffic. The emissions produced by road traffic are influenced by many factors which have an impact on their propagation and on their secondary production. The dispersed emissions in the air (imissions) are mainly subordinate to the current local meteorological conditions. The measurements performed in a rural area at motorway D1 confirmed several assumptions related to the relationships of air pollutants and meteorological parameters. Temperature (TEMP) appeared to be the most influential parameter of concentrations of PM_{10}, NO_x, NO_2, and NO. The correlation with temperature was negative for all four pollutants, i.e. the lower the temperature, the higher the concentration. The other significant variables for the model of concentrations of selected pollutants were wind speed and traffic volume. A high correlation of PM_{10} and nitrogen oxides was found, while their joint dispersion rate is 35%. Their mutually explained proportion may indicate origin in road traffic, since road traffic is a significant producer of nitrogen oxides. The proportion of individual components of NO_x is 39% NO_2 and 61% NO. The high presence of NO_2 in NO_x may be a result of a high proportion of diesel cars on motorway D1, however, it may also be related to the oxidation of NO to NO_2 in the ambient air.

Behaviour and dispersion of pollutants in the air is largely influenced by the character of area, meteorological parameters, and the source of pollution itself. The measurement station was placed in a flat rural area (without any artificial obstacles). The prevailing winds flowed in the direction of motorway D1. The emissions produced by road traffic are influenced by these factors and their “travel” in the air is a result of a coaction of individual components of the environment, which is affected by the air pollution.

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REFERENCES

Breysse, P. N. et al., 2013. US EPA particulate matter research centers: summary of research results for 2005-2011. *Air Quality, Atmosphere & Health* [online]. 6 (2), pp. 333-355 [cited 2014-07-29]. ISSN 1873-9326. Retrieved from: http://link.springer.com/article/10.1007%2Fs11869-012-0181-8

European Environment Agency, 2013. *Air quality in Europe – 2013 report* [online]. Copenhagen (Denmark): EEA. 107 p. [cited 2014-07-29]. Retrieved from: http://www.eea.europa.eu/publications/air-quality-in-europe-2013

Grice, S. et al., 2009. Recent trends and projections of primary NO2 emissions in Europe. *Atmospheric Environment* [online]. 43 (13), pp. 2154-2167 [cited 2014-07-29]. ISSN 1352-2310. Retrieved from: http://www.sciencedirect.com/science/article/pii/S1352231009000508

Huzlík, J., Ličbinský, R., Mikuška, P. 2011. Identification of Re-suspended Particle Matter Particles Sources by Statistical Methods. In *12th Annual Conference of the Czech Aerosol Society: proceedings*, Cejkovice (Czech Republic), pp. 69-74. ISBN 978-80-86186-31-3.

Jandačka, D., 2013. *Vplyv cestnej dopravy na výskyt tuhých častíc [Road Transport Impact on the Occurrence of Particulates]*. Dissertation thesis. University of Zilina. 134 p. (in Slovak)

Jandačka, D., Ďurčanská, D., 2014. Znečistenie ovzdušia plynnými látkami a tuhými časticami mimo zastavaného územia [Air Pollution by Gases and PM in Rural Areas]. In Jandová, V., Mikulová, I., Ličbinský, R. *VI Czech and Slovak Conference "Transport, Health and the Environment"*, Brno (Czech Republic), November 10-11, 2014. Brno: Transport Research Centre, pp. 15-23. ISBN 978-80-86502-85-4. (in Slovak)

Meloun, M., Militký, J., 2006. *Kompendium statistického zpracováni dat [Statistical Data Assessment Compendium]*. Prague: Academia. 982 p. ISBN 80-200-1396-2. (in Czech)

Pant, P., Harrison, R. M., 2013. Estimation of the contribution of road traffic emissions to particulate matter concentrations from field measurements: A review. *Atmospheric Environment* [online]. 77, pp. 78-97 [cited 2014-02-21]. ISSN 1352-2310. Retrieved from: http://www.sciencedirect.com/science/article/pii/S1352231013002732

Thorpe, A., Harrison, R. M., 2008. Sources and properties of non-exhaust particulate matter from road traffic: A review. *Science of Total Environment* [online]. 400 (1-3), pp. 270-282 [cited 2014-02-21]. ISSN 0048-9697. Retrieved from: http://www.sciencedirect.com/science/article/pii/S004896970800658X

Vojtěšek, M., Mikuška, P., Večeřa, Z., 2009. Výskyt, zdroje a stanovení kovů v ovzduší. [Occurence, sources and determination of metals in air]. *Chemical Letters*, 103, pp. 136-144. ISSN 1213-7103. (in Czech)

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Environmentally Friendly Public Transport

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ABSTRACT: The article "Environmentally Friendly Public Transport" deals with the impact of public transport on the environment by selected types of vehicles. Nowadays, many public transport operators face the necessity to renew their vehicle fleets and consequently decide how to acquire the best vehicle fleet composition with the lowest costs. They need to be competitive with other operators as well as with personal car transport; they need to provide sufficient comfort to passengers, be environmentally friendly, and last but not least, they need to have low operating costs. The renewal of the vehicle fleet traditionally strains an operator's budget. A good decision for a suitable alternative of operated vehicles, or a decision for a suitable mixture of operated vehicles, may have a crucial impact on operating costs and thus affect financial support from their founders. New alternatives are available thanks to the development of new technologies – traditional diesel buses meeting the emission standards of EURO 6, CNG buses, electric buses, trolleybuses, trams, buses with hydrogen fuel cells, etc. The presented work is trying to find the answer to the question of which alternative is ideal for operators from a short-term, medium-term and long-term perspective. The article presents a comparison of economic indicators of the operation of individual alternatives, their impact on the environment and their performance.

KEY WORDS: Public transport, environment, vehicle fleet, alternative fuel.

1 ANALYSIS OF PUBLIC TRANSPORT SITUATION IN THE CZECH REPUBLIC

City public transport in the Czech Republic consists of Prague underground, seven tram operations, thirteen trolleybus operations, and many bus operations. Some cities and towns use funiculars and water transport, but their importance is rather supplementary. Most of these services are run by 19 transport companies with a vehicle fleet of 702 trolleybuses, 1 826 trams and 2 888 buses which cover 326 million kilometres. These figures clearly show that public transport operation has a crucial impact on the environment in urban areas. Just last year these operators spent CZK 4330 million for the renewal of vehicle fleets, for which they acquired 30 trams, 21 trolleybuses, 131 diesel buses, and 9 CNG buses (SPD ČR, 2013). Despite this fact, the renewal of vehicle fleet is not fast enough and vehicle fleets are getting old. The combination of renewal of vehicle fleets and the necessity to reduce a negative impact on the environment results in efforts of the operators to cope with these challenges.

The market currently has available alternatives, such as hybrid vehicles, CNG vehicles, electric vehicles, for the needs of public transport. However, they differ in their emission and economic characteristics.

DE GRUYTER OPEN

1.1 City CNG buses

If omitting underground, trams and trolleybuses, which are naturally powered by electricity, we can put compressed natural gas to the first position among alternative fuels used by public transport in the Czech Republic. The operators usually claim that the main reasons for introducing CNG buses are the reduction of negative impact of buses on the environment, renewal of vehicle fleet, and reduction of costs on the operation of city public transport. Despite this fact, according to the Czech Gas Association, which monitors the trends in the use of CNG and regularly prepares statistical data from this field, there are so far only 2.5% CNG buses of all buses in the Czech Republic (or 512 CNG buses, including intercity buses). This figure should change after completing 8 projects in the area of Alternative transport, with the support of the Ministry of the Environment through the State Environmental Fund of the Czech Republic within its 57th call, support for the replacement of the oldest and the most environmentally harmful public transport buses by more environmentally friendly CNG buses (MŽP, 2013).

Most of the funds are allocated to the Moravskoslezský region, i.e. the area with the most problematic air conditions. Dopravní podnik Ostrava (City public transport Ostrava) will use the funds to replace up to one third of their diesel buses with CNG buses. In total, they plan to acquire up to 100 CNG buses. A large project with the acquisition of 100 CNG buses and the construction of a CNG filling station has been in progress in the city of Brno. The first 12 buses were acquired at the beginning of summer 2014 and the delivery of the remaining 88 buses is expected at the turn of 2014/2015. Based on the estimates of the Czech Gas Association, approx. 238 CNG buses will be put into operation within a single year in the Czech Republic.

1.2 Electromobility in city public transport in the Czech Republic

Czech city public transport operators have also been trying other alternatives. The requirement to fill cities with locally emission-free vehicles can be reached through electric vehicles. Regarding city public transport, the development of electromobility in the Czech Republic is still in its testing phase, unless we consider trams and trolleybuses. The only public transport operator who uses electric buses on regular city public transport services is Dopravní podnik Ostrava. There are 4 vehicles in operation on one service in Ostrava. The type of vehicles is the so-called overnight charging vehicles, i.e. no need to charge while driving. Electric buses are used in operation in shifts between peak hours, the charging is provided during the noon break. The morning mileage is 85 veh/km, the afternoon mileage is 100 veh/km. The public transport company claims that the higher acquisition costs (CZK 8.5 million + CZK 2 million for the replacement of the traction battery halfway through the vehicle life span) are compensated with lower costs on operation, reduced emissions and lower noise by 8 dB in comparison with a diesel engine. The higher acquisition costs have a return rate of approx. 12 years. Further expansion of electric buses is prevented not only by economic factors, but also by smaller operating range per charging, which is approx. 150 to 180 kilometres. It is necessary to introduce a network of speed-charging stations, if possible at terminal stations, for common performances of 250 – 300 km in urban traffic (Dopravní podnik Ostrava, 2014).

1.3 Hybrid and fuel cell buses in the Czech Republic

The operators have even less experience with hybrid and fuel cell buses. The representative of fuel cell buses tested in city public transport operations in the Czech Republic is TriHyBus, a prototype produced for the demonstration of hydrogen technology, operated by ÚJV Řež within a project coordinated by ÚJV Řež and cofounded by 75% from EU sources. Being the prototype corresponds with the price which reached almost CZK 60 million for vehicle development and CZK 23 million for the hydrogen infrastructure (TriHyBus.cz, 2008). Therefore, massive expansion is not expected under the current conditions.

A mass produced 12-metre hybrid city bus Volvo 7700 with a parallel drivetrain was a hybrid bus tested in public transport services in Prague and in inter-city transport services in Chomutov. In comparison with a diesel bus the savings of fuel in operation ranged between 28 and 45%. The measured values from Prague show an average consumption of 30.2 l/100 km, which is an average saving of 28% in comparison to comparable diesel buses (Rác, 2012). The bus is very quiet thanks to switching off the engine when stopped and starting by an electric engine up to the speed of 20 km/h. The price for the hybrid is approx. one third higher than the traditional model. In comparison with diesel buses, the studies show a return rate from 5 to 10 years due to higher maintenance costs, depending on the savings on consumption costs.

2 COMPARISON OF DRIVE CONCEPTS

6 concepts were selected for an analysis and comparison. Three were based on combustion engines - *Diesel, CNG, Diesel hybrid* and three were non-emission ones – *Hydrogen fuel cells, Trolleybus, Electric bus*.

Although the basic decision making criteria of Czech operators for choosing new vehicles typically concern price and operating costs, it is necessary to take into account other properties of the concepts, otherwise we could make a statement that walking is the cheapest transport mode and we can cancel public transport.

Regarding the fact that comfort and design of vehicles can be provided at the same level for all vehicles, this article only deals with the aspects which are essential for the operation of city public transport and cannot be easily replaced.

They can be generally summarized into three areas:

- *Financial aspects* (acquisition and operating costs, and infrastructure costs);
- *Performance aspects* (Filling or charging time, mileage, dependence on the infrastructure, flexibility, etc.);
- *Aspects of impacts on the environment* (Well-to-wheel emissions, local emissions, noise).

2.1 Financial aspects

For the simplification, the materials for comparing financial aspects of individual drive concepts are based on the price for a city vehicle with the length of 12m and include costs on energy consumption, acquisition costs, repair and maintenance costs, and other costs that are constant for all types of concepts. Figure 1 shows a comparison of all-life costs obtained from different information sources.

Although the calculated costs of individual sources differ greatly, the relationships between individual concepts are very similar. The graph shows that all-life costs on alternative fuels are much higher in comparison with diesel and CNG. The situation reflects the fact that diesel and CNG are well established products on the market with completed infrastructure. Trolleybuses have high acquisition and maintenance costs of the traction overhead line. The price for electric buses and fuel cell buses is influenced by the parts production, which does not allow the use of economies of scale. In addition, both concepts require completing the infrastructure/hydrogen production.

It is expected that the development of technologies and change to mass production will reduce the costs on electric buses and fuel cell buses, while the trend for diesel and CNG drives will be reversed due to the increase in prices of fossil fuels.

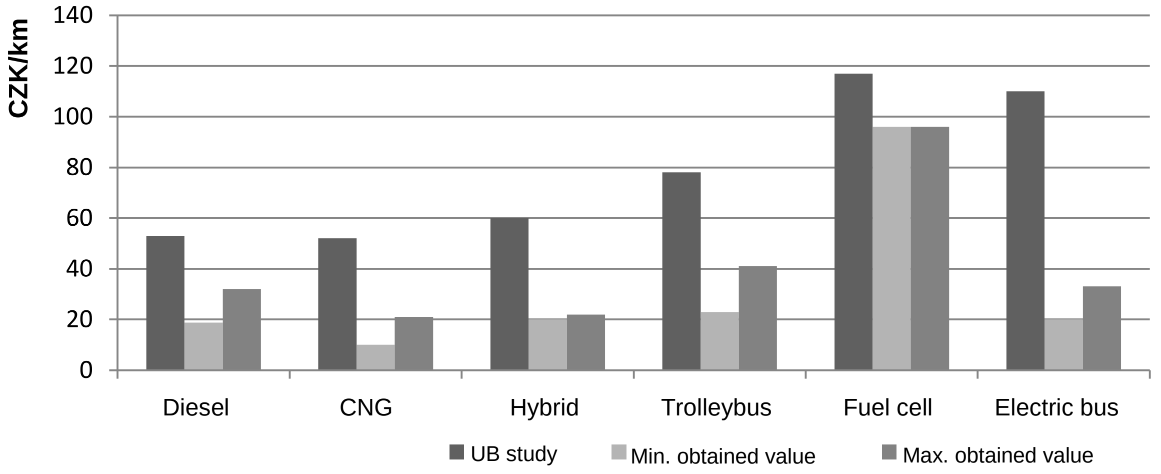

Figure 1: Total costs translated to km.
(Source: Slavík, 2013)

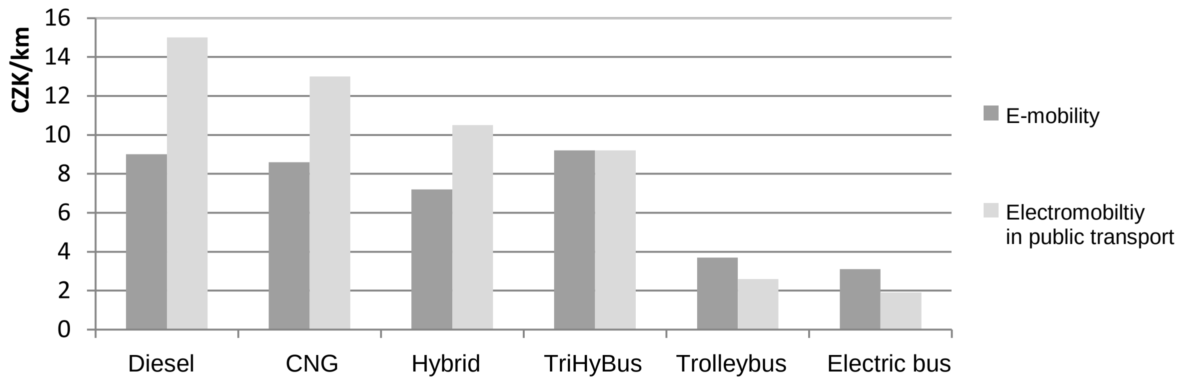

Figure 2: Consumption costs.
(Source: Slavík, 2013; Černý & Pech, 2013)

Regarding the total costs, it is interesting to compare consumption costs where diesel and CNG are among the most expensive. Diesel is particularly influenced by the price of fuel while CNG is by consumption (Figure 2).

2.2 Performance aspects

Regarding the performance, city public transport operators are interested in key properties, such as *fuel consumption, reliability, mileage per full tank of fuel, functional infrastructure, frequency and time of fuel filling,* and last, but not least the property related to the impact of bus operation on the environment - *operating range without locally produced emissions*.

Regarding the first two mentioned properties, i.e. fuel consumption and reliability, they are directly reflected in the costs, thus this article does not pay more attention to them. The article just states that the more conventional technology, the higher reliability of the technology. However, if we considered this risk as a key factor, nothing new would ever be developed and no progress would exist.

The other mentioned properties are balanced in different drive concepts. Some concepts show better properties in large mileage without producing emissions, others in absolute mileage.

Diesel and CNG buses have an operating range for a single full tank of fuel of longer than 300 km, require a short time for fuel filling and can use a functional extensive network of filling stations at the European level. In the Czech Republic, the CNG infrastructure lags behind the European average. However, neither of the concepts can work in the mode with zero emissions.

Hybrid buses have the same properties as the convention ones, and what is more, in short sections they are able to use purely electric drive with zero emissions and lower noise, which increases their use particularly in city centres.

Hydrogen fuel cell buses are actually at the highest level in terms of performance, since they meet everything the conventional buses do with the added value of continuous operation with zero local emissions for a longer distance. However, the problematic factor is the insufficient infrastructure and the ever developing technology is still at the testing stage.

Trolleybuses offer a similar performance as conventional buses, with zero local emissions and without the need of fuel filling. However, the operating range is limited to the traction overhead line. The exception is hybrid trolleybuses which are used in some cities to increase flexibility.

Electric buses have a short mileage range and require a longer time for charging. Their advantage is the operation without emissions. Regarding charging, there are two options, either speed charging during the operation, which requires construction of charging stations along the route and causes complications in case of rerouting of services, or the so-called overnight charging, which is then demanding in terms of time.

2.3 Aspects of traffic impact on the environment

2.3.1 Greenhouse gas emissions

The latest study dealing with a comparison of traffic impact of different drive buses on the environment is "Urban Buses: Alternative Powertrains for Europe". The study concerns the impacts on the environment in the form of "well-to-wheel", so that the impact at the place of operation "tank-to-wheel" was mapped as well as the emissions concerning the production and delivery of energy to vehicle "well-to-tank".

The study shows a production of greenhouse gases of individual drive concepts in comparison with the production of emissions of a diesel engine. To be more illustrative, the study shows the averages of measured values, not the specific values, which vary for each region in terms of different structure of electric energy production, sources of fossil fuels, etc. (FCH-JU, 2012).

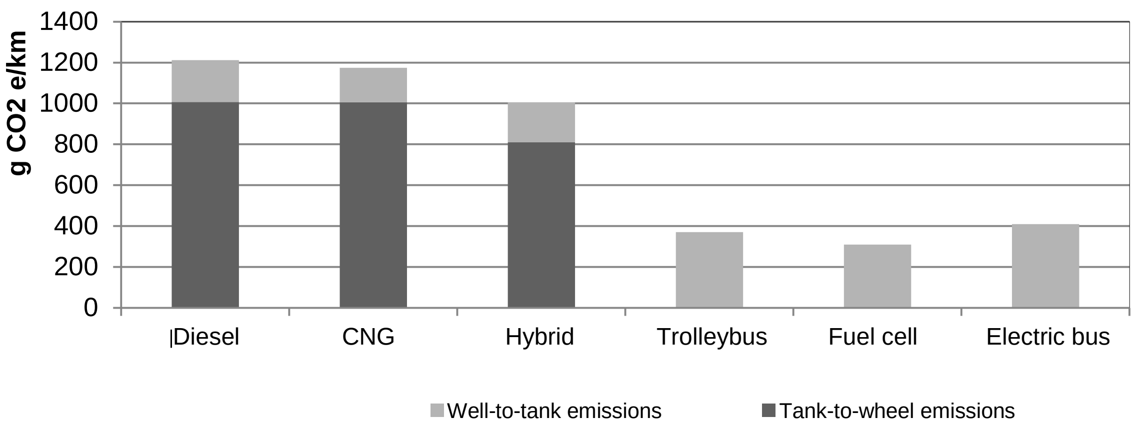

Figure 3: Emission structure.
(Source: FCH-JU, 2012)

The collected information show that buses with electric drive produce the lowest amount of greenhouse gas emissions. In this respect, diesel and CNG buses are the most problematic. What is rather surprising is the production of local greenhouse gas emissions of CNG buses, which are generally considered more environmentally friendly than diesel buses (Figure 3).

Comparisons of diesel buses and CNG buses were dealt with by more studies, namely “Performance and emissions evaluation of compressed natural gas and clean diesel buses at New York City’s Metropolitan Transit” (2002), “Comparative Costs of 2010 Heavy-Duty Diesel and Natural Gas Technologies” (California) and “Clean Diesel versus CNG Buses” (Manchester). Their results cannot be compared between each other since they were performed with completely different input conditions. The studies show that emissions from two of the most serious pollutants, PM and NOx, can be significantly lower with CNG engines - generally 70%, or 30% - in comparison with traditional older diesel buses. However, no up-to-date objective comparison of emission production of new diesel and CNG buses is available. Whether CNG drive is more environmentally friendly than diesel drive or not, CNG technologies have a remarkable ability to meet the strictest emission standards required in advanced countries, while helping to improve the air quality in many urban areas around the developing world. Therefore, they represent an interesting alternative to diesel engines, although they are unable to work in an emission-free mode.

2.3.2 Noise

Apart from exhaust gas emissions, transport affects the environment by noise. A comparison of individual selected drive concepts is shown in Figure 4 (FCH-JU, 2012).

It is not surprising that the systems with electric drive are the least noisy, although buses with hydrogen cells produce equally low level of noise. The difference of 17 or 8 dB may seem negligible, but it is necessary to realize that the noise of 63 dB corresponds with a common conversation, while 80 dB corresponds with very loud music from loudspeakers. In addition, expert studies claim that hearing can be damaged by long-term exposure to noise slightly above the level of 70 dB.

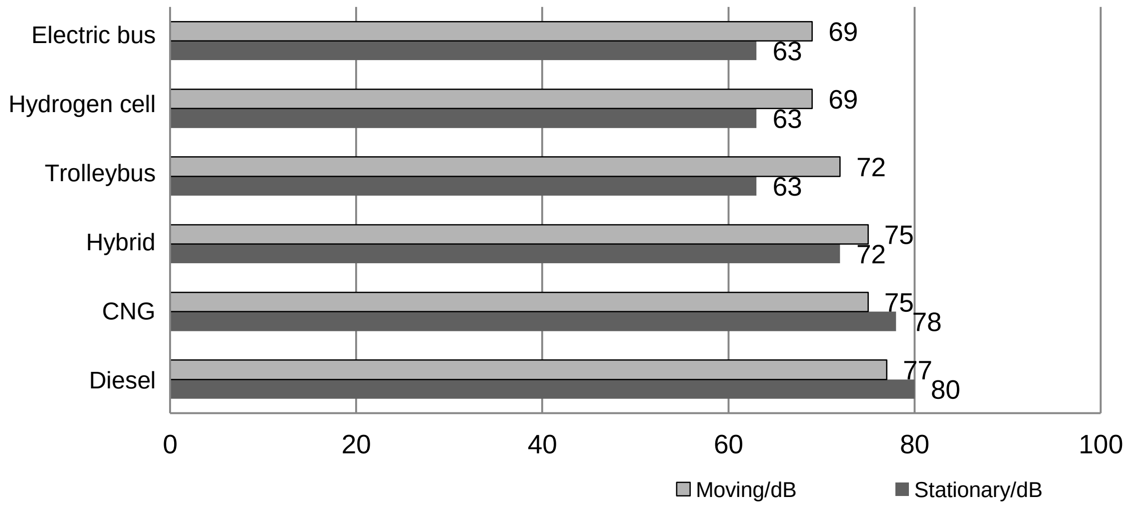

Figure 4: Noise.
(Source: FCH-JU, 2012)

3 RESULTS AND RECOMMENDATIONS

The following summary may become handy when making the decision which direction to take and which drive concepts to accept for the renewal of vehicle fleet. According to the obtained results, all evaluated drive concepts were assigned with numbers from 1 to 3, with 1 standing for the best evaluation. Table 1 shows the ranking of each concept.

Table 1: Final evaluation.

		Diesel	CNG	Hybrid	Trolleybus	Hydrogen cells	Electric bus
Financial aspects	Acquisition costs and funding	1	1	2	3	3	2
	Operating costs	3	2	2	3	1	1
	Infrastructure costs	1	1	1	2	3	2
TOTAL FOR FA		**5**	**4**	**5**	**8**	**7**	**5**
Performance aspects	Time of charging/ fuel filling	2	2	2	1	2	3
	Mileage range without emissions	3	3	2	1	1	1
	Flexibility/ mileage range	1	1	1	3	1	2
TOTAL FOR PA		**6**	**6**	**5**	**5**	**4**	**6**
Aspects of impacts on the environment	Emissions well-to-wheel	3	3	2	1	1	1
	Local emissions	3	3	2	1	1	1
	Noise	3	3	2	2	1	1
TOTAL FOR AIoE		**9**	**9**	**6**	**4**	**3**	**3**
TOTAL		**20**	**19**	**16**	**17**	**14**	**14**

(Source: Our own from study results)

The obtained results show that any significant reduction of the impact of city public transport on the environment can only be achieved by applying alternative drive systems in practice. Nowadays, in the era of available and developing alternative drive systems, only hydrogen cell buses, trolleybuses and electric buses can play a key role in reducing the production of greenhouse gases and dealing with the issue of air pollution in cities. Therefore, the development and increasing of market share for electric buses and hydrogen cell buses need to be supported as much as possible in the cities with the previously built infrastructure.

Diesel hybrid buses, whose overall evaluation is better than that of CNG buses, can help to reduce local emissions up to 20% and overcome the time period before the concepts with zero local emissions get cheaper.

The cheapest alternatives, diesel and CNG drives, are unable to compete with the others in terms of the impact on the environment. However, their strong position in the market, provided infrastructure, flexibility and variability will be a tough nut to crack for the new technologies.

Cities are usually the majority owners of transport companies running city public transport in the Czech Republic. Politicians, who make the final decision regarding the investments in vehicle fleets as the representatives of the owner, usually forget about their pre-election promises on the improvement of the environment and decide to buy more vehicles for less money. Therefore, politicians and transport operators should cooperate and synchronize their efforts to support renewal of vehicle fleets with vehicles with zero emissions. Continuous and regular purchases of buses with new technologies may help to strengthen their position in the market, increase savings from economies of scale, and increase the effort of producers to develop and offer new products.

We need to bear in mind that the life span of buses is longer than 12 years and the buses acquired this year will still be in operation in 2026. To reach the results in improving the environment as soon as possible we should not hesitate to introduce new concepts now.

REFERENCES

Černý, J., Pech, L., 2013. Elektromobilita v městské hromadné přepravě osob. Elektrobusy – hromadné dopravní prostředky pro 21. století. *Busportal* [online]. [cited 2014-07-20]. Retrieved from: http://www.busportal.cz/bpextend/23_Cerny_Evmhpo-revize-I.pdf (in Czech)

Dopravní podnik Ostrava, 2014 [online]. © Dopravní podnik Ostrava a.s. [cited 2014-10-31]. Retrieved from: http://www.dpo.cz (in Czech)

FCH-JU, 2012. *Urban buses: alternative powertrains for Europe* [online]. FCH-JU (Fuel Cells and Hydrogen Joint Undertaking) [cited 2014-07-20]. Retrieved from: http://www.fch-ju.eu/sites/default/files/20121029%20Urban%20buses,%20alternative%20powertrains%20for%20Europe%20-%20Final%20report_0.pdf

MŽP, 2013. Financování ochrany životního prostředí [online]. © 2008–2014 Ministerstvo životního prostředí [cited 2014-10-31]. Retrieved from: http://www.mzp.cz/cz/financovani_ochrana_zivotni_prostredi (in Czech)

Pejšová, M. Městská hromadná doprava, která neškodí [Environmentally Friendly Public Transport]. In Jandová, V., Mikulová, I., Ličbinský, R. (eds.). *VI Czech and Slovak Conference „Transport, Health and the Environment"*, Brno (Czech Republic), November 10-11, 2014. Brno: Transport Research Centre, pp. 125-132. ISBN 978-80-86502-85-4. (in Czech)

Rác, J., 2012. Dopravní podnik měst Chomutova a Jirkova testoval hybridní autobus VOLVO 7700. *Busportal* [online]. [cit. 2014-07-20]. Retrieved from: http://www.busportal.cz/modules.php?name=article&sid=9939 (in Czech)

Slavík, J., 2013. Elektrobusy v ČR a ve světě: studie „E-mobilita v MHD". *Proelektrotechniky.cz* [online]. © 2012 Ing. Jakub Slavík, MBA – Consulting Services [cited 2014-07-20]. Retrieved from: http://www.proelektrotechniky.cz/elektromobilita/42.php (in Czech)

SPD ČR, 2013. *Výroční zpráva SDP ČR za rok 2013*. Praha (Czech Republic): SDP ČR. (in Czech)

TriHyBus.cz, 2008. TriHyBus – Vodíkový autobus s palivovými články [online]. © Copyright 2008 TriHyBus.cz [cited 2014-10-31]. Retrieved from: http://www.h2bus.cz/ (in Czech)

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Dispersion of Pollutants from Line Sources in Small Municipalities

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ABSTRACT: The article deals with the issue of dispersion and spreading of pollutants in small municipalities. The main attention is paid to the spreading of pollutants from line sources, i.e. roads in this case. Numerical modelling for selected localities, complemented with local measurements, is used for finding relations of dispersion of pollutants. The impact of a specific layout of urban areas on the dispersion of pollutants is monitored. Line sources, representing roads in numerical models, are described by the productions of pollutants and corresponding aerodynamic effects of moving vehicles on the ambient air. A large number of concentration maps are converted into a comprehensive database which allows a fast evaluation of similar situations without new immediate solutions or demanding SW tools.

KEY WORDS: Dispersion modelling, particulate matter, small cities.

1 INTRODUCTION

The outcomes presented in this article are a partial outcome of a project "Kvantifikace znečištění ovzduší a z něj vyplývajících zdravotních rizik v malých sídlech České Republiky a systém řízení" (Quantification of air pollution and the resulting health risks in small settlements of Czech Republic and system solutions). The project focuses on creating an operative system that evaluates the exposure of local population to imissions in small settlements. A catalogue of concentration maps of selected model areas of small settlements was designed as a suitable approach allowing for a fast evaluation. This article focuses on imissions from road traffic.

When selecting a suitable model tool for detail calculation of pollutants in small settlements, a CFD (computational flow dynamics) modelling method was chosen. This method allows to calculate complex 3D concentration fields of pollutants on the basis of the real geometry.

Figure 1: Illustrative example of a small settlement Okříšky, aerial view.

2 CLASSIFICATION STRATEGY OF MODEL AREAS OF SMALL SETTLEMENTS

The selection of model areas of small settlements was performed with the aim to prepare numerical models of selected areas which represent characteristic configurations of buildings and emission sources in small settlements in terms of spreading of pollutants. The selected model areas are used for calculating concentration maps of imission levels. The obtained results should be representative and usable for evaluations of a large number of small settlements of a similar layout.

In the first step when selecting model areas, the attention was paid to the character of urban layout in relation to the main road. Small settlements were classified as follows in this step:

- bordering a transit road,
- run through by a transit road.

An extensive study of aerial views of small settlements helped us to select two characteristic shapes of transit roads which frequently appear in small settlements:

- direct road,
- road with a change in direction by 90°.

Another feature of the selected model areas was the shape of built-in areas. In this respect, the characteristic model areas of small settlements were divided into three groups:

- solitary standing family houses forming a settlement,
- continuous row of buildings surrounding the main road and other solitary structures,
- urban character of a small settlement with street canyons in its central part.

3 MODEL OF POLLUTANT DISPERSION AND RELATED BOUNDARY CONDITIONS

CFD (computational flow dynamics) method was used for the creation of concentration maps of pollutants. This method allows to include a detailed description of the geometry of an area and the dispersion of pollutants on computed 3D air velocity field. Euler method was used as a suitable approach to deal with the pollutant dispersion. This method is based on a numerical approach to the system of differential equations accurately describing air flow and transport of gaseous pollutants and small suspended particles. The solution can be stationary as well as non-stationary. The correctness of the calculated air velocity field depends on the quality of the assigned geometry of an area and assigned boundary conditions. In this case, there is no fundamental limitation, thus when dealing with urban areas the calculation can include detailed geometry of individual buildings. The information on the concentration of pollutants is collected in nodal points of the model network on the basis of balance equations for conservation of matter, energy and momentum, which describe the transfer between individual volume elements of the numerical model. The size reduction of the used volume elements increases the accuracy of results but significantly increases the difficulty of the calculation. This fact requires a careful decision of the size of the area in question and of the size of the used volume elements.

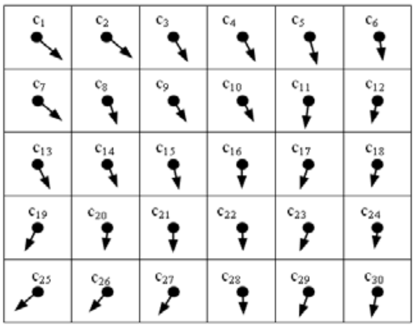

Figure 2: Outlining the description by Euler method – calculation of concentrations are known in the centres of selected control volumes.

The dispersion of pollutants is critically influenced by the existing air velocity field. The air field in a given area is formed by the effects of the assigned wind, geometry of buildings, and the effect of moving vehicles near roads. The impact of vehicles is crucial in most cases when dealing with the area above the road and in close vicinity to the road. The movement of vehicles is crucial for the speed of spreading pollutants, particularly in situations when the natural advection is insufficient (e.g. in windless conditions). The inclusion of moving vehicles in the calculation is performed in two steps:

- inclusion of force effects of vehicle on air,
- inclusion of production of the kinetic energy of turbulence.

The force effects of the air on moving vehicles are described by the resistance force

$$\vec{F}_D = \frac{1}{2}\rho C_D A_p \left|\vec{U}_\infty - \vec{U}_{car}\right| \left(\vec{U}_\infty - \vec{U}_{car}\right) , \tag{1}$$

where ρ … air density,

U_{car} .. vehicle speed,

U_∞ … air velocity in the place of the moving vehicle,

Q_{car} ... traffic volume,

C_D … aerodynamic resistance constant.

The reaction to the aerodynamic resistance force is the force that the vehicle pushes the fluid. This effect is included in the calculation in the form of the volume force active at places where vehicles drive through, see Figure 3.

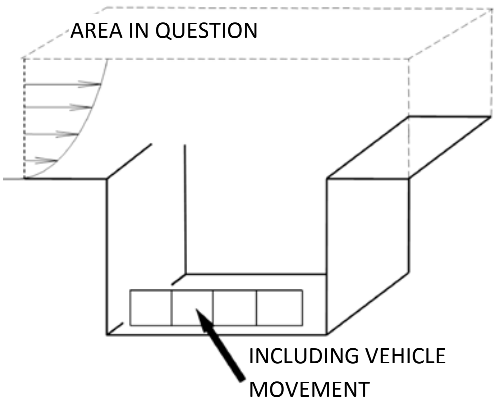

Figure 3: Example of inclusion of moving vehicle impact on a four-lane road enclosed by buildings from both sides.

The created detailed mathematical model always represents only a part of the real area. The size of the model itself is limited by the amount of time for processing and by the used hardware. The limitations due to the limited model size lead to the use of corresponding boundary conditions which accurately substitute the influence of the surroundings. The boundary condition "slip wall" is used for the upper border of the area in question. The boundary conditions assigned to walls must allow prescribing the velocity profile above the terrain corresponding with real conditions in the lower atmospheric level. This approach allows to include the effect of the surrounding environment at the place of the area border. The mathematical expression of the wind velocity profile is

$$u = u_{ref}\left(\frac{z}{z_{ref}}\right)^{a} , \qquad (2)$$

where, u … wind velocity in height z,
u_{ref} … wind velocity in reference height,
z … elevation coordinate,
z_{ref} … referential height,
a … velocity profile coefficient.

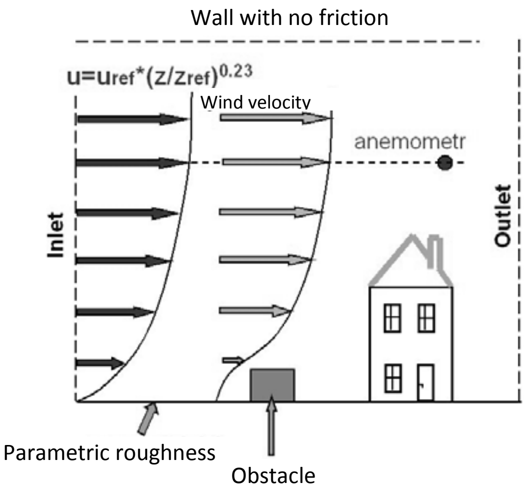

Figure 4: Assigned wind at the edge of area in question with the use of "velocity profile".

The air mass in the model moves above the terrain described by the corresponding parametric roughness. The terrain has an impact on the original velocity profile in relation to specific local conditions, see Figure 4.

4 EXAMPLE OF REACHED RESULTS

In order to calculate concentration maps, an area of 2000 × 2000 m with a village of Okříšky was processed into a numerical model, see Figure 5.

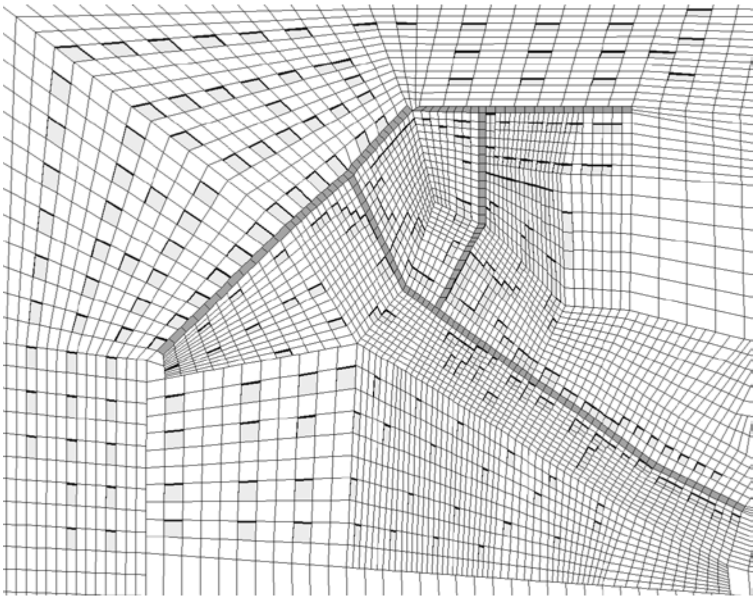

Figure 5: Road and buildings in created numerical network – top view.

The considered line sources representing important roads were described by traffic volume and the corresponding emission factor. In the model area the line emission sources of corresponding roads running through streets of Masarykova, Nádražní and Jihlavská were assigned. The line sources were included in the model along the length of the monitored roads in the village. These roads were assigned with the parameters of the production of monitored pollutants.

The solution includes the advective and diffusion method of pollutant transfer in the calculated air flow field. The diffusion is considered both molecular diffusion and turbulent diffusion due to effect of the complex whirlwind structure of the flow. The used simplified solution is based on neglecting deposition mechanisms (with the exclusion of PM10), whose manifestation is very limited on short distances. The solution was performed with zero concentration of the background. The results show the contribution of line sources to the total imission concentration in the area.

An example of calculated concentration fields of the specific emission for the model area Okříšky is shown in Figure 6 and Figure 7. The expressed imission burden is shown in the form of a specific imission, which provides the qualitative overview on shapes of concentration fields. We can obtain the real pollutant concentration by multiplying the specific imissions with the ratio of the real and specific emissions produced by vehicles on the road.

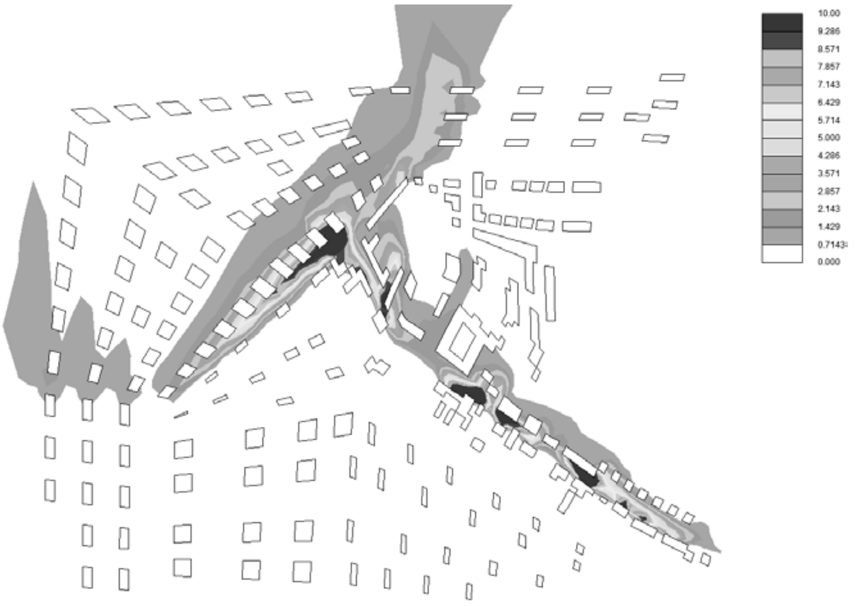

Figure 6: Calculated concentration field of specific emissions for south wind of 2 m/s.

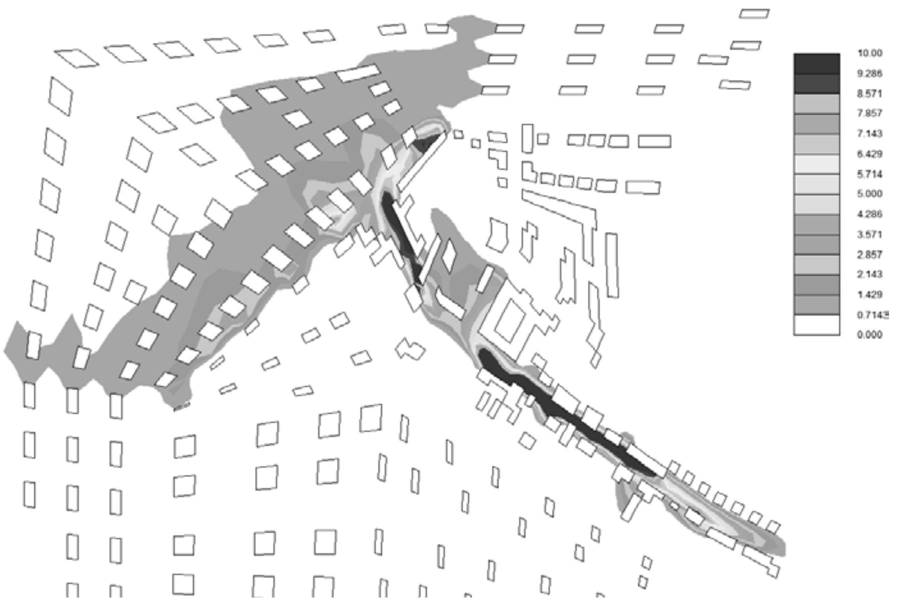

Figure 7: Calculated concentration field of specific emissions for southeast wind of 2 m/s.

5 PRODUCTION OF CONCENTRATION FIELD DATABASE

The concentration fields were formed into a database of concentration maps, so that the calculated concentration fields would not stay only as a content of continuous reports. This database can be a tool for a quick orientation in results and a practical tool for the evaluation of similar areas.

The database is an interactive tool allowing a quick search for corresponding situations and displaying of reached results, which can help the future users to evaluate the imission burden of similar settlements. Taking into account the fact that in the close vicinity of emission sources and in urban areas “under building roofs” it is impossible to use common recommended dispersion models, the database represents the only option to quickly evaluate local areas along roads while considering the specific geometry of buildings and traffic characteristics.

The database is inserted with the outputs of calculations which are expected for further use. Each inserted concentration field is identified with a description of the geometry of an element in question, description of corresponding meteorological conditions (wind velocity and direction), traffic parameters (driving speed, traffic volume), basic average emission level of vehicles, and background concentration.

Figure 8: Example of graphic interface of concentration map database.

The pull-down menus are used for selecting specific parameters. The menus are used for displaying the existing offer of parameters for which results are available in the database. In the current version of the database, the pull-down menus are available for all values of quantities with a background tinge of brick colour.

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REFERENCES

Claiborn, C.S., Lamb, B., Miller, A., Beseda, J., Clode, B., Vaughan, J., Kang, L., Newvine, C., 1998. Re-gional measurements and modelling of windblown agri-cultural dust: The Columbia Plateau PM10 Program. *J. Geophys. Res.* 103, pp. 19753-19768.

Csanady, G.T., 1973. *Turbulent Diffusion in the Environment*. Reidel, Dordrecht, Holland.

Jícha, M., Pospíšil, J., Katolický, J., 2000. Dispersion of pollution in street canyon under traffic induced flow and turbulence. *Environmental monitoring and assessment*, 65 (1-2), pp. 343-351.

Kukkonen, J. et al., 2001. A semi-empirical model for urban PM10 concentrations, and its evaluation against data from an urban measurement network. *Atmospheric Environment,* 35, pp. 4433-4442

Moussiopoulos, N. et al., 2003. *Air Quality in Cities, Fi-nal Report of project SATURN: Subproject EURO-TRAC-2*. Germany: Springer. ISBN 3-540-00842-X.

Pospíšil, J., Jícha, M., 2008. Behavior of Particulate Matter Produced by Cars in a regional Model of Urban Canopy Layer. *Transactions on Transport Sciences*, 1 (4), pp. 157-164.

Pospíšil, J., Huzlík, J., Ličbinský, R., 2014. Rozptyl znečišťujících látek z liniových zdrojů v malých sídlech [Dispersion of Pollutants from Line Sources in Small Municipalities]. In Jandová, V., Mikulová, I., Ličbinský, R. (eds.). *VI Czech and Slovak Conference "Transport, Health and the Environment"*, Brno (Czech Republic), November 10-11, 2014. Brno: Transport Research Centre, pp. 31-38. ISBN 978-80-86502-85-4. (in Czech)

Punjrath, J.S., Heldman, D. R., 1972. Mechanisms of small particle re-entrainment from flat surface. *Aerosol Science*, 3 (6), pp. 429-440.

Saho, Y., Lu, H., 2003. A simple expression for wind erosion treshold friction velocity. *Journal of Geophysi-cal Research* 1005 (D17), 22, pp. 437-443.

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Development and Changes in Characteristics of Infiltration and Retention Facilities for Transport Infrastructure and Paved Area Surface Run-off Treatment

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ABSTRACT: The paper presents the results of water quality monitoring of road and parking surface run-off, which was done in the city of Brno in 2008-2009 and 2013-2014. The main results of the effectiveness of retention and infiltration facility treatment for PAH, petroleum substances, chlorides and selected heavy metals are presented, too. The system of facilities was built for a parking place located in Brno-Bohunice (Masaryk University campus). A retention basin was built near a shopping centre in Brno. The results of analyses and field measurements allow for comparing the evolution and changes of the filtration media characteristics, treatment effectiveness and changes in pollution. The aim of the evaluation is to provide information for the proper maintenance of retention, infiltration and treatment facilities for the surface run-off source of pollution of water bodies.

KEY WORDS: Transport infrastructure, surface run-off, water pollution, water retention, infiltration.

1 INTRODUCTION

The article presents the results of the research aimed at monitoring the retention, treatment and infiltration of surface run-off from transport infrastructure and paved areas (urban roads and car parks) in the Brno city area between the years 2008 and 2014. The conclusions from the analysis of the cleaning effect of selected facilities for the retention of pollutants from the group of PAHs, petroleum substances and metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) are also presented. The article includes information about the changes in the infiltration characteristics of the monitored infiltration and retention facilities in the period 2008 – 2014. The release of the number of pollutants that can affect the elements of the environment and the human health is caused due to car traffic (Hvited-Jacobson & Yousef, 1991; Sansalone, 1999). The origin of particular pollutants in the surface run-off from roads and parking areas is summarized in detail by Lee and Touray (1998) and Bäckström et al. (2004). A part of the harmful substances dissolved in water flows away with the rain water and another part of noxious substances is bound to suspended particles (Norrström & Jacks, 1998). In the period 2005 – 2009 the monitoring of the surface run-off at the control network of the profiles of motorways and expressways was carried out within two subsequent research projects for the Ministry of Transport (Beránková et al., 2008; 2009 & 2010). In the first years the work focused on the quantity and quality of the effluent water. An identification of substances that are present in the effluent water in measurable concentrations was performed, and the tables of characteristic concentrations of the selected PAHs and metals were compiled. Not only were the monitoring and assessment of the occurrence of polycyclic aromatic hydrocarbons and toxic metals in run-off performed but also their toxic effect on the aquatic environment was investigated. In addition, the possibilities of remedial measures were monitored, e.g. their capture in filtration strips during the infiltration. In the period of 2008 - 2009, the selected components of the transport infrastructure – facilities for surface run-off retention and infiltration as a part of one of the mentioned research projects were monitored (Beránková et al., 2010). The results were used as materials for designing new monitoring of built objects and for preparing of design parameters of newly developed objects in the research project TA03030400, which aims to design, implement and by the three-stage pilot plant facility verify a complex treatment technology for stormwater run-off coming from the transport infrastructure and impervious surfaces of the industrial areas. The monitoring was focused on a set of different stormwater management facilities, including retention ponds, sedimentation tanks, infiltration furrows, etc.

The use of the filtration environment of artificially constructed wetlands in combination with a sedimentation area is described, e.g. by Bulc and Sajn Slak (2003). The Directive DWA-A 138 (2005) and the publication Hlavínek et al. (2007) report additional equipment design principles for retention and infiltration of rainwater and surface run-off. The study Aryal et al. (2006) summarizes the results of a longitudinal twenty-year-long monitoring of the cleaning effect of retention and infiltration facilities where the cleaning of surface run-off from roads in the filtration environment of the defined filter cartridge was carried out. The significance of organic matter to enhance the effectiveness of elimination of metals from surface run-off is stated by Aryal et al. (2006) and Seelsaen et al. (2006). The authors identified the best physical-chemical properties for the sorption of metal ions (Cu, Zn, Pb) for compost by the authors. However, the release of higher concentrations of dissolved organic carbon (DOC) was also found at the same time. The combination of sand, compost or even zeolite led to the reduction of DOC leaching and to maintaining the high efficiency of metal retention (75–96% efficiency for zinc; 90–93% efficiency for copper), while in the case of clean sand the efficiency of zinc removal was found out to be 16% and copper removal 29%.

The use of chemical substances for maintenance of roads, car parks and parking areas (for salting) has also an Impact on the change of hydraulic characteristics of filtration environment and mobility of metals. The detailed pieces of information are stated by Novotny et al. (1998) and Bäckström et al. (2004). As a consequence of salting, but also due to the dust run-off, there are changes in granularity, porosity and thus the hydraulic conductivity of the filtration area. Thus, the phenomenon of colmatage (clogging) occurs (Dierkes et al., 2006).

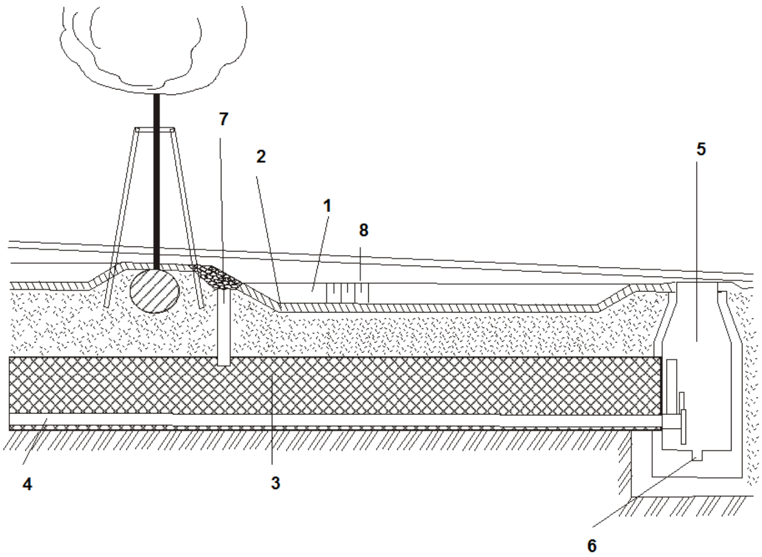
2 METHODS

A car park at the Masaryk University campus in Brno-Bohunice was selected as the first pilot locality of the Brno city area to assess the cleaning effect of the infiltration facilities of polluted stormwater. The car park is drained by the system of the infiltration open ditches (depressed areas) with retention trenches (Figure 1). The system is used for delaying torrential rainfall outflow and for pre-treatment of rainwater fallen in the car park. The more detailed description of the design of the drainage and retention system is introduced in the report of Beránková et al. (2010) and in the project documentation of dJV Project VH (2006). Based on the in-situ reconnaissance, two furrow areas were selected for monitoring. The first furrow is located in the upper, in 2008 and 2009 less used, part of the car park (the profile Bohunice 1). The second furrow is in the lower part of the car park, which was gradually more and more used in connection with the ongoing completion of the campus premises and the shopping centre (the profile Bohunice 2) in 2008. Both parts of the car park were fully used for parking during the period 2013 – 2014. The furrow "Bohunice 1" surface area was 121 m^2 by in-situ measurement and the corresponding area of the car park theoretically drained by this furrow was 592 m^2. The surface area of the other furrow "Bohunice 2 is 195 m^2 and the corresponding area of the car park theoretically drained by this furrow is 1,040 m^2. In the drainage shafts, into which piping drains of the particular furrows flow, collecting sampling containers made of polypropylene were placed, where the seepage water was trapped. Polypropylene sampling containers developed in the T. G. M. Water Research Institute, p.r.i. were put into the top soil. The intensity of collecting mixed water samples for analyses was based on the current weather conditions. The starting period of the car park operation was monitored in 2008 – 2009. The full use of the car park was monitored in 2013 – 2014. In addition the samples of rainwater and snow samples were collected, in order to determine the background levels of the concentrations of the monitored pollutants.

The other monitored facility, located in the city of Brno, is a retention basin intended for trapping, retention and treatment of surface run-off from the paved areas, car parks and roof structures of a shopping centre. The volume capacity is approx. 500 m^3, the depth between 1 and 3 m, drained area approx. 55 000 m^2. The banks and the bottom of the basin are reinforced with concrete perforated panels. The bottom was covered with a layer of sediment during both monitoring periods (0 – 30 cm thick) and a there were few places (approx. area of 0.25 m^2) with macrophyta vegetation (mainly Typha sp.) Samples from the inflow piping and outflow structure were taken, on the basis of the current weather conditions, after rain or snow melting periods.

These physical-chemical indicators of the water quality were measured in-situ in the water samples: water temperature, pH, electrical conductivity. The concentrations of the following water quality parameters: chloride, pollutants from the group of PAHs, petroleum substances (expressed as C_{10}–C_{40}), heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) were determined with the use of accredited methods in laboratory. The selection of the indicators was based on the research of literature (Hvited-Jacobson & Yousef, 1991; Bayerisches Landesamt für Umwelt, 2008 etc.) and author's own findings from monitoring of surface run-off from highways and expressways (Beránková et al., 2008; Beránková et al., 2009). The assessment of the degree of the contamination of rainfall, snow samples, and samples of surface run-off and seepage water was performed with the use of the classification of water quality according to ČSN 75 7221 (1998) and in accordance with the pollution standards of the Government Regulation No. 23/2011 Coll.

As mentioned in the introductory part of the article, the cleaning effect depends on the composition of the seepage (filtration) layer substrate of infiltration furrows and changes in the hydraulic properties of the material. In addition, the use of chemical substances for maintenance of roads, car parks and parking areas (for salting) has an impact on the change in hydraulic characteristics of the filtration environment and mobility of metals. For this reason, the part of the research also dealt with the determination of characteristics of the filter medium (localization of cross profiles of infiltration furrows, determination of fundamental physical properties of filtration medium and transition filters, determination of the characteristics of dependence of filtration velocity on time, or the intensity of filtration depending on time respectively, determination of hydraulic conductivity, granular composition of the material, etc.) of the monitored furrows, after one year of the operation and in the year 2013. The determination of the intensity of filtration was carried out on the spot with the use of two classic infiltrometers. The infiltration capacity of soil was expressed as the amount of water soaked for a time interval or as the percolation rate of progress over time. The detailed description of the work methodology is given in the report Beránková et al. (2010).



1 – infiltration furrow, 2 – top humus soil, 3 – retention space filled by filtration material (loamy sand and fine gravel), 4 – drain piping, 5 – shaft with outflow control unit, 6 – outflow, 7 - emergency spillway, 8 – retention (up to 0.3 m)

Figure 1: Scheme of Infiltration Furrow.
(Source: JV Projekt VH, s.r.o., 2006; Beránková et al., 2010)

3 RESULTS AND DISCUSSION

In the samples of rainfall there were only very low (background) chloride concentrations in the order of mg/l (as well as in the samples of snow). The concentrations of monitored metals also ranged from I. to II. water quality class. The concentrations of petroleum substances and PAHs were always below the detection limit. The collected values are similar to the ones given for rainwater in the publication Hlavínek et al. (2007).

Snow samples were taken directly at the car park, namely in January 2009 (fresh snow) and in March 2009 (old, dense snow containing the remains of the inert material from gritting). Snow samples were not taken during the winter 2013 – 2014, because of warm winter weather conditions in the city of Brno. Warren and Zimmerman (1994) and Novotny et al. (1998) state that the snow contamination by the monitored pollutants increases with its age (time of deposition on roads and around). This statement was also confirmed by our results. In the samples of fresh snow, the contents of the monitored metals did not exceed values of the I. and the II. water quality class according to ČSN 75 7221 (1998), with the exception of zinc, which in one case exceeded the limit of the III. water quality class. The concentration of petroleum substances, expressed by the indicator C_{10}–C_{40}, was below the value 0.1 mg/l (pollution limit of the Government Regulation No. 23/2011 Coll.).

In contrast, regarding the samples of longer lying snow, the concentrations of petroleum substances (C_{10}–C_{40}) were close to 2 mg/l (i.e. an order of magnitude above the limit value), the concentration of metals reached from III. water quality class (Cd, Ni) to V. water quality class (Cu, Pb, Zn) of water quality. The concentrations of PAHs were similar in all samples (the sum of PAHs 20 to 90 ng/l, i.e. I. water quality class, pollution limit 200 ng/l).

Table 1 shows the range of values of particular indicators of water quality and the pollutants determined in the samples of the surface run-off and seepage water. Dierkes et al. (2006) published long-term concentrations of the following substances in surface run-off from car parks: Cd 1.2 μg/l; Cu 80 μg/l; Pb 137 μg/l; Zn 400 μg/l; PAH 3 500 ng/l. When performing a comparison of these values with the data in the Table 1, the concentrations detected on the surface run-off at the monitored location are lower for the both monitoring periods. The confrontation of furrows outflow concentrations of selected pollutants from the periods 2008 – 2009 and 2013 – 2014 showed that the range of values is practically similar.

Table 1: Range of values of selected pollutants in furrows outflows in periods 2008 – 2009 and 2013 – 2014.

Period of monitoring		2008-09	2013-14	2008-09	2013-14
Furrow		Bohunice 1	Bohunice 1	Bohunice 2	Bohunice 2
pH	–	7.3-8.4	8.2-8.5	6.4-8.7	8.2-8.4
EC	mS/m	36-70	43-76	24-891	58-91
Cl^-	mg/l	2-118	61-81	4-1570	65-241
C10 – C40	mg/l	< 0.02-0.58	< 0.1-0.14	< 0.02-0.23	< 0.1-0.16
Σ PAH	ng/l	< 100	< 100	< 100	< 100
Cd	μg/l	< 0.1-0.57	<0.1	< 0.1-1.04	<0.1
Cr	μg/l	8.7-39.5	5.1-10.6	4.7-24.9	8.1-9.6
Cu	μg/l	2.7-7.5	6.1-25.9	9.7-36.5	2.4-4.8
Hg	μg/l	< 0.05-0.22	< 0.1-0.24	< 0.05-0.74	0.1-0.14
Ni	μg/l	4.9-25.1	< 2-15.3	6.5-23.7	< 2
Pb	μg/l	0.9-4.9	< 0.5-1.4	0.5-6.7	< 0.5-0.6
Zn	μg/l	6-22	19-51	23-92	11-15

(Source: authors, T.G.M. WRI, p.r.i.)

Exceeded pollution standards for chlorides and the V. water quality class in the samples from the period January to May 2009 were associated with the winter maintenance (road salting) in the lower part of the car park where sample containers in the profile Bohunice 2 were placed. The upper part of the car park was only treated with inert material (very low occupancy of parking) in that period. A similar situation was observed during winter 2013 – 2014, but with lower maximum values. The values of electrical conductivity of water (correlation coefficient 0.9917) well correlated with the values of the concentrations of chlorides. Thus, in the three of the mentioned cases the values of electrical conductivity reached V. water quality class, otherwise they were on the levels of I and II. water quality classes.

High efficiency of the elimination (capture) of cadmium, copper, lead, zinc, petroleum products (indicator C_{10}-C_{40}) and pollutants from the group of PAHs was found in the filtration environment of the furrows. With regard to the redox conditions and the degree of saturation of the filter media, the release of metals into the aquatic environment was detected during the monitoring. This fact was recorded in the presence of low concentrations of metals in the surface run-off that corresponded to the I. and II. water quality classes (according to ČSN 75 7221). The similar results, when evaluating the efficiency of cleaning of filtration medium at very low concentrations of metals (mainly Cr, Cu, Pb, Zn), and in particular during the dry period are stated by Shutes et al. (2001). The authors report the capture efficiency of Cu, Cr, Ni and Zn 60 to 90% in the filtration environment of artificial wetlands with higher concentrations. Bulc and Sajn Slak (2003) state the efficiency of retention of the selected metals from surface run-off from roads in the gravel filtration media of artificially constructed wetlands. These long-term average values of efficiency: 69% of suspended solid substances, 97% of settleable substances, 90 or more percent metals (Cd, Cu, Ni, Pb a Zn) were reached on the monitored facilities. The authors also proved the binding of metals to suspended solid substances and they determined sedimentation and filtration as the predominant cleaning mechanisms. There are also results available for the comparison of monitoring of the wastewater treatment plants with the biological phase represented by the soil (ground) and gravel filters. A similar ability of the elimination of the monitored pollutants in the filtration media was confirmed for these devices, also usable for cleaning of the surface run-off (as claimed by e.g. Kadlec and Wallace (2009)). For exmple, Kröpfelová et al. (2009) reports the long-term average values of efficiency of 78% (Zn), 67% (Cu), 63% (Pb), 55% (Cr) and 25–50% for Hg, Cd and Ni (found in the Czech Republic).

The results of the retention basin monitoring are summarized in Table 2. In the both monitoring periods, the concentration of metals and PAH has a similar range of values in the basin outflow. The concentrations of zinc and mercury were out of the I. and II. water quality class ranges. The concentration of chlorides in the water samples was different due to different courses of winters. The basin shows a high elimination of petroleum substances (parameter C10-C40), with one exception of the collected samples. In that sample, the C10-C40 value was two orders of magnitude higher than in the other samples. Based on the course of sampling and further testing, the source of such a high amount of petroleum substances in the sample could be assigned to a surface film of oil after the release of oil from the sediment.

Table 2: Range of values of selected pollutants in retention basin outflow.

Parameter	pH	EC	Cl^-	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Σ PAH	C10-C40
Period	-	mS/m	mg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	ng/l	mg/l
2008-09	7.6	174	372	<0.1	1.6	8.2	<0.1	3.4	<0.5	58	<30	<0.1
	8.2	430	1,280	<0.1	7.3	9.3	0.11	6.7	<0.5	283	<30	<0.1
2013-14	7.0	19	27	<0.1	<1	4.4	<0.1	<2	<0.5	21	<30	<0.1
	8.4	83	396	0.31	8	30.9	0.13	12.5	5	291	0.18	41.1

(Source: authors, T.G.M. WRI, p.r.i.)

The absorption capacity of soil is determined as the amount of water soaked for a time interval or as a course of absorption velocity in time. The absorption ability was therefore investigated on the surface of soil with the use of two concentric cylinders that are slightly recessed directly towards the surface of the infiltration strip of the Campus car park. h was evaluated according to the equations by Kosťjakov, Mezencev and Philip. The relationship between the rate of infiltration v_i on time t_i and the relationship of the cumulative value of the cumulative infiltration i_i on time t_i was determined from the field measurements. The simplest way is to express these dependencies by using empirical equations of Kosťjakov and Mezencev. The evaluation according to Philip is computationally more complicated, the detailed process is stated by Kutílek et al. (2000).

The values found for the two selected furrows representing both parts of the car park were similar (again the average values from the calculation by the three methods) in 2009:

K3 – infiltration rate v_t [mm/min] – beginning of the experiment 4; end of the experiment 3 / cumul. inf. i_t [mm] – beginning 15; end 353
K6 – infiltration rate v_t [mm/min] – beginning 3; end 3 / cumul. inf. i_t [mm] – beginning 15; end 334

During the research two samples were collected twice (from the lower and upper car park) for the determination of hydraulic conductivity of the filter material. The obtained values were compared with the requirements for the design of the infiltration furrows (e.g. Hlavínek et al., 2007; JV Project VH, 2006; DWA-A 138, 2005) when the hydraulic conductivity of materials is recommended in the range of 1.10^{-3} to 1.10^{-6} m/s (60 to 0.06 mm/min), while at values close to 1.10^{-6} m/s (0.06 mm/min) and lower, the infiltration with the accumulation of water (controlled retention) is recommended. Hydraulic conductivity of 1.10^{-5} m/s (0.6 mm/min) was assumed for the monitored facilities. The results of the tests performed with the material of the infiltration furrow from the car park after a one-year operation (in detail Beránková et al., 2010) show that the permeability is adequate only at the beginning of the experiment until the entire material is thoroughly saturated with water. The process of saturation occurs within 4-7 hours. We can assume that in operational conditions, e.g. persistent raining, the saturation of the entire filtration media of infiltration furrows will occur (full water saturation capacity when all pores are filled with water). For these reasons, but also because of the fact that the furrows are not designed to an absolute protection, the design and implementation of similar facilities need to allow the construction of emergency spillways as was done on the monitored furrows. Despite these facts, long-term possibilities of using similar equipment for the retention of and cleaning of surface run-off have been proven abroad, as stated by Aryal et al. (2006), and others.

The following values of infiltration velocity were calculated for both furrows in 2013: Bohunice-1 – 6.6 – 10.8 mm/min based on the existing moisture of filtration medium. Bohunice-2 – 9.6 – 15.6 mm/min based on the existing moisture of filtration medium.

The infiltration capacity of the furrows has still been sufficient for several years of operation, and the values measured in 2013 were similar to the values measured in 2009.

4 CONCLUSION

Our findings show that the surface run-off at the monitored area currently contains less pollution, especially metals. As already mentioned, at the time of the monitoring, the car park was increasingly affected as the other buildings in the area were put into service. The amount of monitored pollutants was higher in the surface run-off in transport infrastructure samples than in the rainwater samples, which presents a certain impact of traffic on the run-off water quality (Bulc & Sajn Slak, 2003; Bayerisches Landesamt für Umwelt, 2008; Beránková et al., 2008; etc.). The contamination of outflows from the monitored retention facilities has been in the same range of values since 2008. The retention facilities has been showing high elimination of monitored pollutants, but as was shown in the case of C10-C40 substances, an appropriate management is necessary (e.g. sediment disposal) to prevent secondary contamination of outflow water. Regarding the facts from longer monitored similar facilities abroad (Bayerisches Landesamt für Umwelt, 2008), it is possible to expect the increase in effects by the assessed pollutants. It has been confirmed that pollutants are bound and accumulated in insoluble substances which leads to their deposition in retention and drainage facilities. The infiltration characteristics of both furrows were similar between 2008 and 2014. In further development of the use of infiltration furrow technology with the retention area with regard to the treatment of water from roads and car parks, it is essential to focus on the issue of their operation and maintenance in winter, when more snow comes. The infiltration furrows will undoubtedly be used to store snow from the car park. It will be necessary to monitor the function of infiltration furrows during melting and to prevent flooding of the car park. It is also vital to pay attention to maintenance of the surface of retention areas and infiltration furrows, so that there are suitable filtration media properties (grain size, hydraulic conductivity and infiltration rate) provided.

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REFERENCES

Aryal, R. K., Muramaki, M., Furumai, H., Nakajima, F., Jinadasa, H.K.P.K., 2006. Prolonged deposition of heavy metals in infiltration facilities and its possible threat to groundwater contamination. *Wat. Sci. Tech.*, 54 (6-7), pp. 295-212.

Bayerisches Landesamt für Umwelt, 2008. Bodenkundliche Untersuchungen im Rahmen des Entwicklungsvorhabens „Versickerung des Niederschlagwassers von befestigten Verkehrsflächen“ [on-line]. Augsburg: Bayerisches Landesamt für Umwelt, 2008 [cited 2014-09-12]. Retrieved from: http://www.lfu.bayern.de/boden/boden_daten/veroeffentlichungen/index.htm

Bäckström, M., Karlsson, S., Bäckman, L., Folkeson, L., Lind, B., 2004. Mobilisation of heavy metals by deicing salts in a roadside environment. *Wat. Research,* 38, pp. 720-732.

Beránková, D., Brtníková, H., Kupec, J., Huzlík, J., Prax, P., 2008. Pollution of the highways runoff. *Transactions on Transport Sciences*, 1 (2), pp. 31-38. ISSN 1802-971X.

Beránková, D., Brtníková, H., Kupec, J., Mlejnková, H., Huzlík, J., Prax, P., 2009. Parametry jakosti a množství povrchového splachu z dálnic. *VTEI*, příloha *Vodního hospodářství,* 51 (6), pp. 8-11. ISSN 0322-8916. (in Czech)

Beránková, D., Rozkošný, M., Vítek, J., Huzlík, J., Kupec., J., Kriška, M., Šálek, J., Mlejnková, H., Brtníková, H., 2010. *Kontrola jakosti dálničních splachů a hodnocení účinnosti jejich dočišťování při decentralizovaném systému odvodnění* (závěrečná zpráva projektu VaV 1F84C/031/910 za obd. 2008-2009). Brno: VÚV TGM, 72 p. (in Czech)

Bulc, T., Sajn Slak, A., 2003. Performance of constructed wetland for highway runoff treatment. *Wat. Sci. Tech.*, 48 (2), pp. 315-322.

ČSN 75 7221, 1998. Jakost vod - Klasifikace jakosti povrchových vod. (in Czech)

Dierkes, C., Göbel, P., Lohmann, M., Coldewey, W.G., 2006. Development and investigation of a pollution control pit for treatment of stormwater from metal roofs and traffic areas. *Water Science & Technology*, 54 (6-7), pp 291–298.

DWA-A 138, 2005. Planung, Bau und Betrieb von Anlagen zur Versickerung von Niederschlagswasser. Hennef: DWA, Arbeitsblatt - A138, 2005. ISBN 3-937758-66-6.

Hlavínek, P. et al., 2007. *Hospodaření s dešťovými vodami v urbanizovaném území*. Brno: ARDEC. ISBN 80-86020-55-X. (in Czech)

Hvited-Jacobson, T., Yousef, Y. A., 1991. Highway Runoff Quality, Environmental Impacts and Control. In Hamilton, R.S., Harrison, R.M. (eds.). *Highway Pollution*. Amsterdam: Elsevier, pp. 165-208.

JV Projekt VH, s.r.o., 2006. MU v Brně, Univerzitní Kampus Bohunice - AVVA, AVVA - infrastruktura, SO IV-322.2 parkoviště II – odvodnění, SO IV-325.4 parkoviště III - odvodnění, 051 (technická zpráva; arch. č. 05 065, 03/2006). (in Czech)

Kadlec, R.H., Wallace, S., 2009. *Treatment wetlands* (2nd ed.). Boca Raton (USA): CRC Press.

Kröpfelová, L., Vymazal, J., Švehla, J., Štíchová, J., 2009. Removal of trace elements in three horizontal sub-surface flow constructed wetlands in the Czech Republic. *Environmental Pollution*, 157, pp. 1186-1194.

Kutílek, M., Kuráž, V., Císlerová, M., 2000. *Hydropedologie*. Praha: ČVUT. 149 p. (in Czech)

Lee, P. K., Touray, J. C., 1998. Characteristics of a polluted artificial soil located along a motorway and effects of acidification on the leaching behavior of heavy metals (Pb, Zn, Cd). *Wat. Res*., 32 (11), pp. 3425-3435.

Nařízení vlády č. 23/2011 Sb. Praha: MŽP. [Government Regulation No. 23/2011 Coll., Ministry of the Environment of the Czech Republic] (in Czech)

Norrström, A. C., Jacks, G., 1998. Concentration and fractionation of heavy metals in roadside soils receiving de-icing salts. *Sci. Tot. Env.,* 218, pp. 161-174.

Novotny, V. et al., 1998. Cyanide and metal pollution by urban snowmelt: impact of deicing compounds. *Wat. Sci. Tech*., 38 (10), pp. 223-230.

Rozkošný, M., Kriška, M., Hudcová, T., Novotný, R., Beránková, D. Vývoj a změny charakteristik vsakovacích a retenčních objektů pro čištění smyvů z dopravní infrastruktury a zpevněných ploch [The development and changes in the characteristics of the infiltration and retention for transport infrastructure and paved areas surface run-off treatment]. In Jandová, V., Mikulová, I., Ličbinský, R. (eds.). *VI Czech and Slovak Conference "Transport, Health and the Environment"*, Brno (Czech Republic), November 10-11, 2014. Brno: Transport Research Centre, pp. 63-71. ISBN 978-80-86502-85-4. (in Czech)

Sansalone, J. J., 1999. Adsorptive infiltration of metals in urban drainage - media characteristics. *Sci. Tot. Env.*, 235, pp. 179-188.

Seelsaen, N., McLaughlan, R., Moore, S., Ball, J. E., Stuetz, R. M., 2006. Pollutant removal efficiency of alternative filtration media in stormwater treatment. *Wat. Sci. Technol.*, 54, (6-7), pp. 299-305.

Shutes, R.B.E., Revitt, D.M., Scholes, L.N.L., Forshaw, M., Winter, B., 2001. An experimental constructed wetland system for the treatment of highway runoff in the UK. *Wat. Sci. Tech.*, 44 (11-12), pp. 571–578.

Warren, L.A., Zimmermann, P., 1994. The influence of temperature and NaCl on cadmium, copper and zinc partitioning among suspended particulate and dissolved phases in an urban river. *Wat. Res.*, 28 (9), pp. 1921-1931.

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3 ABSTRACT

The abstract should start after leaving eight blank lines. Type the text of the abstract in one paragraph, after a space behind the word abstract and colon, with a maximum of 250 words in Times New Roman, regular, font size 12, single-spaced, and justified. After leaving one blank line, type KEY WORDS: (capital letters, Times New Roman, font size 12), followed by a maximum of five (5) key words separated by commas. Only the first letter of the first key word should be capitalized.

4 THE TEXT

The main body of the paper follows the key words, after two blank lines (i.e., two blank lines between the first heading and the key words). The body text should be typed in Times New Roman, font size 12 and justified. The first line of the paragraphs should be indented 5 mm except the paragraphs that follow heading or subheading (i.e., the first line of the paragraphs that follow heading or subheading should not be indented). Never use bold and never underline any body text.

4.1 HEADINGS AND SUBHEADINGS

The headings are in capital letters, Times New Roman, font size 12. Subheadings are in title letters Times New Roman, font size 12. The headings and subheadings must be aligned left and should not be indented. Leave two blank lines before and one after the heading. There should be one (1) blank line before and after the subheadings. All headings and subheadings must be numbered. If a heading or subheading falls at the bottom of a page it should be transferred to the top of the next page.

4.2 FIGURES AND TABLES

Figures, line drawings, photographs, tables should be placed in the appropriate location, aligned centre, and positioned close to the citation in the document. They should have a caption, Times New Roman font size 12, with a colon dividing the figure number and the title (Figure 1: Material properties) and should be numbered consecutively, e.g. Figure 1, Figure 2, Table 1, and Table 2.

4.3 REFERENCES

At the end of the paper, list all references with the last name of the first author in alphabetical order, underneath the heading REFERENCES. Please see Reference Style and Examples of References:
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