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Identification of Curves and Straight Sections on Road Networks from Digital Vector Data

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ABSTRACT: Identification of curves and straight sections on roads is important from a traffic safety point of view. We present a method for the automatic identification of curves based on available geographic data – sequence of points which determines a line. The Douglas-Peucker algorithm is used to generalize the lines. At every point of the line, the coefficient of curvature is calculated. According to the coefficient of curvature it is possible to decide which line segments are curves and which are straight sections. For making the decision, other characteristics of lines were also studied, but the obtained results support that the coefficient of curvature is the most suitable of them. The method was applied on two sections from the district of Olomouc.

KEY WORDS: Horizontal curves, classification, osculating circle, coefficient of curvature.

1 INTRODUCTION

The main reasons why the identification of curves and straight sections is important are the increased risk of traffic accidents in curves on the one hand and the calming effect of curves on the other hand. Curves are places where the risk of a traffic accident increases as a result of getting out of the lane, or due to poor driver's visibility. According to the synthesis of the World Road Association (PIARC, 2003) the accident rate in horizontal curves is 1.5 to 4 times higher than on straight sections. In addition to safety risks, curves, to some extent, represent also a calming element, because drivers slow down when entering a curve. They are forced to pay more attention in areas with frequent curves, while in areas with prevailing monotonous straight sections there is a risk of a loss of concentration of the driver. For this reason, it appears that the most dangerous are those curves which follow after a long straight section of the road. Identification of curves and their characteristics – particularly the size of horizontal curves and length of curves, is therefore desirable from both safety experts and for example from road administrators – curves are often equipped with crash barriers or other technical elements and a tool for their automatic identification can facilitate road administrations to perform their management tasks.

Identification of curves and straight sections is an issue which has already been studied in the past, including several recent publications on the use of a GIS to identify curves (Bogenreif et al., 2012; Findley et al., 2012; Rasdorf et al., 2012).

2 AREA OF INTEREST AND DATA SOURCES

The aim of this work was to propose a method for the automatic identification of curves on roads based on available geographic data. The proposed method is based on the principle of determination of the radius of an osculating circle (Fuchs & Tabachnikov, 2007; Stewart, 2011) which adjoins the road. By classifying these radii we can then determine whether a given segment of the road is part of a curve or a straight section.

This method was compared with four other methods based either on identification of the radius of the circle circumscribed to a road segment, or on the calculation of the angle formed by break points of a road line.

The most accessible, while also official, source of data on the road network in the Czech Republic is the recording of road equipment and facilities from the database of the Road and Motorway Directorate of the Czech Republic (RMD CR). Data can also be sourced from OpenStreetMap, however, their relevance is difficult to verify. Geographic data can also be sourced from local authorities, whose data sets are likely to originate from the database of RMD CR. Last but not least, there are commercial products, such as the reason, they have the possibility to acquire the data by using GPS devices or by digitizing maps. In this work we used RMD CR data as they are acquired directly by the administrator of the roads in question, and it is a source accessible to state administration and local governments, the authorities which are the most active both in the field of traffic safety and road administration.

Two test sites were selected (see Figure 1). The first location is a segment of road II/446 between the villages Chomoutov and Pňovice with a total length of 8.7 km. This section is situated in a flat terrain with several shallow curves. The second section is the section of road II/444 located between the village of Lipina and the junction near the mill Těšíkovský mlýn with a length of about 5.6 km. This section contains frequent horizontal and vertical curves, and runs through an urban area as well as a densely forested valley. Both locations are situated near the town Šternberk in the district of Olomouc.

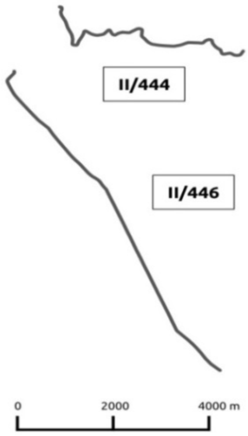

Figure 1: Road sections II/444 (up) and II/446 (down).

3 DATA PRE-PROCESSING

Before using the method itself for identifying the curves, it is necessary to properly prepare the data. It often happens that in some places, the points defining a road segment are too close to each other, contain redundant information, or contain defective information incurred during data collection that could result in the distortion of the identification of curves. This can be avoided by using the geometric line generalization.

3.1 Geometric line generalization

Generalization is used to reduce and simplify the volume of data while maintaining a sufficient amount of information contained in such data. Lines can be generalized with the use of several algorithms:

- Leaving out/maintaining every k-th point of a line;
- Length test (removal of nearby points);
- Angle test (eliminating points with small angle difference);
- Lang's algorithm;
- Visvalingam-Whyatt algorithm;
- Reumann-Witkam algorithm;
- Douglas-Peucker algorithm.

A comprehensive list and description of methods for line generalization is presented in Clayton (1985). In this case, we selected the last mentioned method of line generalization that is described below.

3.2 Douglas-Peucker algorithm

We select the tolerance of accuracy (e.g. 0.1 m). The Douglas-Peucker algorithm works as follows:

- First, connect the start and end point of the section;
- Find a point whose distance from the line segments formed by all the connected points is the largest (we consider the classical Euclidean distance, i.e. we draw a perpendicular line from the point);
- Compare this distance with the selected tolerance and if the distance is lower than the accuracy tolerance, terminate the calculation;
- Include a point whose distance is greatest among the connected points. Return to step 2.

Through this process we obtain a simplified line. This method is illustrated in the example in Section 5.

4 METHOD FOR IDENTIFICATION OF CURVES

Typically, a curve is constructed as a segment of a circle of a given radius and is connected to the straight sections of the road by transition curves. Due to this, it is suitable for the identification of curves to try and locally approximate the line given by points $X_i = \left(x_{i1}, x_{i2}\right)$, for $i = 1, \ldots, n$, by a circle.

The first idea that comes to mind is to draw a circle to every three neighbouring points and then assign its radius to the middle point of these three points as road curvature characteristics at this point.

If we had virtually ideal data available, i.e. break points are approximately equally apart from each other, there are neither “dense” nor “sparse” places in the data and there are only very small measurement errors (up to 0.1 m) that can be removed using the Douglas-Peucker algorithm; we could use the radius of a circumscribed circle to identify curves without much difficulty.

If no precise data are available, the calculation of the radius of a circumscribed circle may lead to the erroneous determination of curves because of the assignment of relatively small radii. For example, in a situation with a straight section, on which all points defining this segment lie on a line except one point, which is deflected from the straight line by only 0.5 m, the radius of a circumscribed circle will be relatively small and therefore there will be identified a false curve.

As we can see, the determination of curves using a circumscribed circle with the approximation of the line between the points it circumscribes has some weaknesses, and therefore a better method is to use the so-called osculating circle, which, if combined with the Douglas-Peucker algorithm, has none of the above-mentioned drawbacks. Its definition implies that it does not approximate three neighbouring points, but tries to approximate the curvature of a line at one specific point. Its radius is dependent on the change in slope of the tangent to the curve and therefore it tells us how much the road is curved at a given point.

Both above-mentioned methods have been tried in order to identify curves and were supplemented with two alternative procedures. The first determines the curves based on the angle formed by three consecutive points, the second method uses the cumulative angle of three consecutive break points.

4.1 Calculation of radius of osculating circle

Let us denote the curve $c : I \subset \mathbb{R} \to \mathbb{R}^2$. Based on the geometry of curves (Fuks & Tabachnikov, 2007; Stewart, 2012) we know the formula for calculating the coefficient of curvature at a given point:

$$\kappa(t_0) = \|\dot{T}(t_0)\| / \|\dot{c}(t_0)\|, \quad t_0 \in I,$$

where $T(t)$ denotes the tangent vector of the curve and $\dot{T}(t_0)$ its derivative with respect to variable t at point t_0. Similarly $\dot{c}(t_0)$ denotes a derivative of curve c with respect to t at point t_0. The number $R(t_0) = 1/\kappa(t_0)$ denotes the radius of an osculating circle at point t_0. The larger is the radius, the smaller is the curvature of the curve.

Since we have no analytical specification of the curve (our road section), we have to approximate the depiction of c and T at each point by finite differences. For $I = 2,\dots, n-1$ the calculation is as follows:

$$T(X_i) = (X_{i+1} - X_{i-1}) / \|X_{i+1} - X_{i-1}\|$$
$$\dot{T}(X_i) = (T(X_{i+1}) - T(X_{i-1})) / (\Delta t_1 + \Delta t_2)$$
$$\dot{c}(X_i) = (X_{i+1} - X_{i-1}) / (\Delta t_1 + \Delta t_2)$$

Here we deduce the formula for calculating the coefficient of curvature easily:

$$\kappa(X_i) = \|\dot{T}(X_i)\| / \|\dot{c}(X_i)\| = \|T(X_{i+1}) - T(X_{i-1})\| / \|X_{i+1} - X_{i-1}\|$$

The use of this method is demonstrated in the examples in Section 5.

4.2 Distinguishing curves and straight sections

When describing a road network (e.g. for statistical purposes), it is strictly necessary to distinguish which part of a road is a curve and which is not. This distinction can be made on the basis of:

- Expert recommendation or legislature (it is stated what the radius of a road section must be so that we consider it to be a curve);
- A histogram of radii of osculating circles (e.g. the case of bimodal distribution would be indicative of two groups of data in the database);

- Manual identification of curves and straight sections by an expert on selected data and finding a classification rule which, after entering the characteristics (osculating circle radius, distance to the nearest break point, angle between three neighbouring points, etc.) would say whether a certain section is a curve or a straight section (this would be the so-called classification with a teacher).

5 RESULTS AND DISCUSSION

This section describes the results achieved by applying the methodology described above to data from Section 2.

First, we used the Douglas-Peucker algorithm for line generalization. As can be seen in Table 1, regarding section II/446, which is not very curved (see Figure 1), a relatively large amount of points were eliminated in contrast to section II/444. This is in accordance with expectations.

Table 1: Number of points defining a road section before and after using the Douglas-Peucker algorithm.

	Before	After
II/446	125	113
II/444	212	210

It is interesting that the data from RMD CR before and after generalization differ very slightly. It is possible that these data have already been processed using some generalization algorithm.

In the second step, we calculated for each point:

- The radius of an osculating circle that touches the curve (our road section) at this point;
- Radius of a circle circumscribing three consecutive points;
- Angle between three consecutive points;
- Cumulative angle of three points.

For both road sections, a traffic engineering expert defined curves and straight sections. For each of the analyzed break points it was then determined whether after this classification it is a curve or straight section. For each of the four monitored variables, histograms were prepared comparing the distribution of values in both categories.

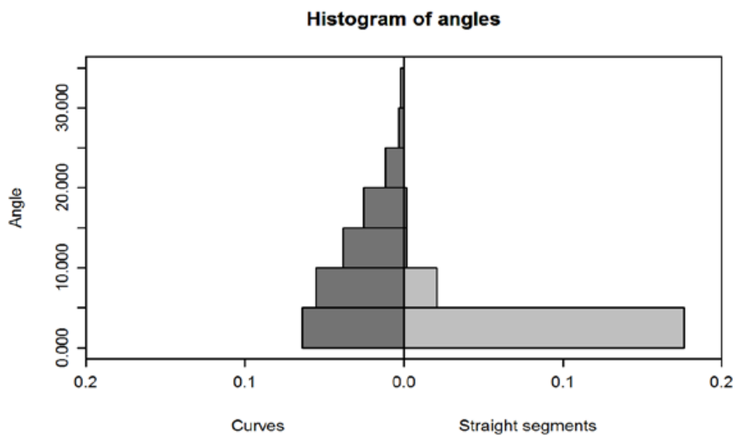

Figure 2: Histogram of angles.

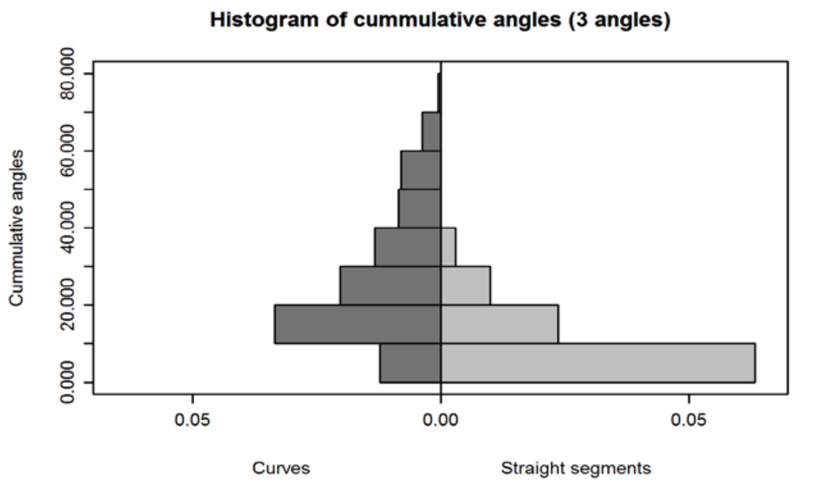

Figure 3: Histogram of cumulative angles (sum of three angles).

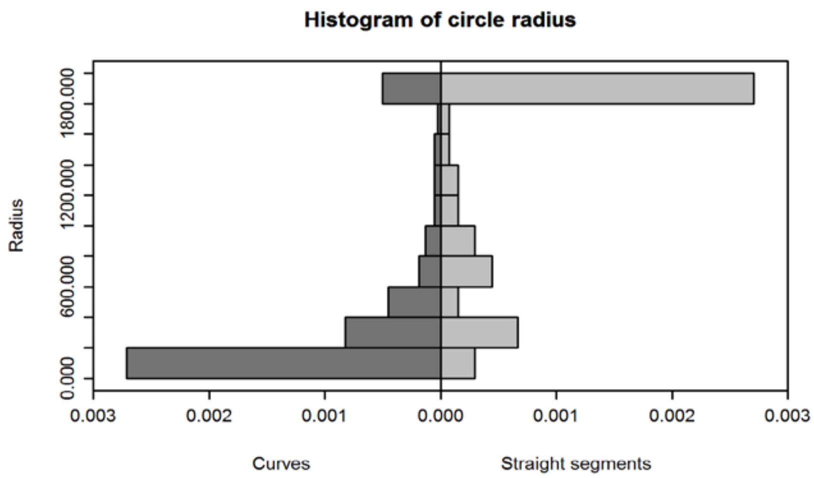

Figure 4: Histogram of radii of circumscribed circles.

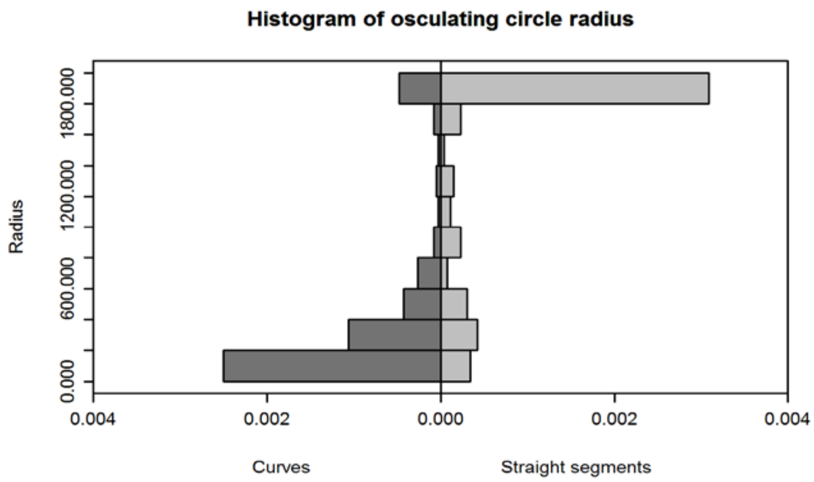

Figure 5: Histogram of radii of osculating circles.

Figures (2 – 5) clearly show that it is not possible to find a value that would clearly define straight sections and curves when using the characteristics derived from the size of angles. Histograms of the radii of circles are strongly asymmetrical and more suitable for this purpose. Table 2 shows a comparison of the osculating circle method and circumscribed circle method for different classification levels.

Table 2: Classification success rate for the given boundary values of radii. The values indicate the proportion of correctly classified break points.

	II/446		II/444	
Threshold value of radius (m)	Circumscribed circle	Osculating circle	Circumscribed circle	Osculating circle
100	65%	65%	54%	56%
300	73%	72%	74%	76%
500	74%	73%	80%	80%
1000	70%	78%	80%	81%
1500	70%	74%	78%	80%
2000	72%	75%	77%	78%

The success rate for the section II/444 is specified in more detail in Table 3. The specificity value indicates the probability that if the point is determined as a part of a curve, this determination is correct. Sensitiveness is an analogy to specificity for straight sections. The value of PPV (positive predictive value) indicates what percentage of curves was correctly identified, and NPV (negative predictive value) indicates what percentage of straight sections was correctly identified. As shown in table 3, the difference between these two methods lies in the specificity, where the osculating circle appears to be a better solution. Identification of straight sections is therefore equally successful in both methods, for the identification of curves the osculating circle method is more successful.

Table 3: Specificity and sensitivity of the circumscribed circle method and osculating circle method when used on section II/444. Threshold value of radius is 1000 m.

	Circumscribed circle	Osculating circle
Sensitivity	80.1%	80.3%
Specificity	79.5%	83.8%
PPV	94.5%	95.9%
NPV	47.7%	47.7%

6 CONCLUSION

A method was proposed for the automatic classification of curves and straight sections based on the geometry of roads. This method is based on calculating the radius of an osculating circle and was compared with three alternative methods. The methods based on the calculation of curve radius appeared significantly better than those based on the calculation of break angles of lines. Both methods based on the calculation of the radii of curves are comparable in identifying straight sections, while for the identification of curves, the osculating circle method produces better results. Determination of margins for identifying curves is a matter for further research and was not further addressed in this work. Overall, the proposed method of automatic identification is successful and easy to implement into a GIS environment, and thus suitable for broader use.

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REFERENCES

Bogenreif, C., Souleyrette, R. R., Hans, Z., 2012. Identifying and Measuring Horizontal Curves and Related Effects on Highway Safety. *Journal of Transportation Safety & Security*, 4 (3).

Clayton, V. H., 1985. *Cartographic Generalization: A Review of Feature Simplification and Systematic Point Elimination Algorithms*. NOAA Technical Report NOS, 112. Rockville, Md.: National Oceanic and Atmospheric Administration, National Ocean Service, Office of Charting and Geodetic Service.

Findley, D. J., Zegeer, CH. V., Sundstrom, C. A., Hummer, J. E., Rasdorf, W., Fowler, T. J., 2012. Finding and Measuring Horizontal Curves in a Large Highway Network: A GIS Approach. *Public Works Management & Policy*, 17 (2).

Fuchs, D. B., Tabachnikov, S., 2007. *Mathematical Omnibus: Thirty Lectures on Classic Mathematics*. Providence (USA): American Mathematical Society. ISBN 0821843168.

PIARC, 2003. *Road Safety Manual*. Paris: PIARC. ISBN 2-84060-158-3.

Rasdorf, W., Findley, D. L., Zegeer, C.V., Sundstrom, C.A., Hummer, J. E., 2012. Evaluation of GIS Applications for Horizontal Curve Data Collection. *Journal of Computing in Civil Engineering*, 25 (2).

Stewart, J., 2011. *Calculus.* Brooks Cole Publishing, USA.

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Legislative Intent of the Noise Act with Respect to Traffic Noise Control

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ABSTRACT: A bill on the protection of public health against noise and for noise control in the municipal environment ("Noise Act") has the character of a Codex due to the issue of noise control in the municipal environment affecting the competence of many departments. An effective solution to this problem requires not only a comprehensive legislative approach, but also the necessity of coordination. It is proposed to set up a National Council of Noise that would work within the Office of the Government. The bill is designed to maximally apply the principles of subsidiarity and shared responsibility. To control the health impact of traffic noise in the outdoor area the previous legally enforceable system of one-figure noise limits is being abandoned and a new noise zone system is proposed. The noise limits should be used in this instance in accordance with the practice in other European countries as an interval of values (zones), which will be respected in noise control. The emphasis for the protection of public health against noise is placed on the protection of the interiors of buildings for housing, education, health and social purposes, where the level of health risks is minimized by setting an obligatory noise limit, which is the same for all noise zones and all noise sources.

KEY WORDS: Noise, transport, noise control, impact of traffic noise.

1 INTRODUCTION

Noise is a serious detrimental factor of the human environment. Noise is intrusive, annoying and can cause harmful effects on the health of the exposed persons (Havránek et al., 1990; WHO, 2009; WHO, 2011). The problem of health protection and noise management in the environment is a typical interdisciplinary issue, the solution of which requires a coordinated approach and comprehensive legal regulation that does not exist in the Czech Republic up to now.

The Ministry of Health has prepared and submitted a bill on the protection of public health against noise and for noise control in the municipal environment ("Noise Act"). The bill is designed in accordance with the Policy Statement from the Government of the Czech Republic and Czech Government Resolution No. 69 of 26 January 2011 and was discussed within the framework of internal and interdepartmental amendment procedures.

As the problem of noise control in the municipal environment affects the competence of many departments, the bill has the character of a Codex. The strategic aim of the bill is to replace the existing obsolete system of population protection against noise in the municipal environment by setting new rules that would allow for solutions to problems that the existing legal regulation neither sufficiently permits nor resolves. It is important to overcome the current fragmentation in the field of legal enactments controlling noise in the municipal environment, and to propose a comprehensive legal regulation defining the competences and responsibilities of different departments in the field of the protection of public health against noise in the municipal environment. It is advisable to replace the existing paternalistic approach and delegate the appropriate authorities and responsibilities to different levels of state and public administrations, including individuals, on the principle of shared responsibility and subsidiarity.

Experience has shown that the current legislative approach does not satisfactorily solve the problems such as the question of so-called “old noise pollution”, “noise capacity of areas” (prevention of the cumulative effect of different noise sources), sporadic or short-term exposure to over-the-limit noise. It has not yet been possible to establish an "acoustic easement" which would allow for a better solution to the problem of subsequent and conditional entry of persons (builders) into an exposed area.

It can be stated that harmonizing the law with legal regulations controlling town and country planning and construction relative to noise has not been satisfactorily resolved yet. (Construction Act and its implementing regulations).

An unsatisfactory situation is also found in the field of supervising road and railway traffic noise. Exceeding the noise limits can often be solved only by imposing sanctions which does not solve the underlying problem. The situation is frequently handled via time-limited authorizations.

2 BASIC CLASSIFICATION OF NOISE SOURCES

Requirements for noise control pollution in the municipal environment need to be distinguished by the character and impact of the noise on humans. It concerns, on the one hand, the area of protection of public health that means reducing or possibly eliminating the health risks resulting from the exposure to noise, and, on the other hand, the area of acoustic comfort. It is relatively easy to distinguish noise sources arising in these areas.

As for the protection of public health, the control of so-called technical noise sources, which means all types of transport noise and stationary noise sources such as machinery and equipment (industrial sources), plays a dominant role. In the case of acoustic comfort, it concerns the limitation of the general annoying and intrusive effects of noise that do not have a direct impact on health, but may lead to a deterioration in the quality of the lives of persons exposed. Noise disturbance and annoyance is caused primarily by random (stochastic) noise sources, which are mainly people's voices, acoustic manifestations of animals, neighborhood noise, public performance of music, sports, cultural and other leisure activities, etc.

The bill separates the regulation of technical noise sources and subordinates it to the State Health Supervision, and random noise sources. The effect of technical noise sources can jeopardize human health; random noise sources can cause acoustic discomfort through general disturbance and nuisance. The Bill on noise entrusts the responsibility for solving random noise sources to municipalities as is common in all other developed countries in Europe.

The emphasis in the field of the protection of public health against noise is put on the protection of interiors of buildings for housing, education, health and social purposes. Noise exposure in these areas, particularly in residential areas, has a decisive influence on human health. The health risks are in this case minimized by setting the binding hygienic noise limit which is the same for all noise zones and all technical sources.

3 THE MAIN OBJECTIVES OF THE PROPOSED LEGAL REGULATION

The main objectives of the proposed legal regulation can be summarized in the following points:

- Solve the current fragmentation in the field of noise legislation in the municipal environment;
- Propose a comprehensive legislation defining competencies and responsibilities of individual authorities in the protection of public health and noise control in the municipal environment;
- Replace existing paternalistic approach;
- Delegate authorities and responsibilities to each level of state and public administration, including the participation of citizens based on the principle of shared responsibility and subsidiarity;
- Exclude situations (exposures) which are not a direct threat to health from the state health supervision, because the state cannot guarantee good noise conditions in all cases and from all possible sources of noise, particularly in the case of random sources, voluntary exposure, etc.;
- Delegate competences of noise control to municipalities on the basis of acoustic comfort;
- Emphasize the responsibility of every citizen, designer and operator of noise sources for the general reduction of environmental noise;
- Establish central coordination in the field of noise control and management;
- Establish a professional coordinating and advisory body of the Government;
- Establish a regular blanket assessment of traffic noise load on CR citizens and corresponding health risks as a basis for the policy of noise management and noise control;
- Categorize noise sources based on their impact on people and to determine the competences of state administration and self-government in noise control in each category;
- Control of technical noise sources to be left as the responsibility of public health protection authorities;
- Control of stationary noise sources such as machinery, equipment, industrial complexes, etc. based on one-figure noise limits, both outside and inside the protected buildings;
- Control of noise sources based on acoustic comfort to be fully transferred to the responsibility of municipalities;
- Define a concept of sporadic or short-term exposure to noise and transfer responsibility to the municipalities;
- Resolve noise control from construction activities by setting organizational and technical measures where noise limits from the stationary sources would serve as guidelines;

- Change the non-functioning system of environmental traffic noise control;
- Control the environmental traffic noise by abandoning the legally enforceable system of one-figure noise limits and set a system of noise zones representing intervals of socially acceptable levels of health risk;
- Set up a system of acquisition, approval, promulgation and changes of noise zones.
- Link strategic and operational approaches to noise control, including the obligation of action plans to be in compliance with the END directive;
- Integrate strategic noise mapping in the system of blank noise mapping of the Czech Republic;
- Set up responsibility of implementing and providing the action plans of noise control measures within the competence of relevant statutory persons (noise maker);
- Precisely define the term “hygienic noise limit”;
- Establish health risk assessment within the state health supervision as is recommended by the World Health Organization (WHO) in analogy to the procedures used in the EU developed countries as an obligatory instrument for noise control;
- Introduce new tools into the legal regulation that it will allow for the flexible cumulative effect, old noise pollution, shared noise measures by property owners, etc.;
- Introduce the possibility of acoustic easement where the property owner may partially or completely reject noise control measures proposed by a noise maker.

4 TRAFFIC NOISE CONTROL PROPOSAL

A necessary condition for enabling reduction and noise control in the municipal environment is an introduction of central coordination in the field of noise control and management, including regular surveys of the Czech Republic’s population who are burdened by traffic noise (which accounts for 80% of the overall noise burden of the population) and the assessment of the related health risks. The proposed extended version of the strategic noise mapping, based on the implemented directive 2002/49/EC of the European Parliament and of the Council dealing with assessment and environmental noise control (Environmental Noise Directive - END), has been running since 2005 (Official Journal of the European Communities, 2002). The END directive implemented into Act No. 258/2000 Coll., on the protection of public health, as subsequently amended, established the strategic noise mapping and produced action plans for noise control measures. However, the national amendment does not solve the duty of putting these action plans and policies into effect. The Noise Act should align strategic and operational approaches to noise control, including a binding force of action plans under the END directive, incorporating strategic noise mapping into the system of blank noise mapping of the Czech Republic. Moreover, authorized persons (noise makers) should be obliged to implement action plans into the system of noise control measures.

To control the impact of environmental traffic noise, the legally enforceable system of one-figure noise limits is abandoned. The limits would be used in accordance with the practice in other European countries as guidelines that should be respected in noise control. However, there is concern that the concept of non-binding noise limits will not be fully functional in the Czech Republic, which in other countries is respected and successfully used without any problem. So it is necessary to formulate an obligation to control traffic noise in the environment in another way. The Noise Act therefore introduces an institute of noise zones in conformity with the approach of many European countries. The zones represent the extent of values tiered according to a level of health risk. In the Noise Act, the four zones (A, B, C, D) are proposed which are defined for day and night time and for each traffic noise source. The zone A represents the lowest load, zone D the highest. The noise zone boundary is chosen in the interval of the socially acceptable level of health risks of exposure to noise. The requirements for an adequate level of protection against noise are defined in each zone. The appropriate level of protection shall be provided at expenses of a person (builder) who enters in a given area with his/her property (building). The noise zones are defined on the basis of calculated noise maps which are created by the competent government authority and become an integral part of the planning analytical materials. The design of noise zone categories and their meaning is presented in Table 1.

Table 1: Design of noise zones and their meaning.

Designation	Description of noise zones
A	**Noise need not be considered** as a determining factor in granting a permit for the intended project for the construction of protected buildings.
B	**Noise shall be considered** in determining the intended project for the construction of protected buildings or sources of traffic noise and, where appropriate, shall be subjected to prescribed conditions (noise protection measures may be applied).
C	**Granting a permit for the intended project is not guaranteed**. Where the permit is considered to be granted, for example, because no other suitable sites for the construction of protected buildings or sources of traffic noise are available. The prescribed conditions have to be met to ensure an adequate level of protection against noise (noise protection measures have to be applied).
D	Permission for the intended project for the construction of protected buildings is commonly rejected.

The Bill proposes to update the traffic noise zones every 5 years, which means at intervals in accordance with the END directive (Official Journal of the European Communities, 2002).

The institute of protective noise zone of airports and rules for the determination of its boundaries and operating mode are amended.

The submitted legislative intent of the Noise Act envisages the implementation of health risk assessment, as recommended by the World Health Organization (WHO) as the binding instrument of noise control (WHO, 2012; European Environment Agency, 2010). Methodologies are known in the Czech Republic and authorized persons for the health risk assessment of noise exposure use them as standard operating procedures (Potužníková et al., 2012).

4.1 Responsibilities of Owners and Operators of Roads and Railways

Owners of roads and railways are obliged to ensure that noise shall not exceed the hygienic health limits of noise inside the protected buildings. They are also obliged to comply with the noise zones of roads and railways in built-up and non-built-up areas of municipalities. Operators of noise sources are required to get an expert opinion on noise levels in protected areas and on possible noise control measures in Zone D. Such opinions may be included in the action plan for noise control measures.

The operators are required to design and implement noise control measures to minimize the extent of noise in zones D based on the action plans, i.e. to reduce the exposure of protected outdoor areas. These measures should be based on the principle of a reasonably achievable rate so as to reduce the maximum number of protected buildings located in this noise zone.

For existing residential buildings, family houses, buildings for education and training, buildings for health and social care and functionally similar buildings located in the noise zone D, the operator must ensure the implementation of noise control measures to the extent that hygienic noise limits shall not exceeded inside the protected buildings. Urban, organizational measures and noise control measures protecting outdoor areas are preferred to noise control measures inside each protected building.

The operator of the source of traffic noise is not responsible for the above mentioned obligations in the protected buildings the construction of which has been initiated after the declaration of noise zones. In these cases the responsibility belongs to the builder of protected buildings.

If it is proved that sound insulation no longer meets the original standard value due to the poor technical condition of the building envelope, the responsibility belongs to the property owner.

In case the traffic intensity spontaneously increases after the expiry date of this *Bill*, which leads to the need to change (update) the declared noise zones, or the original standard values of airborne sound insulation of protected building envelopes shall no longer be satisfactory, the operator of the traffic noise source together with the owner of the protected property are responsible for the implementation of subsequent noise control measures.

4.2 Responsibilities of Airport Operators

The airport operator is obliged to ensure that noise from air traffic related to the particular flight day shall not exceed hygienic noise limits inside the protected buildings. Furthermore, he is obliged not to undermine the boundaries of noise zones for air traffic noise in built–up areas of municipalities. The operator of the military airport and the airport with 50,000 or more take-offs and landings shall provide the action plan for noise control measures in the noise zones C and D at his own expense. Particulars of the action plan for noise control measures shall be applied similarly to the above mentioned measures of the operators of traffic noise source. For protected buildings located in the noise zones C and D, the operator is obliged, on the basis of the action plan, to ensure the implementation of noise control measures to such an extent that the noise limits are not exceeded inside these buildings. The operator is required to design and implement measures to minimize the spatial extent of zone D on the principle of a reasonably achievable rate so as to reduce the maximum number of protected buildings located in this noise zone.

This obligation does not have an operator for residential buildings the construction of which is commenced after the date of declaration of the noise zones. In these cases, the liable party is the builder.

If it is proved that the insulation no longer meets the original standard value due to the poor technical condition of the building envelope, the liable party is the property owner.

In the D noise zone for air traffic noise new construction of buildings for health, social, educational and training purposes is not permitted.

5 CONCLUSION

The legislative intent of the Act on the protection of public health from noise and for noise control in the municipal environment represents a completely new approach to health protection against noise compared to the current legal regulation in the Czech Republic. It is based on the WHO expert documents, approaches in providing health protection in the European countries and also on many years of experience of the Ministry of Health, particularly the Hygienic service, in this area. In view of the fact that this is a new professional and comprehensive legislative approach, consultations with experts from other ministries, processing of comments and communication with the public are an integral part of work on the Bill. Based on the above mentioned, the draft will be further refined and the professional and general public will be familiarized with the new approaches.

This article is based on the legal intent of the Noise Act and the explanatory report.

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REFERENCES

European Environment Agency, 2010. *Good practice guide on noise exposure and potential health effects, technical report,* No. 11/2010. Bonn: WHO, pp. 14-15. ISSN 1725-2237.

Havránek, J. et al., 1990. *Hluk a zdraví.* Praha: Avicenum. ISBN 80-201-0020-2. (in Czech)

Official Journal of the European Communities, 2002. *Directive 2002/49/EC of the European parliament and of the council of 25 June 2002 relating to the assessment and management of environmental noise.* Official Journal of the European Communities, l. 189/12, 18.7.2002.

Potužníková, D., Hellmuth, T., Bednarčík, P., Fiala, Z., 2012. Zkušenosti z hodnocení zdravotních rizik expozice hluku ze silniční dopravy [Experience in the health risk assessment of exposure to noise from road traffic]. *Hygiena,* 57 (3), pp. 100-104. (in Czech)

WHO, 2009. *Night Noise Guidelines for Europe* [online]. Denmark: World Health Organization, Regional Office for Europe [cited 2013-07-23]. ISBN 978 92 890 4173 7. Retrieved from: http://www.euro.who.int/pubrequest

WHO, 2011. *Burden of Disease from Environmental Noise* [online]. [cited 2013-07-23]. ISBN 978 92 890 02295. Retrieved from: http://www.euro.who.int/pubrequest

WHO, 2012. *Methodological Guidance for Estimating Burden of Disease from Environmental Noise.* Regional Office for Europe [online]. [cited 2013-07-23]. Retrieved from: http://www.euro.who.int/pubrequest

The Capacity of a Ramp of the Pražský okruh x K Barrandovu Grade Separated Junction

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ABSTRACT: The aim of the article is to describe the method of experimental assessment of a grade-separated junction arm for ultimate traffic volume (capacity). The results of the assessment are compared with values stated in the current Czech Technical Standard ČSN 73 6102, in the German guideline HBS, and in the Highway Capacity Manual (USA).

KEY WORDS: Traffic engineering, flyover, road capacity, traffic volume, traffic survey velocity.

1 INTRODUCTION

Grade-separated junctions are the ultimate capacity solution for an intersection layout. In view of the increasing rate of motorization, grade-separated junctions will form an ever-growing treatment of road junctions in the future, in spite of being the most expensive solution. Great attention should be paid to their capacity and efficiency. The capacity issue was the topic of the research project “Updating of models for grade-separated junctions capacity calculation” funded by the Czech Ministry of Transport within the National Research Program. The project has been carried out by the EDIP Ltd. and the DHV CR companies with the planned completion in 2010. The output of the project is TP 236 Assessment of capacity grade separated junctions (Rozsypal, 2011). A research project supported by the Technology Agency of the Czech Republic is currently being conducted whose aim is to unify and update the methodology for calculating the capacity of roads and a comprehensive methodology.

Four main elements influencing a grade-separated junction capacity were subsequently analyzed during the project, namely the beginning and end of the taper, the slip road ramp and the weaving distance. The aim of the article is to describe the traffic survey which has been carried out on a grade-separated junction ramp and to analyze data obtained and determine the ultimate limiting ramp capacity value. This value has been subsequently compared with theoretical values of ultimate capacities mentioned in relevant technical standards and guidelines.

2 TRAFFIC SURVEY

Figure 1: Queue of slowly moving vehicles on city circle in Prague (road R1) in the direction from Pilsen (Plzeň) at the place of the beginning of the ramp (the Pražský okruh x K Barrandovu x Pod Lochkovem grade-separated junction).

The Pražský okruh x K Barrandovu x Pod Lochkovem grade-separated junction in Prague was chosen for the traffic survey implementation due to the criteria which clearly showed that this junction is reaching its ultimate capacity during peak hours (at the approach from Pilsen an almost 2 km long queue of slowly moving vehicles can be observed very often). Based on the site survey it was found that the limiting element of the junction is the capacity of the one-lane ramp in the direction from Pilsen to Barrandov. The layout of the trumpet junction mentioned is shown in Figure 2. The width of the relevant traffic lane is not constant – it varies from 4.75m to 5.00m in relation to the widening in the curve. The ramp is going uphill in the above-mentioned direction.

Figure 2: Layout of the grade-separated junction Pražský okruh x K Barrandovu x Pod Lochkovem.

An automatic detector was used to collect the traffic data in a one week period (25^{th} March – 1^{st} April 2008) in the location of the ramp exit (see Figure 2 – gray rhomb). The detector was able to register time periods when vehicles (differentiated by their lengths) passed the detector, as well as the speed of each vehicle. In order to verify the results of the survey and for observation of the traffic behavior, an 80 minute video recording has been recorded during the afternoon peak.

3 TRAFFIC VOLUMES

The maximum volume of 22,114 vehicles per day as recorded on Friday, March 28th, 2008 indicates the high level of the one-lane above-mentioned ramp usage.

Daily variations of traffic volumes during the one week period are shown in Figure 3. A steep increase in traffic volume was observed in the morning peak (6 AM – 7 AM) when the volume reached values round 1,300 vehicles per day. Such high volumes persisted until 6 PM thus indicating capacity exhaustion. The traffic volume declined during the evening and later in the night when heavy goods vehicles begin to dominate in the traffic flow.

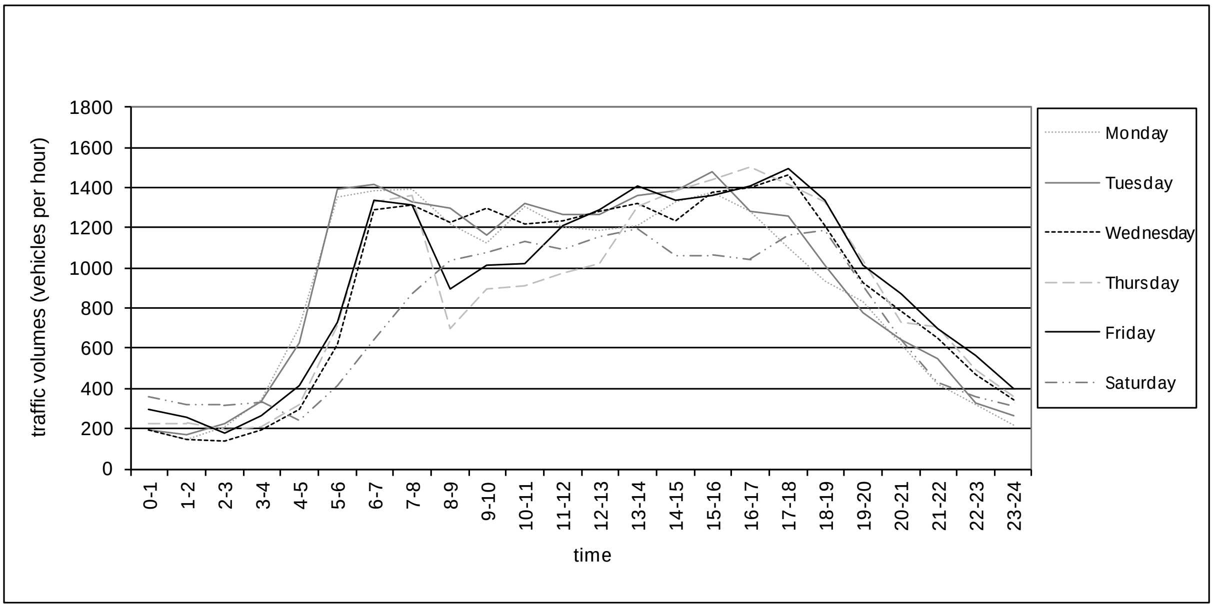

Figure 3: Daily variation of traffic volume on the afore-mentioned one-lane ramp.

Note: Omitted Sunday values were caused by a technical defect of the detector. A traffic abnormality in volumes can be seen during morning hours on Thursday and Friday, but this anomaly has not been further investigated.

Peak hour traffic volume was found on Thursday between 4 PM and 5 PM when a value of 1,503 vehicles per hour was reached. It corresponds to 7.2 % of the whole day’s traffic volume. During the peak hour the traffic flow consisted of 79.5% of passenger cars, 6.3% of heavy goods vehicles, 13.3% of long heavy goods vehicles and 0.4% of buses.

4 SPEED

The average profile speed of the traffic flow was 43 km/h at the ramp exit. The highest speed of 94 km/h was measured at 10:20 PM on Saturday and due to the small diameter of the curve the passengers of that car must have experienced a very emotional event.

Frequency speed curves in an average working day (Tuesday) are shown in Figure 4 (for passenger cars) and in Figure 5 (for long heavy goods vehicles). The theoretical Gauss distribution is schematically illustrated in both graphs. The Gauss distribution was defined only from measurements carried out in the period outside of the ramp capacity depletion. Two obvious humps indicate that the speed is slowing down to 30km/h when the capacity was depleted, while outside this period the average speed is just below 50km/h.

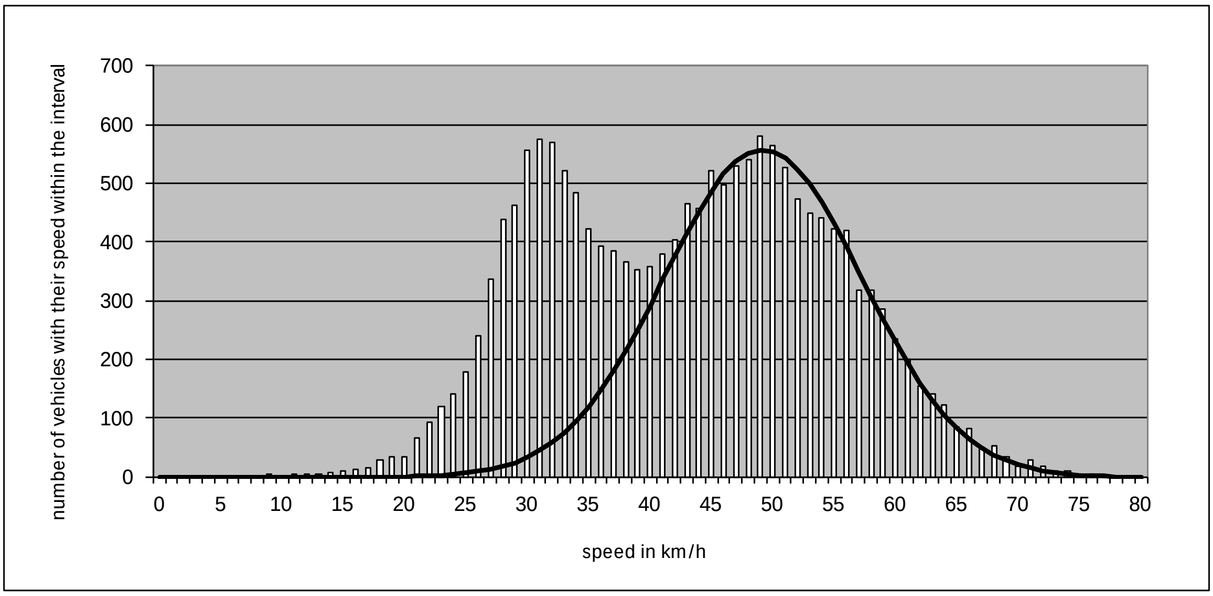

Figure 4: Histogram of speeds at the ramp exit on an average working day (Tuesday) – passenger cars.

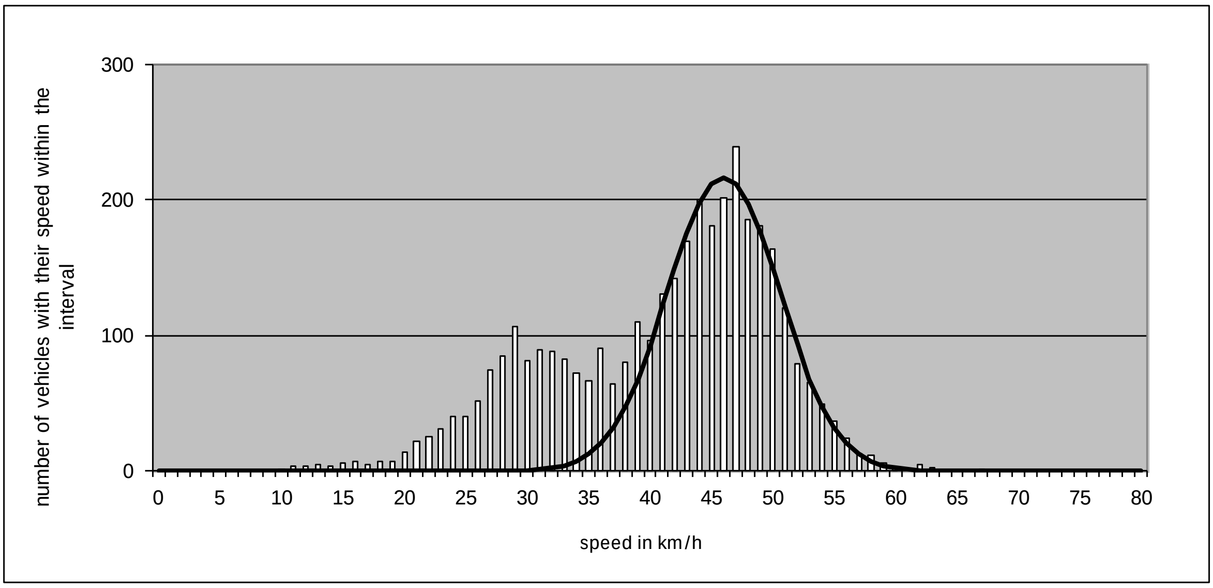

Figure 5: Histogram of speeds on the ramp exit on an average working day (Tuesday) – long heavy goods vehicles.

The value of average speed varies during the day. Comparison of these variations with daily variations of traffic volumes in an average working day (Tuesday) is shown in Figure 6.

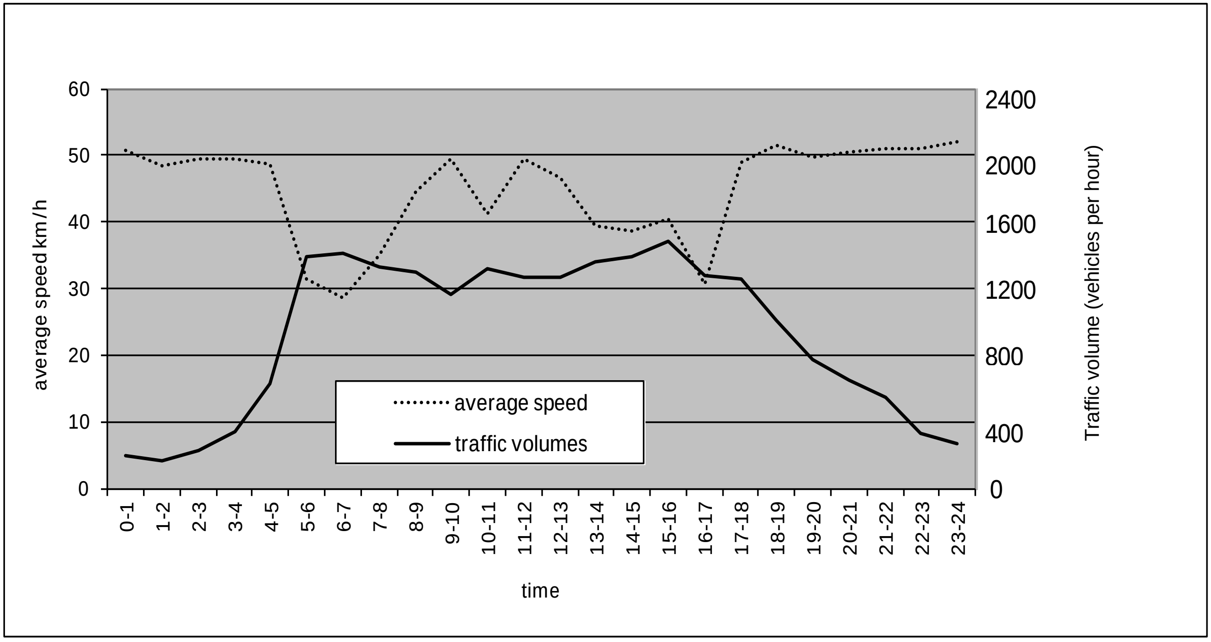

Figure 6: Comparison of average speed of the traffic flow at the ramp exit and the traffic volumes on an average working day (Tuesday).

5 ULTIMATE TRAFFIC VOLUME (CAPACITY)

Figure 7 demonstrates the level of ultimate traffic volumes (= capacity) of the ramp. Mutual dependence of the speed and the traffic volume is shown in the graph for each one-hour interval during the survey. The different colors show different shares of slow vehicles in an one-hour interval.

A particular dependence of the traffic flow speed on traffic volume, respectively on the level of load of the ramp, is evident. This dependence can be observed from a certain level of the traffic volume. Parameters of the traffic flow then contribute to a lower quality level because vehicles are influencing each other. Therefore, when assessing the capacity of a grade-separated junction ramp, it is essential to seek the value of traffic volume that the ramp can take without a radical decrease in the quality of traffic.

The ultimate level of the ramp traffic volume has been stated by measuring the value of 1,503 vehicles per hour with an average speed of 38 km/h. Based on the results shown in the graph in Figure 7, it can be seen that an increase in traffic volume above a value of approximately 1,200 vehicles per hour has a reciprocal effect on vehicles in the traffic flow and thus contributes to a slowing of the traffic.

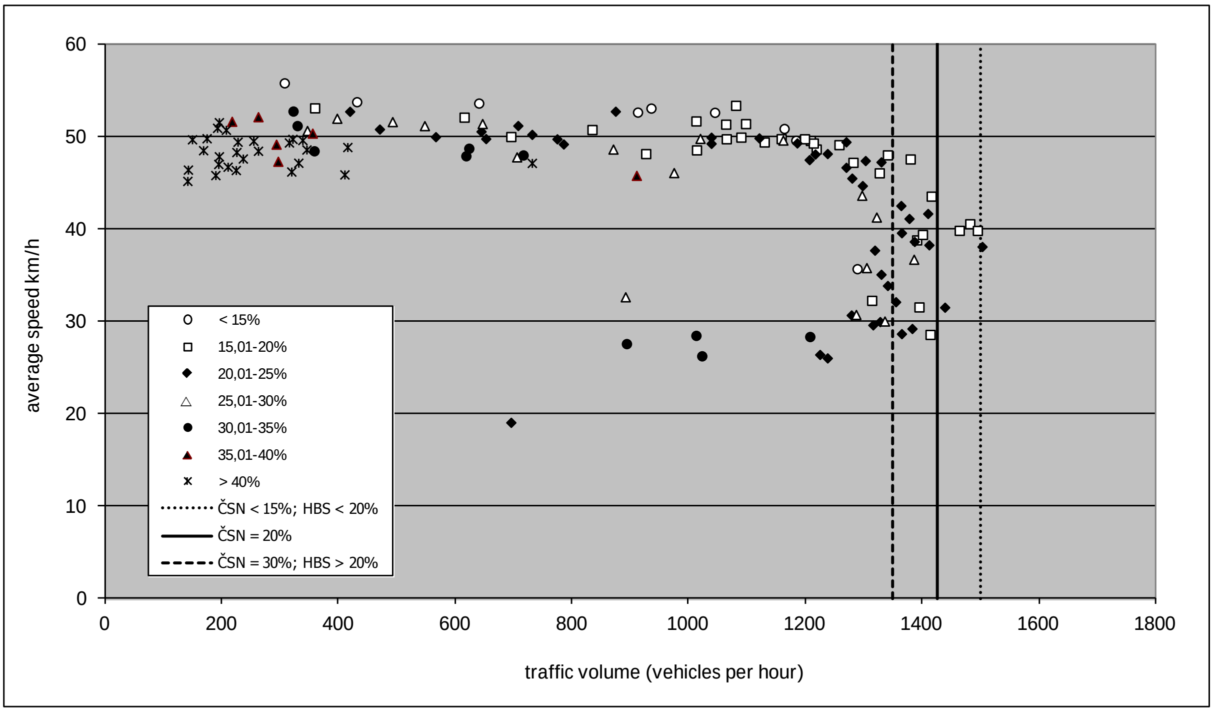

Figure 7: Dependence of speed and traffic volume on the ramp exit (all one-hour measurements within a one week period).

6 COMPARISON OF MAXIMUM MEASURED TRAFFIC VOLUME WITH VALUES CALCULATED ACCORDING TO RELEVANT FOREIGN METHODS

The above mentioned results were compared with the values of theoretical capacity for ramps of similar layout, which are stated in selected methodologies and guidelines - Czech technical standard (ČSN 73 6102, 2007), German guidelines (HBS, 2001) and the US guidelines (HCM, 2000). The results are shown in Table 1.

Table 1: Comparison of measured values of ultimate capacity with theoretical capacity values according to relevant methodologies.

	Traffic survey	*ČSN 73 6102*	*HBS 2001*	*HCM 2000*	*TP 236*
Capacity of the ramp	1 503 v/h	1 421 v/h	1 350 v/h	-	
Capacity of the ramp (according to HCM)	1 657 pce/h	-	-	1 900 pce/h	1 800 pce/h

According to the Czech technical standard (ČSN 73 6102, 2007), the afore-mentioned ramp belongs to category O1, where the maximum capacity is set as 1,500 vehicles per hour for the 15% share of slow vehicles. The share of slow vehicles has been found to be 20.5% on the above mentioned ramp. Such a value reduces the capacity by 5.25 %, according to the standard, so resulting in a value of 1,421 vehicles per hour. Detailed information can be found in TP 236 (Rozsypal, 2011), Chapter 4.2.

German guidelines (HBS, 2001) indicate the same value as the Czech standards (ČSN 73 6102, 2007), i.e. 1,500 vehicles per hour. This value remains for proportions of heavy good vehicles up to 20 %. For higher proportions the value of the maximum capacity is reduced to 1,350 vehicles per hour, which corresponds with the proportion of heavy vehicles of 20.5 %. It is evident that a reduction of the heavy vehicles proportion of just 0.5 % calculated in accordance with the German methodology represents an enormous impact on the capacity assessment. Such a big reduction from 1,500 to 1,350 vehicles per hour seems to be rather disproportional and may, in the course of assessment, require a lot of the traffic engineer’s experience.

Examination according to the HCM guidelines (HCM, 2000) enables the taking into account of the speed of the traffic flow. The average speed of free traffic flow was found to be lower than 50km/h in our study. This value corresponds with the capacity of 1,900 pce/h (“Passenger Car Equivalent” vehicles). The earlier mentioned ramp goes up-hill (3 %) by a length of 500 meters, so the coefficient 1.5 can be used for the conversion of heavy, long vehicles and buses into unitary vehicles. The value of the ultimate capacity measured, after correction, is 1,657 pce/h. Theoretical assumption used in the US guidelines is 15 % higher than the measured value.

It can be concluded that the value of ultimate capacity, found by the traffic survey, is higher than the theoretical value listed in the Czech technical standard (ČSN 73 6102, 2007) and the German guidelines (HBS, 2001). On the contrary, the value of theoretical capacity stated in the US guidelines is expressly higher than afore-measured value.

Measurement was carried out at a single station. It would be appropriate to carry out surveys on more ramps with different parameters on multiple measurements, however the project did not have enough money.

7 COMPARISON OF ALL MEASURED TRAFFIC VOLUMES WITH THEORETICAL VALUES STATED IN RELEVANT METHODOLOGIES AND GUIDELINES

The comparison is depicted by the vertical lines shown in Figure 7. These lines indicate the ultimate values according to the Czech technical standard ČSN 73 6102 (2007) and the German HBS (HBS, 2001).

According to the German HBS (HBS, 2001), the ultimate value of 1,500 vehicles per hour remains for up to 20 % of the share of slow vehicles. This corresponds with the red and especially the blue dots in the graph in Figure 7. With a higher share of slow vehicles the capacity is 1,350 vehicles per hour; this corresponds especially with the yellow and green dots in the graph in Figure 7. While the basic value of capacity (1,500 vehicles per hour) seems to be set relatively realistically in the HBS guidelines (HBS, 2001), the values measured in our project indicate that even intervals with more than a 25 % share of slow vehicles surpassed the value of 1,350 vehicles per hour (green line).

According to the Czech technical standard (ČSN 73 6102, 2007) the highest value of capacity (1,500 vehicles per hour) corresponds with 15 % of slow vehicles. A 20 % share of slow vehicles (compare with the blue dots in the graph) corresponds with a capacity of 1,425 vehicles per hour, while the share of slow vehicles (green dots) of 30% with a value of 1,350 vehicles per hour.

It is evident that the ultimate values stated in Czech technical standards (ČSN 73 6102, 2007) for different shares of slow vehicles correspond to a larger extent with values measured during our project than with values of capacity reduced according to the German HBS (HBS, 2001).

8 CONCLUSION

The capacity of 1,503 vehicles per hour was found on a grade-separated junction one-lane ramp by the traffic survey, the share of slow vehicles was 20.5 %.

A comparison with relevant methodologies has shown a relatively good compliance with the values of the theoretical capacity stated in the Czech technical standard ČSN 73 6102 (2007) and the German guidelines HBS (HBS, 2001). Minimal compliance has been found with values stated in the US guidelines HCM (HCM, 2000). The value 1 800 pc/h was used with the resulting methodology - TP 236 (Rozsypal, 2011).

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REFERENCES

Bartoš, L., Rozsypal, V., Kašpar, J., 2008. Kapacita větvě mimoúrovňové křižovatky Pražský okruh x K Barrandovu. *Dopravní inženýrství*, (1), pp. 2-4. ISSN 1801-8890. (in Czech)

ČSN 73 6102, 2007. *Projektování křižovatek na pozemních komunikacích,* změna Z1, 2009. (in Czech)

FGSV, 2008. *Richtlinien für die Anlage von Autobahnen.* Köln: FGSV. ISBN 978-3-939715-51-1.

HBS, 2001. *Handbuch für die Bemessung von Strassenverkehrsanlagen (HBS).* Köln: FGSV. Fassung 2009. ISBN 3-937356-44-4.

HCM, 2000. *Highway Capacity Manual (HCM).* Washington, D.C.: National Research Council. ISBN 0-309-06681-6.

Martolos, J., 2012. *TP 189 Stanovení intenzit dopravy na pozemních komunikacích,* 2. vydání. Plzeň: EDIP s.r.o. ISBN 978-80-87394-06-9. (in Czech)

Rozsypal, V., 2007. *Projekt č. CG723-032-910 „Aktualizace výpočtových modelů pro stanovení kapacity mimoúrovňových křižovatek“.* [Redakčně upravená závěrečná zpráva 2007]. Plzeň: EDIP s.r.o. (in Czech)

Rozsypal, V., 2011. *TP 236 Posuzování kapacity mimoúrovňových křižovatek* [Assessment of capacity grade separated junctions]. Plzeň: EDIP s.r.o. ISBN 978-80-87394-04-5. (in Czech)

Distances between Vehicles in Traffic Flow and the Probability of Collision with Animals

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ABSTRACT: This article describes a model used to establish the probability of a collision between a vehicle and animals on roads. Analysis of data obtained from measurements provided by automatic radar enabled us to find general relationships which determine the distribution of time gaps between vehicles in traffic flow. These results were applied (with other applications) to assessments of the impact of traffic on wildlife. These simplified models have demonstrated the road barrier effect, with a certain traffic intensity, on the wildlife.

KEY WORDS: Traffic flow gaps, collision probability, animal, vehicle, traffic, intensity.

1 INTRODUCTION

The so-called barrier effect of roads, which is associated with the mortality level of animals, depends on a wide range of factors, which may themselves be divided into factors/elements relevant to animals and factors relevant to the road itself. Factors relevant to animals include the following:

- Ethology of the relevant species resulting in basic behavioural patterns;
- Migratory pressures resulting from food or population issues and relationships;
- Character of ecosystems present in the evaluated location.

Factors relevant to roads include the following:

- Type of road and applicable technical solutions;
- Directional and altitude (vertical) structure in the relevant location;
- Traffic intensity.

Therefore, the probability of a collision between a vehicle and an animal also depends (besides other factors) on the traffic intensity occurring on the particular road and on the distances (gaps) between individual vehicles.

2 DISTANCES BETWEEN VEHICLES IN TRAFFIC FLOW

Traffic flow is a sequence of vehicles moving in one (or more) lanes in one direction.

The basic characteristics of traffic flow are:

- Volume of traffic (expressed in number of vehicles per certain time interval – hour, day);
- Speed (average, immediate ...);
- Density (number of vehicles present on a particular section of the road and at a particular time);
- Time gap;
- Distance.

A distance or gap between vehicles may be defined as follows:

- Time gap between vehicles – time between two fronts of passing vehicles travelling one after another in one traffic lane;
- Distance between vehicles – distance between two fronts of passing vehicles travelling one after another in one traffic lane;
- Gap between vehicles – time between the front of a vehicle and the rear of a vehicle travelling one after another or between two oncoming vehicles.

The defined distances and the gaps are used for the following:

- Inclusion of other vehicles into the traffic flow – this is used for example at intersections – the theory defining distances between vehicles at intersections is used to determine the actual capacity of a particular intersection;
- Pedestrian crossings – pedestrians use sufficiently long distances to cross roads;
- Animal road crossings – similarly as for a person, a road represents a barrier for animals (we will focus on this issue in the second section of this article).

3 POISSON'S DISTRIBUTION OF PROBABILITIES

The traffic flow theory describes the division of time gaps between vehicles in various ways. Analytical or stochastic (random) models may be used based on direct traffic flow measurements. As far as stochastic models are concerned, probabilistic models are used more frequently, such as Poisson's model, negative-exponential model, etc.

The most suitable model used for the description of the existence of individual gaps/distances between vehicles in accordance with the results of previous and similar measurements (Pistulka, 1970) is Poisson's division method.

Poisson model requirements of use (the so-called Adams-Kinzer criteria):

- Vehicles in traffic flow maintain various distances between them. These distances depend on the density and on the speed of the traffic flow;
- All vehicles may move freely and do not interact with each other. Overtaking is always allowed (corresponds with A traffic quality class);
- Passage of a vehicle through the monitored section of the road is random;
- The probability of the existence of a certain distance between vehicles at the specified time interval is (approximately) equal to the length of the interval.

Although the actual division of distances do not precisely correspond to the theoretical Poisson's distribution, for our purposes (application used to calculate the probability of a collision with an animal) it is sufficient (animals do not behave exactly according to formulas either).

Note: However, we will show that this type of model is precise. Larger deviation was recorded at locations where the traffic flow was affected, i.e. by an intersection nearby (mostly with traffic lights), or by a long section of the road without any possibility to overtake.

Let us monitor a random phenomenon: "In a distance *t* we will find *x* vehicles".

Poisson's division with random value X represents the following formula:

$$P(X) = e^{-\lambda} \cdot \frac{\lambda^X}{X!} \tag{1}$$

$\lambda > 0$ is the only parameter of these division. If we know this parameter, then the Poisson's division is firmly established.

The mean value of a random variable is for $\mu = \lambda$ and distribution (dissipation) $\sigma^2 = \lambda$. Then we have a traffic flow with intensity I (vehicles/hour). Therefore, during the time interval t (s) an average of $\frac{I}{3600}t$ vehicles will pass through the specified section of the road.

Note: the value 3600 in the denominator represents the number of seconds in one hour. Due to the fact that the parameter λ represents the average number of vehicles passing through a particular section of the road and during the time interval t, the following statement is true:

$$\lambda = \frac{I}{3600}t \tag{2}$$

If we do not expect the occurrence of a vehicle within the interval (x = 0), but we are looking for the occurrence of a certain distance (or rather longer than t seconds), the probability (1) has the following form:

$$P(X = 0) = e^{-\lambda} \tag{3}$$

This changes the original discrete probabilistic division to a continuous division (negative-exponential) – the time gap is also a continuous phenomenon.

Example: A road with traffic intensity I=360 vehicles / hour

$$\lambda = \frac{360}{3600}t = \frac{t}{10}$$

Then the distribution probability function of the distance occurrence is $P(t) = e^{-\frac{t}{10}}$.

And the probability of the occurrence of a gap longer than 10 seconds is

$$P(10) = e^{-\frac{10}{10}} = 0{,}37 = 37\%$$

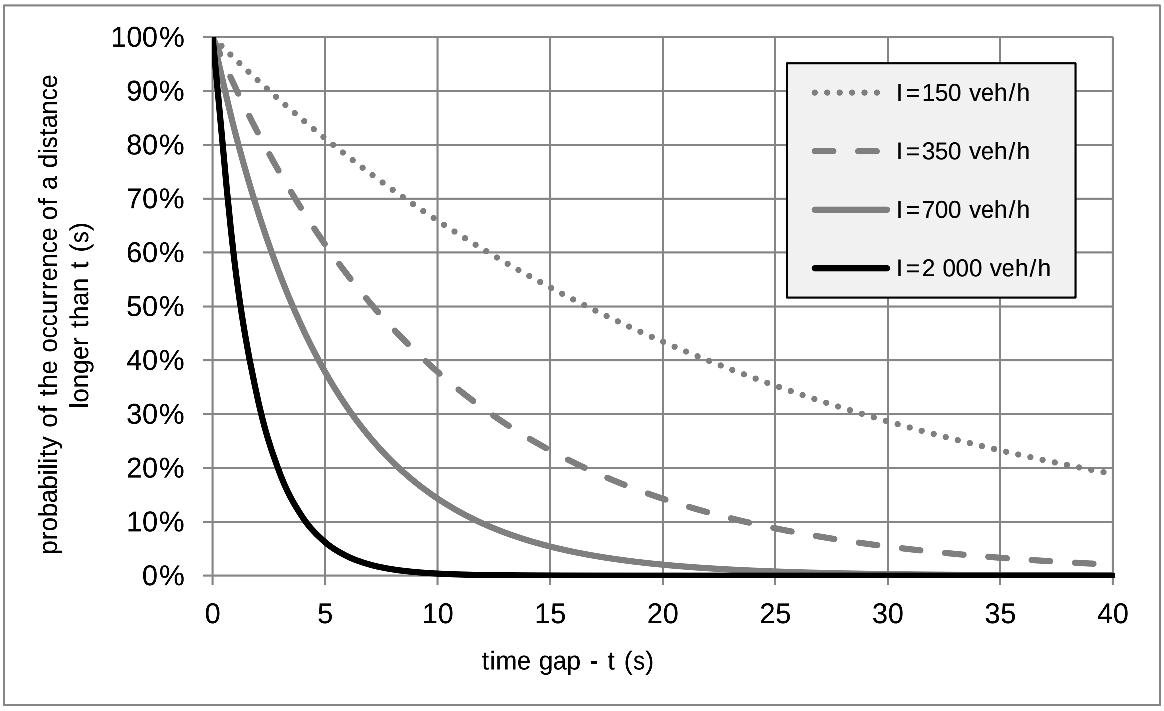

Figure 1: The occurrence of time gaps in various traffic intensities.

Figure 1 shows distribution functions of distance occurrences (i.e. the probability of the occurrence of a longer gap than the given time) for different traffic intensities.

4 TRAFFIC SURVEYS

For the purpose of a detailed analysis of gaps / distances, the necessary measurements were performed. An automatic detector (radar) was used, which allowed us to record the exact times of passing vehicles and determine the distances between vehicles. Each week the radar was used at 19 stations on 2nd and 3rd road classes and on local roads. At each station a radar measured continuously for 1 week. Radar records the passage of every vehicle and measures: passage of time, the length of the vehicle, vehicle speed, direction and spacing for the previous vehicle.

The list of stations, time and period of measurements and estimates of average daily intensities (RPDI) (in vehicles per day) are shown in Table 1.

Table 1: List of stations used during the analysis (MK – local road).

No	*Station*	*Rod*	*Estimation AADT*
1.	Rokycany	II/183	2 527
2.	Holoubkov	III/2341	439
3.	Dobřany	II/180	4 157
4.	Aš	II/216	5 730
5.	Zbůch	I/26	8 671
6.	Mirošov	II/117	793
7.	Třemošná	I/27	7 645
8.	Rokycany-B.Němcové	MK	4 387

9.	Plzeň-Radčická	III/18050	3 769
10.	Plzeň-Borská	MK	12 763
11.	Plzeň-Valcha	III/18043	4 278
12.	Králův Dvůr	III/2363	1 807
13.	Františkovy Lázně	III/21330	5 519
14.	Dobrotice	III/1882	591
15.	Oldřichov v Hájích	III/2904	3 246
16.	Stráž nad Nisou	MK	5 104
17.	Jenišovice	III/28719	907
18.	Písková Lhota	II/611	4 194
19.	Malá Skalice	II/304	1 234

Data from automatic detectors installed on highways and 1st class roads administered by the Roads and Motorways Directorate were used.

Data collection analysis focused on:

- Determination of general relations – division of gaps based on sizes and according to traffic intensity,
- Establishment of typical distribution of distances applicable to the probability of collision of a vehicle with an animal.

5 DISTRIBUTION OF DISTANCES

Detectors recorded the value of individual distances between vehicles from 1 to 25 seconds and then from 1 to 20 minutes. For this reason the distribution of distances between vehicles was divided into two steps: (i) analysis with a step ranging from 1 to 25 seconds and (ii) analysis with a step ranging from 1 to 25 minutes. Relative values were used in order to be able to compare individual stations. We can observe this phenomenon on the basis of one particular example.

Example: A station located on Borská road in Plzeň was selected. Traffic intensity I=12,763 veh/day, average theoretical intensity per one hour I=12,763/24=530 veh/hour.

To monitor the situation an interval of t = 25 s was selected (intervals up to 25 seconds).

$$\lambda = \frac{530}{3600} 25 = 3{,}69$$

Figure 2 shows the distribution of measured values of time gaps using theoretical Poisson's division.

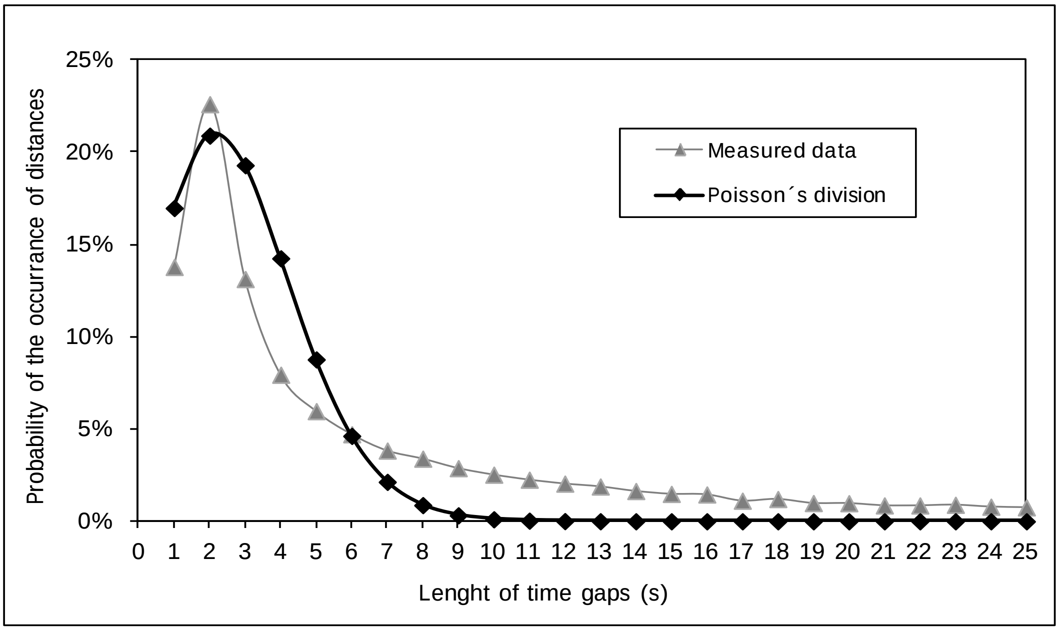

Figure 2: Division of probability of time distances, sample.

The analysis confirmed that the Poisson's division method approximates well the distribution of time gaps between vehicles in traffic flow.

More accurate results were obtained through an analysis of a set of hourly measurements. Here, the influence of the simplification of the conversion of the daily traffic intensity to the hourly intensity was eliminated. The following evaluations took into account hourly traffic intensities – that is, daily variations in traffic intensities were considered.

6 ROAD BARRIER EFFECT

The analysis of the time intervals allowed us to evaluate in detail the impact of the traffic intensity on the mortality of animals and the barrier effect of roads at specific locations. When we combined the analysis of time gaps with the estimated speed of animals crossing the relevant road under certain behavioural regimes, we obtained an illustrative idea about the level of the throughput (permeability) of a particular road as well as about the development of this parameter during various times of the day. Analogous analysis may be used in the preparation of detailed measures focusing on reduction of animal mortality and barrier effects such as eco-ducts or road fences.

For the first general approximation we have used a typical distribution of distances for each road category. Average AADT values were determined for each road category (from results provided by the 2005 national traffic census) – see Table 2.

Table 2: Typical AADT values for different road categories.

Road categories	Average AADT (vehicles / day)
Motorway	23,900
1st class road	9,700
2nd class road	3,400
3rd class road	2,360
Local road	6,800

These typical or characteristic values determined in this way represent only general simplification when compared with the actual dissipation of AADT values on individual road categories, but they are sufficient for our illustrative purposes.

Using general and derived relations, the existence of time gaps during the day for individual road categories was established (typical AADT value). Daily variations in traffic intensity specified in TP 189 (2012) were used in order to establish the traffic intensity during individual hours of the day.

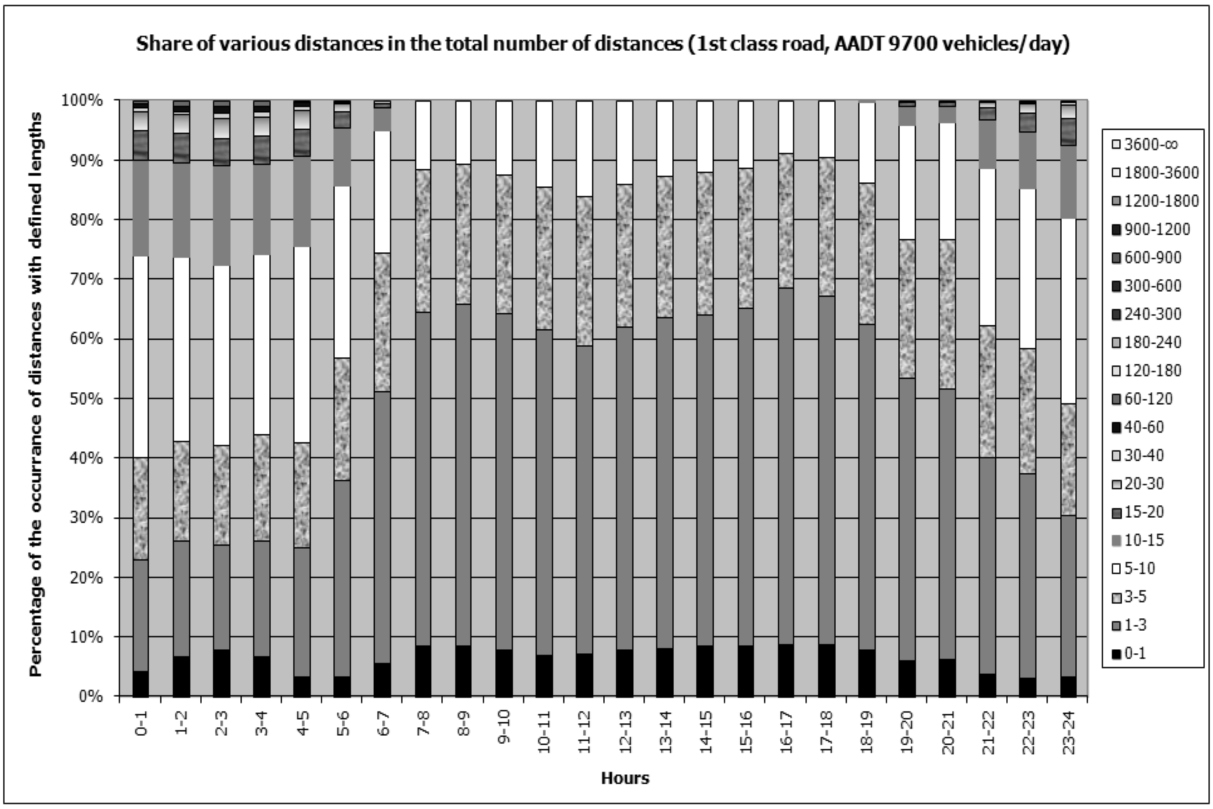

Figure 3: Distribution of time gaps over a regular workday on a typical motorway.

Figure 3 shows the distribution of time gaps between vehicles over a day on a typical motorway.

For the calculation of the probability of vehicle collisions with animals a crucial component is the time which the animal remains on the road. This time is of course dependent on the type of animal, the road parameters (width, center guardrail, etc.), but may vary on the road type even concerning a single species, therefore the value is of statistical nature. The credibility of calculating the probability of occurance depends primarily on how good a model of animal road crossing behavior can be built. In the simplest case, we can consider a uniform rectilinear motion (different speeds for different kinds of animals) in a direction perpendicular to the road.

A road is a barrier for an animal (mechanical - moving vehicles and noise). At low volumes of traffic, for example at night, vehicles distances of tens of seconds to minutes often occur. Such distances allow species to cross easily and the risk of a vehicle striking a deer is small. With an increasing volume of traffic collision risk also increases, but growth stops and the volume of traffic is certain to fall again. During rush hours distances over 5 s would rarely occur and the road for the animal becomes an insurmountable mechanical and noise barrier with the possibility of migration decreasing to a minimum.

A typical motorway with AADT 23,900 vehicles / 24 hours between 6:00 am - 10:00 pm does not show time gaps longer than 10 seconds, whereas a 1st class road with a lower AADT value shows time gaps between vehicles up to one minute long. During night time between 10:00 pm - 6:00 am, a motorway shows time gaps between vehicles ranging from 20 to 30 seconds and 1st class roads show time gaps longer than 2 minutes.

Using these diagrams to demonstrate the throughput of the road for animals gives us figures 4 and 5, which demonstrate the throughput of a motorway and 1st class road – when an animal crosses the road quickly and directly.

These diagrams demonstrate the share of five model states in terms of road throughput starting with a completely closed road (no throughput) through three, relatively permeable statuses and also a situation with time gaps when the model may be regarded as permeable. Although this is a highly simplified model approach, by comparing both diagrams we see a fundamental difference between the two road types, especially during night time, which is crucial in terms of animal migration. In general, an average highway / motorway is permeable 24 hours a day, whereas an average 1st class road shows relatively high permeability during the night.

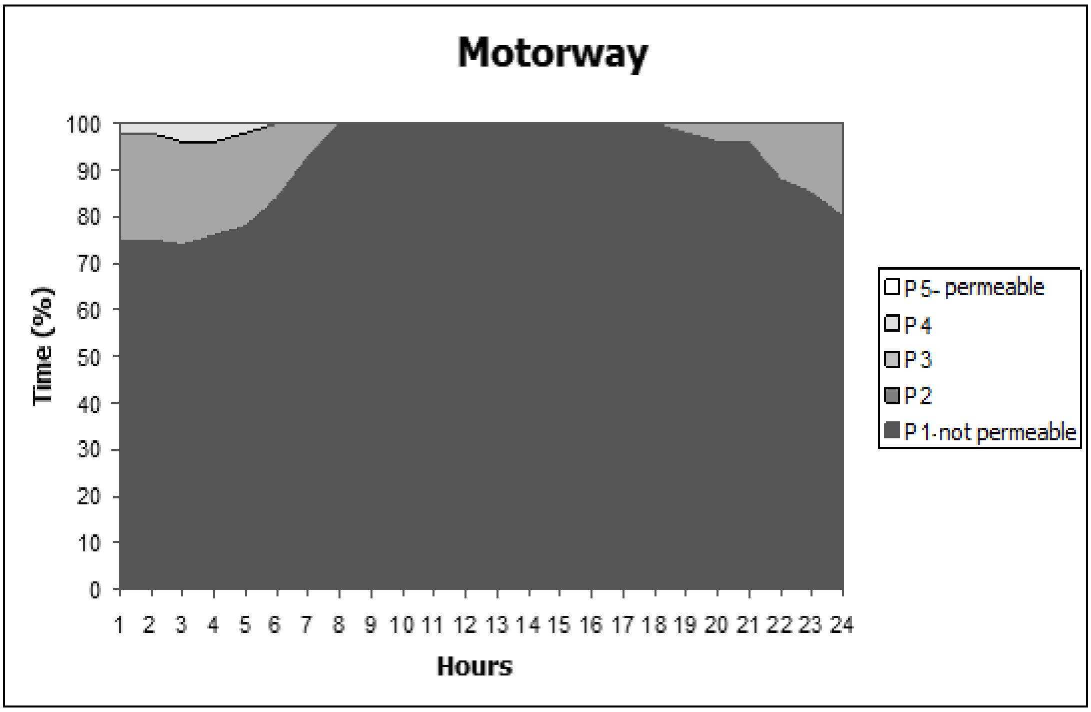

Figure 4: Permeability of a typical motorway during individual hours of a regular workday.

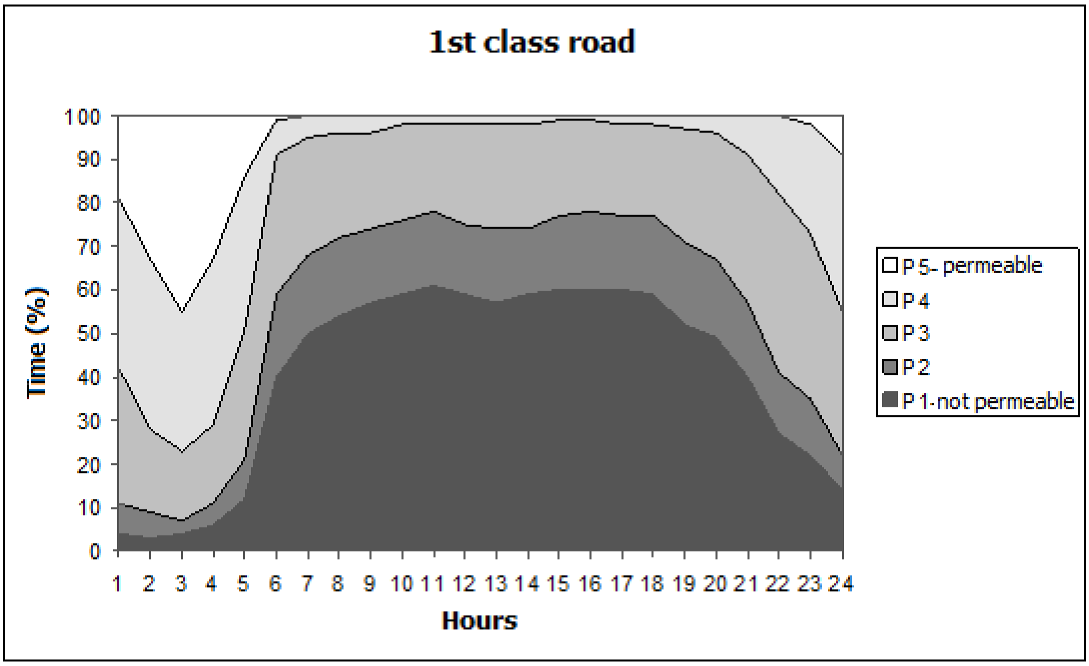

Figure 5: Permeability of a typical 1st class road during individual hours of a regular workday.

2nd and 3rd road classes represent (due to their lower traffic loads) a smaller barrier, especially at night. However, it depends, of course, on the specific traffic intensity at the monitored section of the road.

Local roads (located inside built-up areas, cities and municipalities) do not pose a high danger of collision with animals (not taking into account pets that sometimes wander on these roads rather than cross them). On the other hand, the species "Homo sapiens sapiens" are abundantly present here, but we assume that these species will use the sufficiently large distances between vehicles to properly cross these roads.

7 CONCLUSION

Analysis of data obtained from measurements provided by automatic radar enabled us to find general relationships which determine the distribution of time gaps between vehicles in traffic flow. These results were applied (among other applications) to assessments of the impact of traffic on wildlife. These simplified models have shown us the road barrier effect, with certain traffic intensity, on wildlife.

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REFERENCES

EDIP, 2007. *Využití dopravně inženýrských dat a metod pro kvantifikaci vlivů dopravy na životní prostředí* [roční zpráva 2007]. Projekt VaV č. 1F55A/065/120. Plzeň: EDIP s.r.o. (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.* Havířov: ČVT Silniční společnost. (in Czech)

ŘSD, 2006. *Výsledky celostátního sčítání dopravy na silniční a dálniční síti ČR v roce 2005* [online]. Praha: Ředitelství silnic a dálnic ČR [cited 2013-07-12]. Retrieved from: http://www.scitani2005.rsd.cz/start.htm (in Czech)

TP 189, 2012. *TP 189 - Stanovení intenzit dopravy na pozemních komunikacích*. Plzeň: EDIP s.r.o. (in Czech)

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