Czech University of Life Sciences Prague

Faculty of Engineering

Diploma Thesis

THE TRAFFIC ACCIDENTS AS PART OF ENVIRONMENTAL ASSESSMENT

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DIPLOMA THESIS ASSIGNMENT

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Technology and Environmental Engineering

Thesis title

The traffic accidents as part of environmental assessment

Objectives of thesis

The thesis's aim is to survey chosen parts of the transport infrastructure and to propose (design) improvement of traffic engineering elements to decrease occcurence of accidents.

Methodology

1. Literature overview (traffic accidents and their influence on human health and environment, quality of transport infrastructure and its influence on accidents)

2. Traffic survey and data processing

3. Modeling of traffic situation in simulation software, proposal of precautions

4. Discussion and conclusions

The proposed extent of the thesis

50 including tables and figures

Keywords

traffic accident, transport infrastructure, environment

Recommended information sources

GUEST, P. – SLINN, M. – MATTHEWS, P. *Traffic engineering design : principles and practice.* Amsterdam ; London: Elsevier Butterworth-Heinemann, 2005. ISBN 0-7506-5865-7.

KOLEKTIV. *Traffic engineering for isdn design and planning. : – BONATTI MARIO – DECINA MAURIZIO ED.* AMSTERDAMM: ELSEVIER, 1991.

ROESS, R P. – PRASSAS, E S. – MCSHANE, W R. *Traffic engineering.* Boston: Pearson, 2011. ISBN 978-0-13-207652-4.

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Declaration

I declare that I have worked on my diploma thesis titled "The traffic accidents as part of environmental assessment" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the diploma thesis, I declare that the thesis does not break copyrights of any other person.

In …………… on ……………

……………………...

Mariia Khrapova

Acknowledgement

I would like to thank doc. Ing. Miroslav Růžička, CSc., for his advice and support during my work on this thesis.

The traffic accidents as part of environmental assessment

Summary: The master thesis is devoted to different aspects of the traffic accidents as a part of environmental assessment. The relevance of environmental pollution by the road vehicles and relevant terminology are drawn in the thesis. The analysis of chosen part of the transport infrastructure is illustrated using traffic survey and PTV Vision VISSIM software. The thesis includes assessment of the current state of the selected site and verification of design improvements to decrease occurrence of accidents. This work could provide the basis for further improvement of the transport infrastructure in order to minimize damage to the environment.

Keywords: traffic accident, transport infrastructure, environment

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Introduction

A danger foreseen is half avoided.

Proverb

Transport is currently one of the main factors that reduce quality of the environment. The most adverse impacts of transport include discharge of harmful substances into the atmosphere, noise, vibration and annexation of fertile areas. It is also demanding on the consumption of energy resources, particularly oil. Transport routes create many obstacles for regular movement for certain animal species, which often leads to disastrous consequences.

Every year European Environmental Agency makes assessment of traffic pollution in the Europe region. The result for the year 2015 is impressive – the quarter of Europe greenhouse gas emissions were caused by different type of transport. The major part of all transport pollution leads to automobile traffic [1].

The assessment of current state of environment includes researches of the impacts caused by the road infrastructure. Traffic accident is one of the subjects of the research because most of them lead to major types of environmental pollution (gaseous emissions, damage to habitats or species, water and soil pollution, etc.).

The concept of environmental assessment includes not only determination of harmful consequences on the environment but also includes detection of ways to minimize or eliminate harmful effects of their impact.

Precisely harmful consequences of traffic accidents and requirements for reducing them are described in this work.

1 Objectives and methodology

The aim of this work is to analyse chosen part of the transport infrastructure, to find a causal connection between accidents formation with the current state of the site and to propose design improvement to decrease occurrence of accidents.

The methodology of work consists of four interrelated parts.

Work begins with literature review, which is a theoretical basis, necessary for understanding and analysing the following parts. The review includes terminology connected with road infrastructure and traffic accidents, causes of their occurrence and description of accidents analysis. The environmental impact assessment is described as well as the separation and description of specific types of automobile pollution. The road safety procedures complete the literature review.

The next part begins with the analysis of road accidents on the territory of the Czech Republic and selection segment of the road network with a high accident rate. Selection is made on the basis of police data which are collected on the JDVM application [24]. Then there is analysis of traffic accidents by creating a database and sorting by selection criteria using Microsoft Excel. After analysis of the intersection, that consists the determination of its position in Prague, commenting the current situation, will be carried out by traffic survey. It will be carried out according to the Czech technical specification number 189 [2] by manual method. This survey will detect traffic intensity at the intersection, including determination of the structure of traffic flows. Data from traffic surveys will be electronically processed, the 50th highest hour intensity will be determined. The assessment of road quality will be provided using online software program EDIP-eL, which is based on the Czech technical specification number 225 [3].

The continuation of the analysis of selected road site is carried out in chapter number four. Based on the obtained data in previous chapter a model of traffic in PTV VISSION program will be created. The output data will be analysed in add-on software - Surrogate safety assessment model and validation. The results will show the number of supposed accidents based on the analysis of vehicle trajectories. The obtained results will be compared with outputs of the improved design model. The improvements of the intersection are explained according to results obtained from previous analysis.

Final chapter summed up the success of the analysis of the selected transport infrastructure.

2 Literature overview

Literature overview is an evaluative report of information found in the literature related to the traffic accidents and their impact on the environment.

2.1 Terminology

It would seem that an accident may occur on any part of the road, but in fact 30-40% of accidents occur only on 3% of the road [4]. To explain this statement, it is necessary to understand what a traffic accident means. The next part is addresses theoretical overview on this issue.

2.1.1 Transport vehicles and users

The classification according to the Czech technical standards [5] is shown in Figure 1.

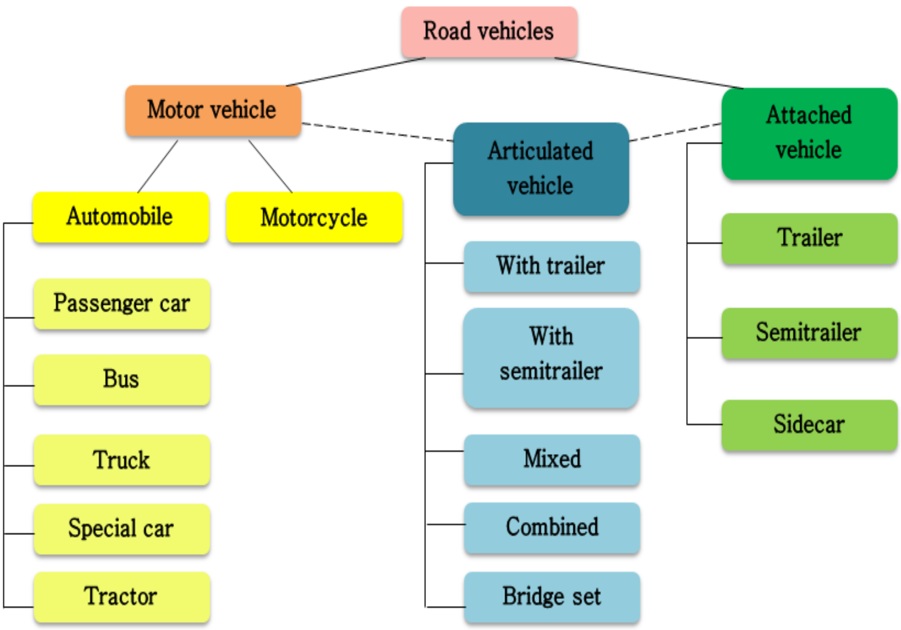

Figure 1 Classification of the road vehicles. Source: Author's work

Occupant is any person who uses a transport vehicle to achieve his destination [6].

Pedestrian is any person who is involved in traffic but he is not the occupant [6].

Driver is an occupant who is in actual physical control of a transport vehicle or, for an out of control vehicle, an occupant who was in control until control was lost [6].

2.1.2 Transport ways

Traffic way is any land way open to the public as a matter of right or custom for moving persons or cargo from the origin to the destination [6] (Figure 2).

Roadway is a part of the traffic way normally designed for vehicle traffic [7] (Figure 2).

Shoulder is a part of a traffic way contiguous with the roadway for emergency use, for accommodation of stopped motor vehicles, and for lateral support of the roadway structure [7] (Figure 2).

Median is an area of traffic way between parallel roads separating travel in opposite directions [7] (Figure 2).

Roadside is the outermost part of the traffic way from the property line to other boundary [7] (Figure 2).

Traffic lane is a strip of roadway for a single lane of vehicles [8].

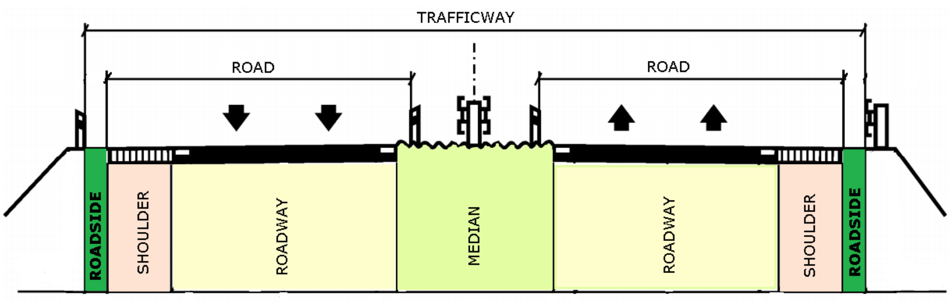

Figure 2 The road intersection design terms. Source: Author's work

Classification of the roadway types constitutes the terminology used in the "Project Development and Design Guidebook" [9] and the corresponding terminology using in the Czech Republic.

- **Motorways** *("dálnice")* are primarily constructed for interstate and regional travel (high regional connectivity at high speeds with limited access to nearby land and forbidden for pedestrians and cyclists) [9]. The owner is the state and these roads are administered and maintained by the Directorate of Roads and Motorways (hereinafter referred to as "RSD").
- **Major arterials** *(silnice I. třídy)* service all over the country travel as well as major traffic movements among urbanized areas or suburban centres (high regional connectivity and a lower level of local access than the following roadway types) [9]. The owner is the state, and these roads are administered by RSD.

- **Major collectors** *(silnice II. třídy)* connect arterial roadways and provide connections between cities and towns (low regional connectivity at a wide range of speeds, higher local access than motorways and major arterials) [9]. The owner of the road is the regional authority on whose territory the road is located.
- **Minor arterials** *(silnice III. třídy)* connect cities and towns in rural areas and interconnect major arterials within urban areas (high to moderate regional connectivity at a wide range of speeds, and moderate degrees of local access) [9]. The owner of the road is the regional authority on whose territory the road is located.
- **Field roads** *(účelová komunikace)* connect local roads to major collectors and arterials (lower regional connectivity at lower speeds and higher degrees of local access than the previous roadway types) [7]. Owners are legal entities or individual persons.
- **Local (municipality) roads** *(místní komunikace)* are not intended for regional connectivity (low speeds, high degree of local access) [9]. The owner is the municipality on whose territory the road is located.

Intersection (or junction) is an area, which contains a crossing, or a connection of two or more roadways not classified as driveway access and embraced within the prolongation of the lateral curb lines or, if none, the lateral boundary lines of the roadways [6].

The key elements of the road intersection are shown in Figure 3.

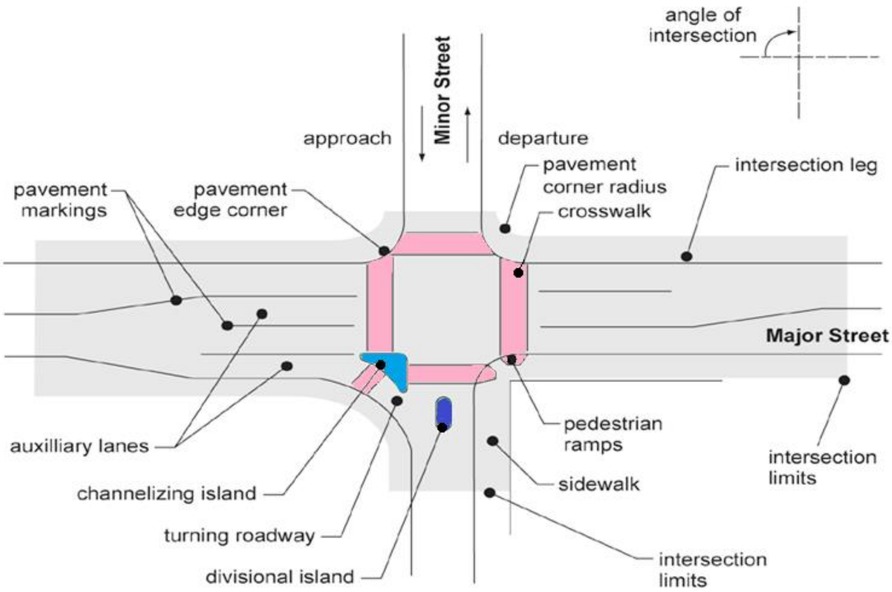

Figure 3 The basic elements of the road intersection. Source: [10]

Major street of intersection is the crossing street with higher traffic intensity (number of vehicles per time), larger cross-section and higher functional class [9].

Minor street of intersection is the crossing street with less traffic volume, smaller cross-section and lower functional classification than the major street [9].

Intersections are divided into several groups, so that each particular junction can be classified into two or more groups at the same time.

So, first intersections are distributed according to:

a) the number of legs:

- tree legs:
  - T intersection (Figure 4a);
  - Y intersections (Figure 4b);
- four legs – cross-intersection (Figure 4c);
- five and more and not circular (Figure 4d);
- circular:
  - roundabout (Figure 4e);
  - other circular intersections (Figure 4f).

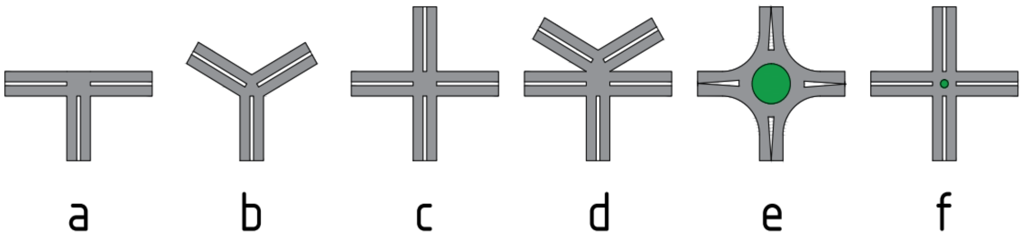

Figure 4 Types of the road intersections according to the number of arms. Source: Author's work

b) the number of levels (Figure 5):

- on one level – communications intersect at one level, may include all types of conflict points[1] (Figure 5a);
- multilevel – communications intersect at two or more levels, do not include conflict points (Figure 5c);
- combined – communications intersect at two or more levels, may include conflict points (Figure 5b).

[1] More details in the chapter 2.5.1

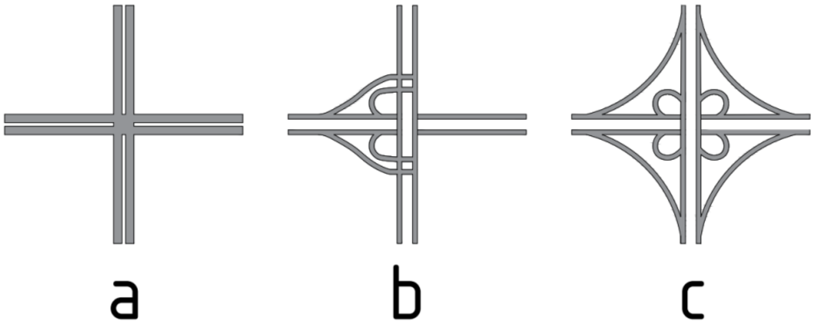

Figure 5 Examples of intersections with different number of levels.

Source: Authors work

c) control:

- uncontrolled intersection;
- intersection with traffic signs.

2.1.3 Accidents

Traffic road rules may differ in different countries; however, determination of traffic accident is similar in various sources:

Traffic accident (hereinafter referred to as "TA") is

- a road vehicle accident in which the unstabilised (uncontrollable) situation[2] originates on a traffic way or a harmful event[3] occurs on a traffic way [6];
- an incident resulting in property damage, personal injury or death and involving the loss of control and/or the striking of one or more vehicles with another vehicle, a person, an animal or an inanimate object [11];
- an extraordinary event incurring injury to persons or damage to property, directly related to the operation of the vehicle or transport equipment [12].

Location of TA

On-roadway accident is a TA in which in the harmful event occurs within a roadway [6].

At-intersection accident is a TA in which the harmful event occurs within the limits of an intersection (Figure 3) [6].

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[2] An unstabilized situation is a set of events not under human control [3].

[3] A harmful event is an occurrence of injury or damage [3].

Location of frequent traffic accidents (hereinafter referred to as "LFTA") is a part of road with a length up to 250 (m) or intersection if there occurred:

- at least 3 accidents with personal consequences during one year;
- at least 3 accidents with personal consequences of the same type during three years;
- at least 5 accidents of the same type during one year [2].

Classification of TA

Typology of accidents is an effective tool, particularly for identifying locations of frequent traffic accidents and their analysis.

Typology of TA is a system of classification based on distinction of the accompanying characteristics. According to the Transport Research Centre [4], there are 10 main groups and 107 subgroups of TA. The main groups are described in the Appendix 1.

Causes of accidents are a topic of classification as well.

2.2 Causes of traffic accidents

Each road traffic participant can be involved in an accident. Different factors play certain role in the occurrence of TA. Accidents are rarely the result of a single factor; more often they involve a chain of circumstances and events that may lead to an emergency situation. The Figure 6 is a schematic representation of accident development as a result of unsafe actions and latent errors.

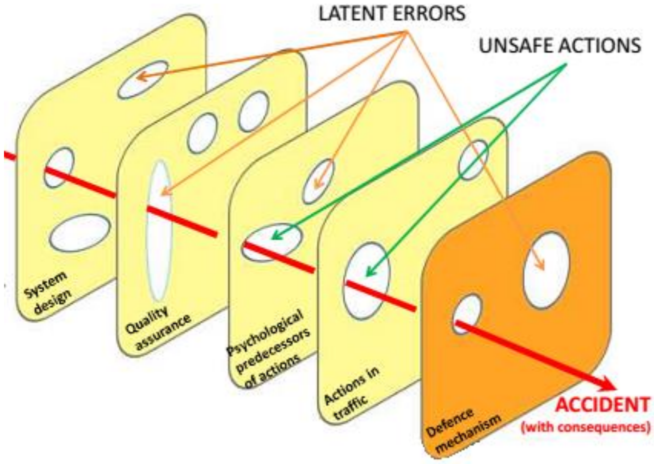

Figure 6 The Swiss Cheese Model of TA. Source: [13]

Thus, the causes of TA are numerous and they are often a consequence of a number of events that can be associated with one of three components of the safety triangle: human – vehicle – environment.

Respectively causes are divided according to three main components, namely factors:

- human;
- vehicle;
- road environment.

The causes of accidents and their percentage of the total number of accidents are described in Figure 7.

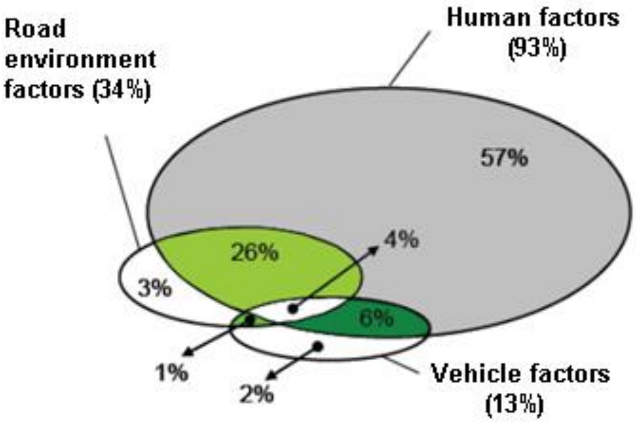

Figure 7 Accident contributing factors. Source: [14]

2.2.1 Human factors

According to statistics, most accidents occur because of human factor. The driver makes a lot of small mistakes in driving a vehicle because of carelessness, inexperience, embarrassment and eventually current state of health. These errors do not always lead to TA but in conjunction with other adverse circumstances they can cause a road accident.

Causes of TA according to human factor may be divided into two main groups:

- Unconscious.
- Conscious.

Unconscious causes of TA

Unconscious causes are driving mistakes because of health condition of driver, his fatigue or reaction rate.

- Teenage drivers. Insufficient experience in driving may result in serious TA.
- Night driving. This type of driving can lead to a collision, as a consequence of reduced night time visibility, increased fatigue, increased risk of falling asleep while driving.
- Road rage. Anger caused by stress and frustration involved in driving a vehicle may cause TA.
- Illness. Accident may be caused by common cold or disease that is more serious. High temperature and malaise because of cold cause reaction reduction and vision deterioration in some cases. In case of severe diseases, such as heart disease, asthma, etc. when driving, this can cause a heart attack resulting in loss of vehicle's control.

Conscious causes of TA

Conscious causes - driver deliberately violates traffic rules. Such violations may be:

- Speeding. The problem of high speed is that the higher speed, the less reaction time to prevent TA.
- Drunk driving. Alcohol reduces the ability of driver to focus and function properly.
- Distracted driving. Distractions caused by eating, using mobile phone, smoking, listening to loud music, looking or talking with other passengers in the vehicle.
- Reckless driving. Reckless drivers are those who speed, change lanes too quickly, turn improperly or tailgate thus causing a car accident.
- Running red lights (to pass through an intersection having a red traffic light without stopping) or stop signs. Drivers who run red lights or run a stop sign may cause a wrongful death because they often cause side-impact accident at high speeds.

2.2.2 Vehicle factors

Common cars' defects can cause severe injuries to occupants including tire defects resulting in vehicles being more prone to rollovers, defective airbags, seatbelt defects [15].

There are few most common problems:

- Design defects. Despite careful control of all car parts, some of the components may have defects that can lead to serious accidents.

- Tire blowouts. Tire blowouts may cause losing control of automobile, especially dangerous for bigger vehicles like semi-trucks.
- Wear details. Many motorists ignore established terms of use and replace certain car parts or fluids not in a timely manner, and as a result, the vehicle may break down at the most inopportune moment.

2.2.3 Road environmental factors

Environmental conditions include road infrastructure, weather conditions, others.

Road infrastructure

The owner of certain type of roads[4] is responsible for the quality of road infrastructure: its design and maintenance.

Accordingly, the reasons for TA can be divided into two main groups:

- Incorrect roadway design.
- Poor roadway maintenance.

Such factors may be attributed to incorrect roadway design:

- psychological right of way;
- unsuitable width arrangement;
- large collision areas at junctions;
- unsuitable junction arrangement;
- inadequate traffic signs;
- unsuitable background of traffic signs;
- unsuitable horizontal and vertical alignment;
- sudden changes of width alignment;
- sight obstruction;
- fixed obstacles;
- tree alley as fixed obstacles;
- ruts, road surface [13].

---

[4] More details in chapter 2.1.2

As a result of poor road maintenance:

- debris on the roadway;
- faded road signs;
- potholes;
- zone of roadway construction with reduced width of the road;
- inadequate salting or sanding of icy roadways [16].

Weather conditions

Despite the fact that more accidents occur under normal weather conditions i.e. in daylight, deteriorating weather increases the probability of accidents as:

- Rain**.** When it rains, the risk is higher because water creates slick and dangerous surfaces for vehicles and often causes car to go out of control and skid during braking. Besides heavy rainfall causes bad visibility.
- Snow and ice. These weather conditions can lead to loss of control over the car and spinning out.
- Fog. For some regions it is one of the common reasons of collision because fog hinders visibility at a distance of more than tens of meters.
- High speed winds. High speed wind is defined as a wind of at least 60 km/h [16] and may cause loosened control of vehicles.

Others

This category may include encounter with living beings (pedestrians, animals) and the variables (time of day, day of week, season).

- Animal crossings. In rural, woody areas quite often wild animals wade out into the road.
- Pedestrian crossing. Failure to comply with traffic rules during crossing the street can lead to fatal consequences not only for pedestrians, but also for the occupants.
- Variable factors (time of the day, day of the week, etc.) – are reasons that at first glance are unimportant, but are determined statistically according to the number of accidents in Czech Republic.

2.3 Analysis of TA

Qualitative analysis of TA may prevent further accidents by adoption of countermeasures. For analysis, it is necessary to know precisely particular events that occurred before and during a TA. In some cases, simple analysis is enough, but in other more thorough research is needed. Details of analysis are referred to below.

2.3.1 Simplified analysis of TA

Simplified analysis of TA is intended to give an idea about the accident location. Objects of the study are [18]:

- time of TA occurrence (day or night, time period during the day, week, etc.);
- weather conditions (drought, rain, fog, snow, ice, sunrise and sunset etc.);
- accident location (concentration of accidents in a certain place, straight stretch direction and altitude arch bridge, railway crossing etc.);
- direction of traffic (including directional movements of the vehicles in the intersection);
- type (accidents by type of the participant of traffic and vehicles involved, the nature of the crash – the frontal or side collisions, crashes, collisions with obstacles etc.);
- causes (speeding, disregarding driving, improper overtaking or not giving way, etc.);
- TA consequences (killed, seriously injured, slightly injured, material damage).

2.3.2 Detailed analysis of TA

In cases when a simplified analysis cannot accurately determine the cause of an accident, the accident location is subjected to closer scrutiny by detailed analysis.

A detailed analysis of the traffic system entails not only structural characteristics of the road (the quality of the surface and its implementation, safety equipment and traffic signs) but also traffic characteristics (traffic load; speed of the vehicles; sight conditions; conflict point).

The **main traffic characteristics of the intersection** as the highest level of the organization of traffic ways are:

- Design vehicle – the largest type of motor vehicle that is accommodated through the roadway [8].
- The target speed is the desired speed along roadway [8].

- Traffic control on different types of roadways varies. As an example, different types of intersections are observed. At uncontrolled intersections – STOP and YIELD control, vehicle capacity and delay are influenced by conflicting traffic streams. At signalized intersections - the time provided for each movement, and the volume and mix of other users are key impacts on both motor vehicle capacity and delay [8].
- Motor vehicle capacity - the number of motor vehicles that can move through a section of roadway under normal conditions [8]. As a result, the data about the average residence time are obtained and used to assess the quality of service. The evaluation of the quality according to the average residence time is shown in the Table 1.

Level of quality		Average residence time [s]
Designation	Characteristics of service quality	
A	very good	≤ 20
B	good	≤ 35
C	satisfactory	≤ 50
D	sufficient	≤ 70
E	unstable condition	> 70
F	capacity exceeded	∞

Table 1 The assessment of service quality. Source: [19]

- Motor vehicle traffic volumes – the number of vehicles crossing a section of roadway per unit time at any selected period. Two methods are available for conducting traffic volume calculation: manual and automatic.

2.4 The environmental assessment

The **environmental impact assessment** is a process of estimating and evaluating significant effects of a process on the quality of its location's environment. It also includes detection of ways to minimize or eliminate harmful effects and compensate for their impact.

The impact of a road traffic is environmentally dangerous – leads to biological, mechanical, physical and chemical contamination of ecosystems and causes environmental losses.

Environmental losses – is emission of harmful substances into the atmosphere, water and soil pollution, noise exposure and vibration. The main reasons for raising the level of environmental losses are overloading individual road sections, increased level of manoeuvring heavy traffic flows, including braking, stopping and acceleration; forced reduction in speed and movement on inefficient modes, poor technical condition of vehicles, etc. Even such “useful" improvements, as lowering established limit of speed traffic in settlements or mandatory turning on the light during the day, leads to increased fuel consumption and increased environmental losses.

According to Starkov [20], environmental losses may arise from the short-term and long-term impact of the road traffic on the environment.

2.4.1 The long-term impact

A permanent environmental hazard is a consequence of the normal functioning of the transport complex. It is manifested in increased, compared to the natural, level of air pollution, pollution of water bodies, soil cover and noise near the traffic ways.

Polluting emissions from cars exceed emissions from rail vehicles. The exhaust gases of internal combustion engines contain more than two hundred kinds of harmful substances and hazardous compounds, including carcinogens. Roadsides and water bodies are polluted by petroleum products, products of wear of tires, brake pads, loose and dusty loads, chlorides used as defroster of road surfaces.

The total number of motor vehicles in the world exceeded 1,2 billion units in 2014 [21]. A vehicle with mileage of fifteen thousand kilometres burns an average of two tons of fuel, about thirty tons of air, including five tons of oxygen, which is fifty times higher than human needs [19].

Air pollution

The most serious geo-ecological problem is associated with the transport. From 40 to 70% of the nitrogen oxides, from 70 to 90% of carbon oxides and at least 50% of lead oxide in the atmosphere is caused by car exhaust. The effects of air pollution are becoming important global geo-ecological problem.

Air pollutants directly produced by cars, such as carbon monoxide, nitrogen oxides, hydrocarbons and lead, mainly accumulate close to the sources of pollution, i.e. along highways, streets, tunnels, intersections, and so on.

Some pollutants are transported over long distances from the place of emission; they are transformed during transfer and cause regional geo-ecological impacts. The most common process is acidification.

Carbon dioxide is the most important greenhouse gas emitted by vehicles. High levels of these gases lead to greenhouse effect, which in turn leads to global warming, melting of glaciers, etc.

Water pollution

Vehicles are a source of many pollutants in storm water. Oil, suspended solids, antifreeze, and other fluids are spilled during maintenance of a car and then get into water bodies with sewage. The runoff from the roadway contains not only petroleum products, but also heavy metals (lead, cadmium, etc.) and chlorides, which in winter (in some countries) are used as antifreeze for road surface.

One quart of oil will contaminate thousands of gallons of water because it does not dissolve. Trace metals and degreasing agents used on automobiles contaminate drinking water and can cause major illnesses. Some of these metals and toxins are absorbed in sea life and cause medical problems to people when eaten. Phosphorus and nitrogen cause explosive growth of algae, which depletes water of oxygen, killing fish and aquatic life [23].

Soil pollution

Another environmental problem caused by using vehicles. Soil research in the area of transport routes has shown that maximum permissible concentrations of heavy metals exceeded in approximately 15% of the samples [22]. This land pollution is direct. As an example, oil leaks from cars to the ground actually pollute the soil.

But more often, pollution of the soil is indirect. The acid rain formed from gases in car exhaust dissolving in rain can lead to soil acidification. Beneficial soil organisms are killed in this soil-acidification process. Eventually, the soil might become barren and incapable of supporting life.

Human exposure

Humans are a part of environment and respectively harm caused to a person can be attributed to the negative impact on the environment. According to “Global status report on road safety” [24], over 1,2 million people die each year on the world’s roads, and between 20 and 50 million suffer non-fatal injuries.

2.4.2 The short-term impact

The short-term environmental hazard arises in emergency situations (TA) in which air pollution, water and soil pollution, destruction of biota and other consequences are observed. In contrast to the long-term effects, environmental losses from the short-term hazards can be estimated more accurately.

Figure 8 Consequences of TA that have harmful effect on the environment: 1 – fluid leakage, 2 – gas leakage, 3 – fire, 4 – heat emission, 5 – noise emission, 6 – reduction of animal populations.

Source: Author’s work

Consequences of TA which are shown in the figure are described below according to the numbers:

1. Road TA cause fluid leakage, which can poison the soil and neighbouring plants and do harm to wildlife. Major oil spills from mangled cars are one of the main problems related to TA, especially those that occur near the water.

Another, less obvious reason is that many vehicles cannot be repaired after serious accidents. With regard to the fact that processing requires additional cost, a big quantity of cars end up in a landfill, where it will take thousands of years for all parts to decompose. Many car parts are also left on the roadside where they can cause harm to animals or plants. So TA is a soil and water contaminant.

2. TA often results in gas leaks, emitting harmful chemicals into the atmosphere. These harmful substances lead to respiratory diseases and cause the accumulation of greenhouse gases. In this case, TA is the air pollution sources.

3. TA with another vehicle can cause a significant damage and as a result, it may cause fire and then explosion. Explosion of a vehicle is the source of not only long-distance air and land pollution, but also it leads to death of the living creatures.

4. As a result of the collision of vehicles huge amount of heat is released, which in combination with other energy sources lead to global warming.

5. It is also accompanied by a sonic blast that causes temporary disruption in the natural balance. Accordingly, TA creates noise; animals may suffer from hearing loss which makes them an easy prey, and leads to dwindling populations. Others become inefficient at hunting, disturbing the balance of the eco-system.

6. Also, an accident can be the reason of extinction or even disappearance of species included into the Red Book. This can be caused not only by single cases when animals are hit by vehicles, but also by violation of the LFA migration routes, which can lie through this section.

2.4.3 Assessment of environmental damage

The damage caused to the environment is assessed based on the established fact, instrumentally measured and documented negative impact on the environment. The amount of compensation for damage caused by the negative impact on the environment is defined as the amount of damage caused by a variety of natural resources, but can also be determined by one of them.

Calculation of damage and losses performed on the basis of regulatory and methodical documentation, as well as taxes for calculation of penalties for damages amount to flora and fauna.

The concept of "a negative impact on the environment" includes direct and indirect damage or loss.

Direct – expression in the form of money from harmful environmental impact.

Indirect – material losses and financial costs for the nature users (citizens, enterprises, institutions and organizations) arising from:

- Elimination of the environmental consequences of the accident and recovery of impaired environment.
- Loss of health, property damage, and production of natural resources.
- Loss of profit from the operating system changes the state and natural resources [25].

For evaluation of total losses usually only indirect component is used since visible consequences are calculated by the following formula:

$$\mathbf{TL = C_x \cdot N_K + C_x \cdot N_{SI} + C_x \cdot N + C_{xMD}} \qquad (1)$$

Where:

C_x – unit costs depending on the severity of TA in selected year;

C_{xMD} – unit costs of material damage in selected year;

N_K – number of accidents with killed;

N_{SI} – number of accidents with severe injuries;

N_I – number of accidents with slight injuries;

N_{MD} – number of accidents with only material damage.

2.5 Safety of the transport system

Safety transport system can be understood as a system performance generating inappropriate interactions between individual components of the system within the system changes over time.

2.5.1 System security analysis

An important role in the analysis of the selected traffic system safety is played by the conflict studies, which determines conflict points.

Conflict – is a critical event, having features of road accidents (e.g. sudden braking, change in direction), but not resulting in a road accident.

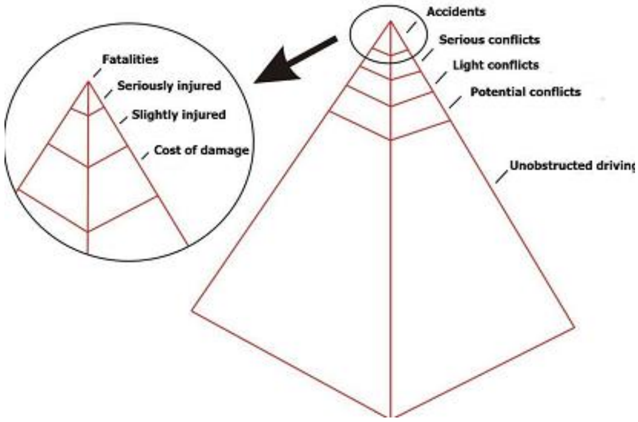

Figure 9 Pyramid of traffic conflicts. Source: [13]

Conflict point is the point at which a driver crossing (Figure 10a), merging with (Figure 10b), or diverging from (Figure 10c) a road or driveway conflicts with another driver using the same road or traffic way.

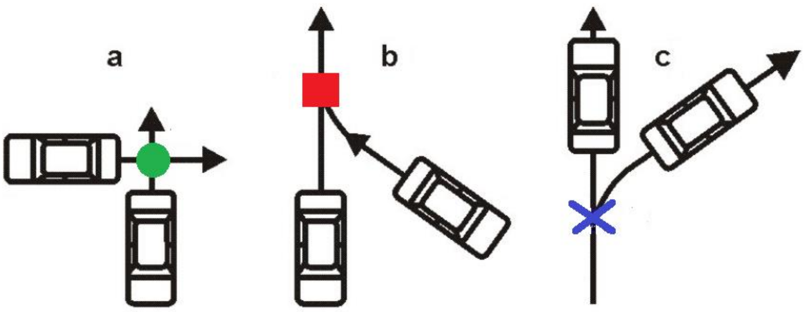

Figure 10 Types of conflict points. Source: [22]

The conflict study determines suggestion of the place of accident, the existing safety evaluation is conducted by the number of indicators. There are various indicators, but in this paper the indicator of relative accident rate is considered

The **indicator of relative accident rate –** is commonly used criterion for evaluating road safety hazard. It indicates the probability of TA on certain communications in relation to its transport capacity. The disadvantage is that it operates with the absolute number of personal TA and not their severity.

For no intersections, an indicator of relative accident rate is given by:

$$\mathbf{R = \frac{N_o}{365 \cdot ADDT \cdot L \cdot t} \cdot 10^6} \qquad (2)$$

For intersections:

$$\mathbf{R} = \frac{\mathbf{N_o}}{\mathbf{365 \cdot ADDT \cdot t}} \cdot \mathbf{10^6} \qquad (3)$$

Where:

R – indicator of relative accident $\left[\frac{\text{the number of personal accidents}}{\text{million vehicle kilometres per year}}\right]$;

N_o – a total number of accidents in the period [-];

ADDT – average annual daily traffic $\left[\frac{\text{vehicle}}{\text{day}}\right]$;

L – the length of the section [km];

t – the period [years].

Indicators values are relative and usually range between 0.1 and 0.9. Higher values already indicate minor flaws from the standpoint of safety.

2.5.2 The road safety procedures

European Directive 2008/96/EC on Road Safety Infrastructure Management (hereinafter referred to as "Directive") provides legal requirements for safety management of Trans-European Road Network. Research is vital to improving safety on the roadways. Developing and demonstrating components, methods and measures, disseminating research results play an important part in increasing safety of road infrastructure [26].

The Directive [23] defines the following legal aspects:

- Road safety impact assessment – comparative analysis on the strategic level, the impact of the planned road works and alternatives to network security indicators.
- Road safety audit – independent systematic inspection of road infrastructure safety projects, covering all stages in order to identify danger features.
- Safety ranking and management – identification, analysis and ranking of sections of the road site with a large number of accidents in order to reduce accidents.
- Safety inspections – periodic inspection of safety of the road network to identify defects for corrective measures.

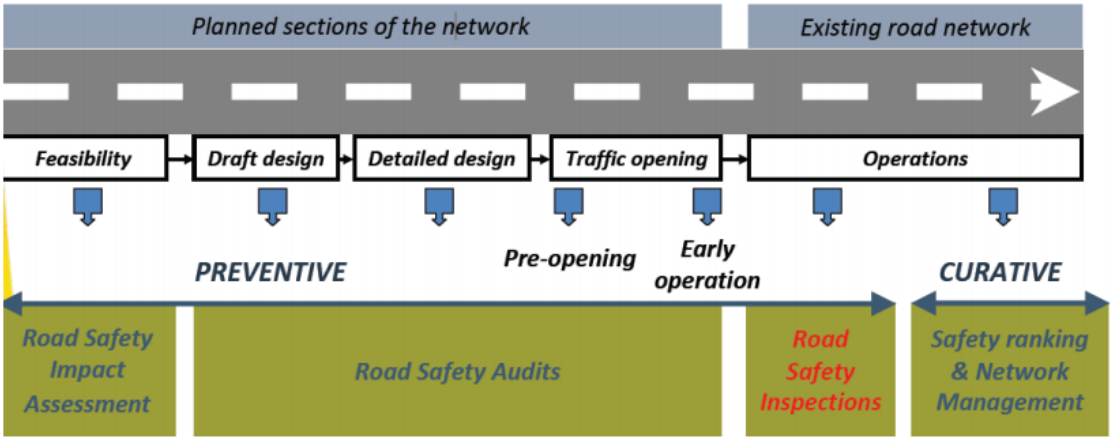

Figure 11 Key legal aspects according to the Directive. Source: [13]

Proposal for corrective measures is a key element of the solution sites of frequent TA. Draft measures to remediate critical points must be prudent, to avoid the possibility that the newly rehabilitated location must be adjusted after a short time again.

According to Slinn and other [27], the measures to be considered depend on the approach adopted:

- single site treatment (for example: improved signing, carriageway markings, road surface treatment, lighting improvements);
- mass action plans (for example: anti-skid surfacing, speed enforcement cameras, pelicans, zebras and pedestrian phases at signals);
- route action plans (for example: side road closures or left-in, left-out only, carriageway widening at junctions, cycle routes);
- area action plans (for example: vertical deflection – hump and table; horizontal deflection – chicane and narrowing).

Striegler and other [18] divide measures based on:

a) The **lifetime** of measures is mainly influenced by the material composition and is defined as the time when the measure fulfils its original function without fault and can be:
   - short-term measures (lifetime of measures is less than or equal to 5 years);
   - medium-term actions (lifetime of measures is from 5 to 15 years);
   - long-term measures (lifetime of measures is more than 15 years).

b) **Costs** for implementing measures are split as per price limit, but based on the duration and complexity of the preparation for the proposed measure:

- low cost;
- medium cost;
- high cost.

c) **Efficiency** is defined as percentage of expected decrease in the risk of accidents caused due to implementation of the measure:

- low efficiency of measures (efficiency of measures is less than or equal to 5%);
- medium efficiency of measures (efficiency of measures ranges from 5 to 25%);
- high efficiency of measures (efficiency of measures is higher than 25%).

However, the holistic methodology for implementation of measures is offered by Andres and other [4]:

a) Construction measures:

- draft major structural modifications (such as redefining intersection, rerouting roads, road widening, etc.);
- draft smaller measures (such as installing barriers, installation of railings, building a middle dividing strip, installation of barriers at railway crossings, etc.);
- draft minimal structural modifications (e.g. removal or vice versa planting vegetation, installation of mirrors, etc.).

b) Transport - organization measures:

- organization of transport measures (such as prohibition of entry, change-of-way, etc.);
- assess functioning of telematics;
- use of light-signalling devices;
- modifications of traffic signs.

c) Monitoring effectiveness of implemented measures

All LFA applied to traffic – safety measures must continue to be monitored and evaluated. Their evaluation is intended to determine effectiveness and impact of their further use in addressing other locations. For this purpose:

- statistics of TA;
- comparing statistics before and after implementation of traffic-safety measures;
- periodic verification and control measures are effective;

d) Economic evaluation of implemented measures

It is necessary to quantify the economic impact of the proposed traffic-security measures. For this purpose:

- to quantify the damage caused by TA (including death, severely and slightly injured) before and after implementation of traffic-safety measures;
- to express economic effect of realized traffic safety measures and savings compared to damages from TA before and after implementation of above mentioned measures.

3 Traffic survey and data processing

Number of TA in a particular region depends on numerous factors: the economic development of the region as a whole, the state of the road infrastructure, the number of vehicles per thousand inhabitants.

With the technological progress and the growth of the world population, the number of road vehicles increased. In different countries the number of vehicles per thousand inhabitants varies. The Czech Republic is considered in this work.

Analysis of the relationship between numbers of passenger cars per thousand inhabitants and the total number of accidents was carried out based on statistical data [28] [29]. Data were collected from 2009 to 2015 for analysis and are plotted in the Chart 1.

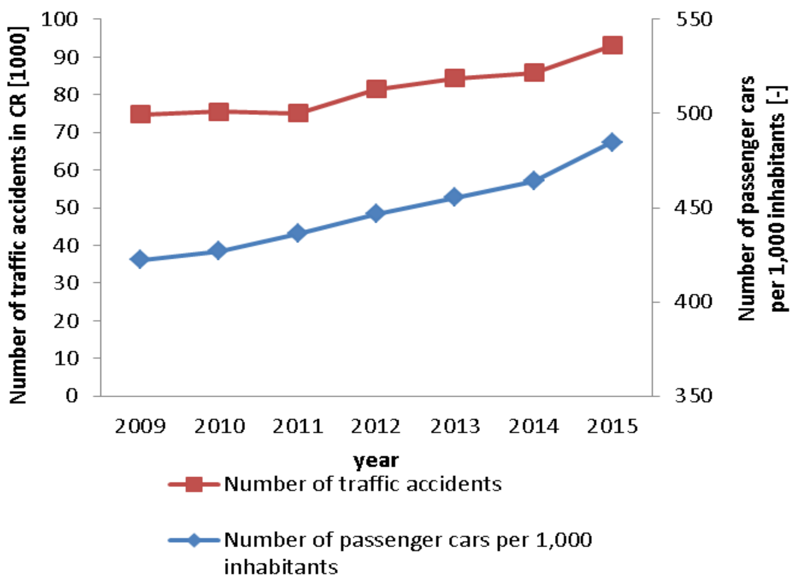

Chart 1 Relation between number of TA and number of passenger cars per thousand inhabitants. Source: Author's work

Based on this graph, it appears that the number of TA stands in proportion to the number of cars per thousand inhabitants. It may be concluded, that the larger amount of population – the larger number of TA – hence the larger environmental pollution.

Prague, the capital of the Czech Republic, takes the first place in terms of population in the country, the road transport and TA respectively. The total number of TA in the past decade is higher than in any other region of the country. This fact confirms the Chart 2.

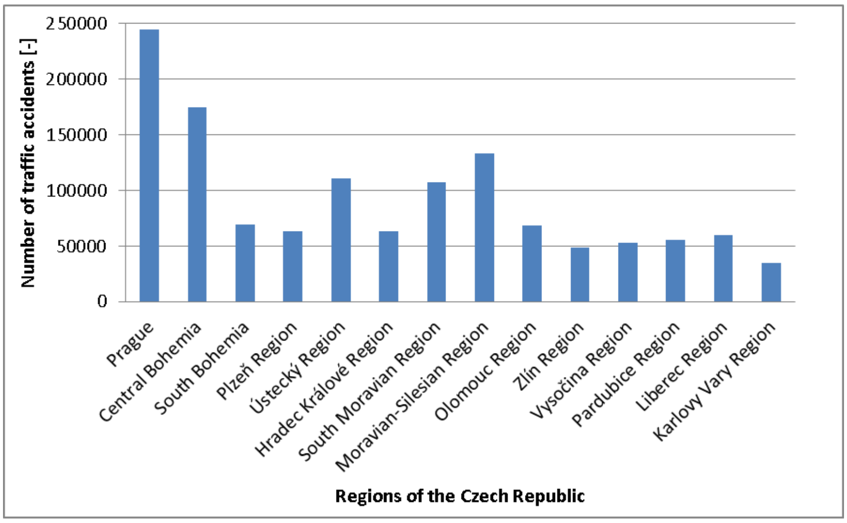

Chart 2 Total number of TA in all regions of Czech Republic (2005-2015).

Source: Author's work

Consequently, TA occurred on the territory of the capital are more likely to bring the greatest environmental damage. So Prague was chosen for determination of LFTA.

3.1 Selection and description of LFTA

Analysis of the TA and the subsequent determination of LFTA was conducted according to police reports collected in the online JDVM application [30]. Application allows to analyse the site in the shape of a polygon for a certain period of time.

Using this application, the intersection was chosen according to determination of LFTA. According to the statistics during one year (1.01.14-1.01.15) there were 5 TA with personal consequences – 7 slightly injured passengers and 1 severely injured passenger (Appendix 2). Under these circumstances, this intersection relates to the LFTA. Therefore, it is considered in this work.

Selected junction is located in the southwestern part of Prague. This is a cross-intersection with four legs on one level, controlled by traffic signs.

It includes a crossing of major collector (K Barrandovu – legs A and C) and local roads (K Austisu – leg B and Ke Smíchovu – leg D). The main street is K Barrandovu, minor streets are – K Austisu and Ke Smíchovu .The current state of the intersection is shown in Figure 12.

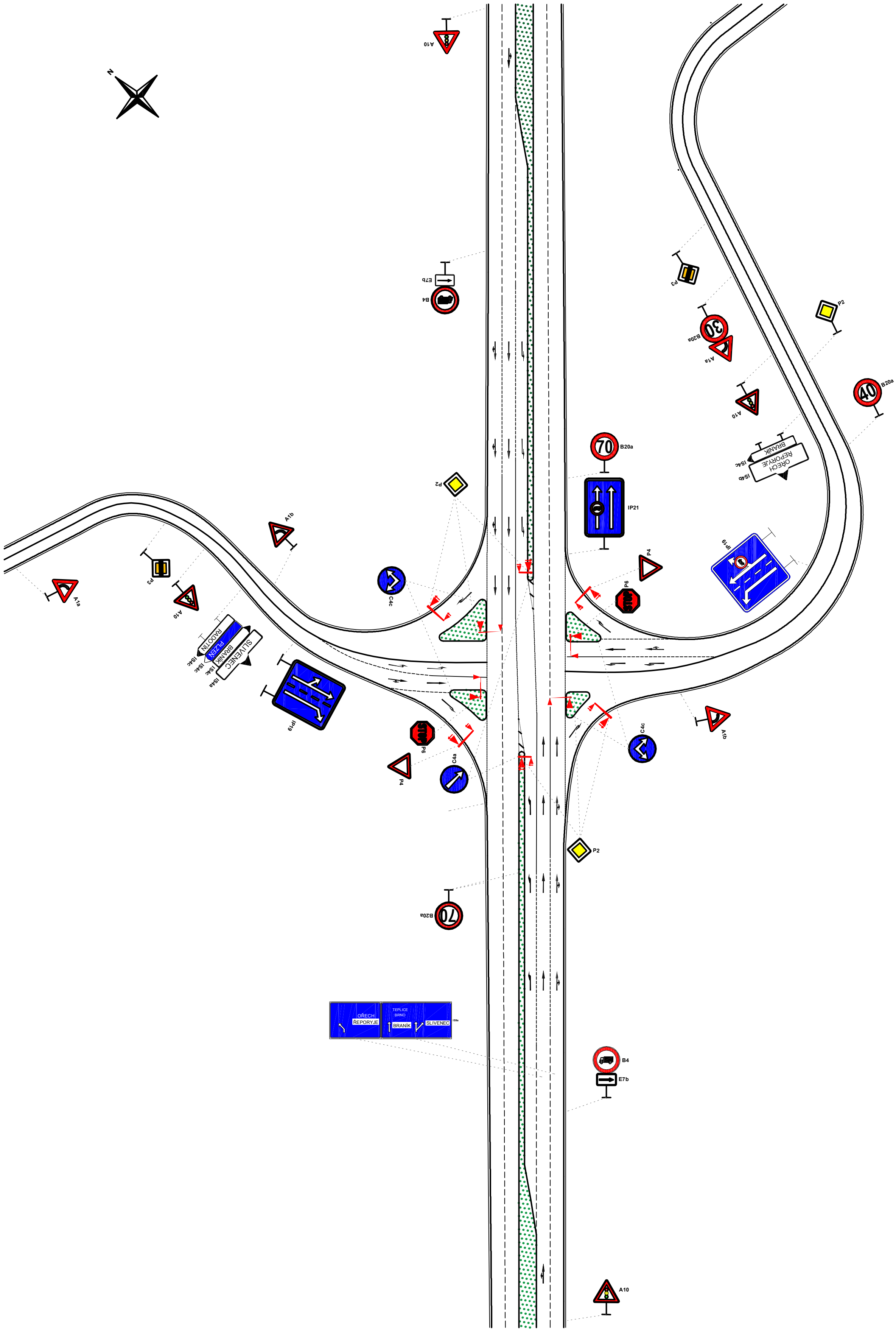

Figure 12 Current state of the intersection. Source: Author's work

All legs have three lanes – lane for left turns, lane for driving straight, lane for turning right. All legs have channelizing islands to delineate right turn. The opposite direction is separated by divisional islands in the legs A and C.

Height slopes were determined from the centre of the intersection: street leg A rises about 3%, leg B has 0% grade, leg C declines of 3% and leg D declines about 2%. The roadway surface of the intersection is bitumen. Horizontal and vertical markings are in good condition and present in full, according to the requirement standards (Appendix 4).

Routes of buses no.130 and no. 230 pass through the intersection. Bus traffic no.130 is limited by legs B and D, no. 230 – legs C and D. The movement of trucks is prohibited on central lanes, banned turns from the street K Barrandovu the street Ke Smíchovu.

3.2 Analysis of TA on the selected site

For determination of LFTA it is enough to analyse data for the period of one year but for in-depth consideration data for longer period are required, in this case – data during last five years. Using JDVM application, it is possible not only to determine the TA location for a certain period of time, but also to find details about each TA.

It is also is possible to obtain a statistical summary based on the police reports about all TA in the selected area.

After analysing the statistical summary and all protocols, following regularities were inferred.

3.2.1 Overview of TA in five years

During the entire period (4.10.11 – 4.10.16) there were 90 TA on the selected intersection (Appendix 3). Most of all accidents (88%) represent the accident with moving road vehicles. Collisions with fixed objects (lighting poles and road signs) were accounted for 7% of TA, 1% – are accidents with participation of pedestrians (as a result of exit on a roadside), the remaining 4% – were other uncatalogued types.

3.2.2 The main causes of TA on the selected intersection

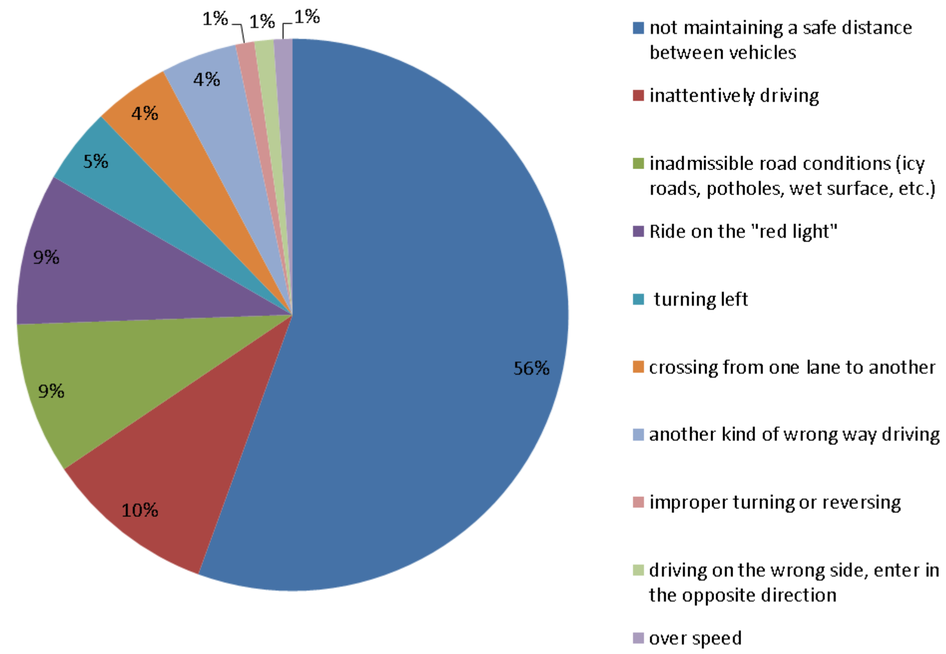

Chart 3 Distribution of accidents according to their causes. Source: Author's work

One of the major reason of TA (56%) – not maintaining a safe distance between vehicles. The largest accumulation of accidents of this type occurs near the traffic lights, which means the drivers did not start to slow down in time. The reason lies in the forced stop at a traffic light and the speed mode of the road (speed up to 70 km/h). During rush hour, a convoy of vehicles standing at a traffic light is increased and consequently the driver has to brake earlier. It may be assumed that drivers do not have enough time to stop.

The following reasons entailed far less TA (from 1 to 9%), nevertheless, each of them are going to be discussed.

Inattentive driving may be a consequence of the abundance of billboards (Figure 13), traffic signs, and therefore missing the most important. Abundance of information from the roadside leads not only to loss of attentiveness of the driver, but it also leads to rapid crossing from one side to another (4% TA for this reason) and improper turning or reversing (1% TA for this reason).

Figure 13 Abundance of billboards - view from the driver's seat on leg A.

Source: Author's photo

The construction of the roadbed and design of the intersection became direct or indirect causes of the TA, as well as weather conditions. Poor quality of the roadway (material, potholes, etc.) may lead to TA. However, only for 2% of all cases poor quality of the roadway leads to one of the conditions related to the accident. But not only this factor has influence on the appearance, the angle of the slope, the presence of water or ice on the road surface change coefficient of friction between the cover and the tire and leads to TA . The vertical alignment of main road is at angle of 3%, it reduces (though only slightly) the frictional force required for braking (Appendix 5).

As for the weather conditions, 13% of the accidents occurred when visibility is limited (due to rain, fog, snow). Figure 14 shows a view on a main road at a foggy night and despite the good illumination, the dimension of the front vehicle is not particularly visible.

Such natural phenomena not only worsen the visibility, but also form ice or water layers depending on the temperature. Precipitation on the road is very dangerous, because it reduces the coefficient of friction. The braking distance in the rain is among two times longer than under normal conditions (Appendix 5).

Figure 14 Night view on the street K Barrandovu (leg C) in the fog (24.01.2017). Source: Author's photo

It is also worth noting such reason as ride on the "red light". This reason is on the level with poor design that is not an isolated case and consequently requires consideration.

In most cases (6 of 8), this type of accident occurred in the afternoon, under normal weather conditions which means that in most cases, the main cause is the human factor (namely incorrect assessment of the duration of a yellow traffic light and the car's own speed).

Over-speeding and other kinds of wrong way driving may also be attributed to human factor.

The accident occurred during the left turn can be explained by disregard for the priority of traffic or incorrect cycle of traffic lights.

Besides the obvious reasons of TA, statistical regularity was also found between the frequency of TA and the time when it occurred. The analysis is performed on hourly intervals throughout the day, day of week and month of the year, when there were TA.

Data were processed using statics method "Box-and-Whisker Plot" (Appendix 6). Results are shown as histograms in the Figure 15, outliers values from range are marked in different colour: red column means that value is over range, yellow – below range.

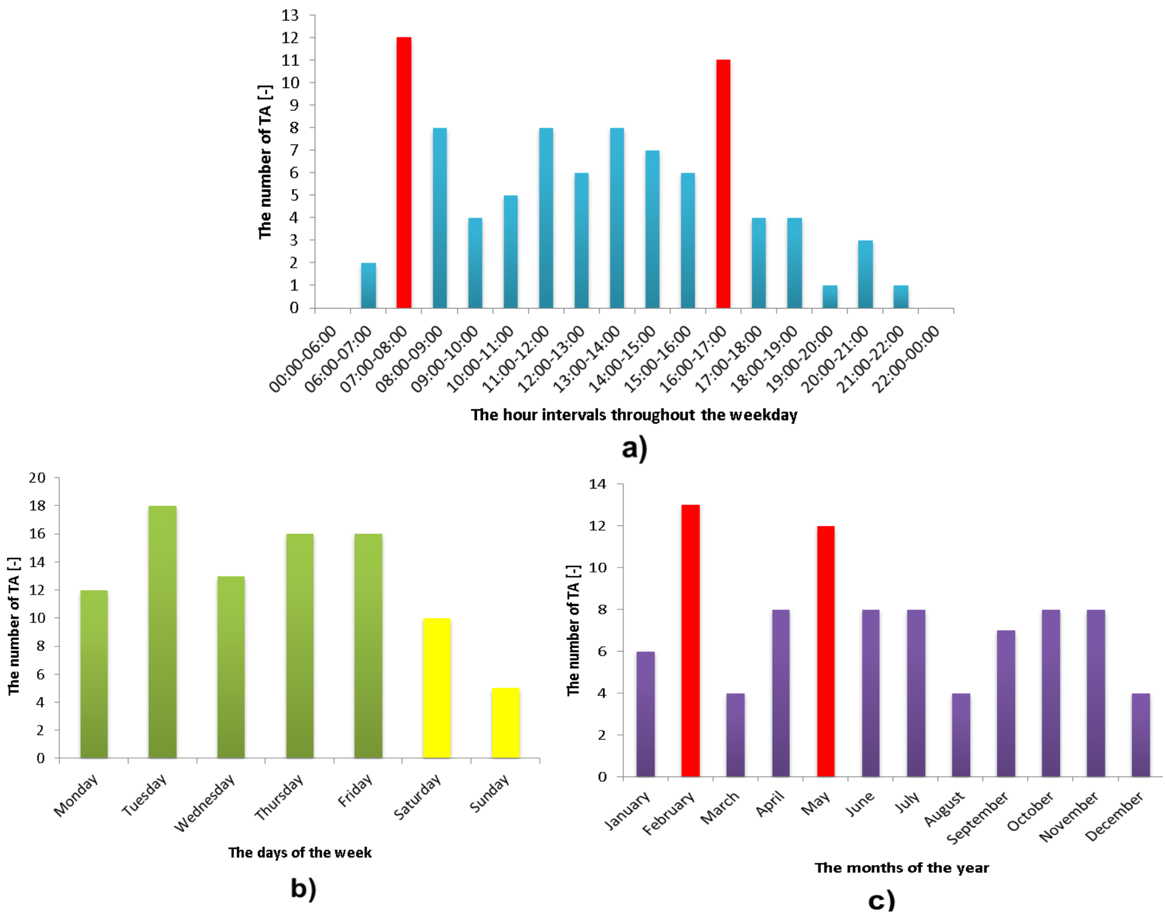

Figure 15 Distribution of the TA according to the incident time:

a)–hour intervals during weekdays; b)-days of week; c)-months of the year.

Source: Author's work

From the histogram, it is clear that the biggest number of accidents occurred in the morning and evening rush hour (7-8 and 16-17 hours), it is explained by the increase in traffic flow when most of inhabitants are going to or from work activity. The presence of such distinct peaks inherent for weekdays.

The distribution of the TA during the week is also related to the traffic flow. From Monday until Friday, the rate of TA does not vary substantially, but on weekends it is less. It can be explained decreasing the traffic flow in general on weekends and uniform flow distribution during the day (no peak hours).

The monthly pattern normally reflects the seasonal variation of the traffic flow. The variation between the traffic flow during the wet season and during the dry season is insignificant but there are two peaks observed because of bad weather conditions in February and in May (about half of all accidents occurred due to wet road surface in these months).

3.3 Determination of traffic intensity

It is essential to know the magnitude of traffic intensity that determines the level of safety of the intersection which is important for further modelling. For this purpose, manual calculation was carried out.

3.3.1 Survey implementation

The survey of hourly traffic flow intensities was conducted on October 4, 2016 (Tuesday) over a period of two hours, between 7 and 8 o'clock in the morning, and between 16 and 17 o'clock in the afternoon on the given intersection. This time was chosen as the time with the highest number of accidents. Distribution of traffic streams into individual directions was performed as shown in Figure 16.

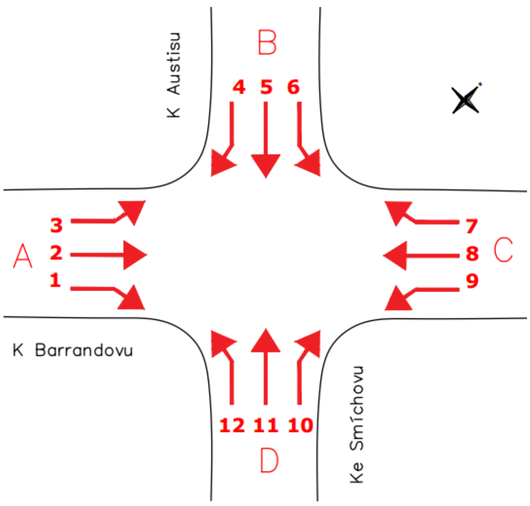

Figure 16 Scheme of arrangement of streams at the intersection.

Source: Author's work

Values that were obtained during the survey and the subsequent processing of these values are given in the Appendix 7. Average annual daily traffic (hereinafter referred to as "AADT") and magnitudes of the 50th highest hour traffic intensity (hereinafter referred to as "TI_{50}") were calculated to each lane.

The results of calculation for all legs according to vehicle type are shown in the Table 2. These values represent quantitative composition of the four incoming flows.

	Type of vehichle	TI_{50} [veh/h]	AADT [veh/day]
A	passenger car	1 270	15 492
	truck	20	249
	bus	0	0
B	passenger car	528	6 428
	truck	0	0
	bus	3	32
C	passenger car	1 339	16 322
	truck	17	211
	bus	3	33
D	passenger car	451	5 498
	truck	0	0
	bus	6	65
Σ		**3 637**	**44 330**

Table 2 The magnitudes of main traffic characteristics for all legs according to the type of vehicle. Source: Author's work

To determine quantitative composition of traffic at any point of intersection the load intensity diagram is used – a graphical representation of flow. The load diagram of I_{50} for different types of vehicles is represented in Appendix 8.

3.3.2 Analysis of intensity from 1990 to 2036

According to my traffic survey, the AADT for whole intersection was calculated for year 2016 (Table 2). Values of ADDT of previous years were taken from the website TSK [31]. This website offers to the public intensity map, from which data were obtained for years 1990, 2000, 2007, 2015. Comparing the measured intensity with values from previous years it is necessary to establish the causality of the formation of TA on the selected intersection. But what is more important is to predict intensity in future. Using TP 255 "Forecast automobile traffic intensity" [3], the intensity for 2036 was calculated (Appendix 9). The results are demonstrated in the Chart 4:

This graph displays growth of ADDT that assumes growth in the number of vehicles. As mentioned earlier, increasing in the number of vehicles (without radical changes in the road infrastructure) leads to increase in accidents. This in turn leads to environmental damage.

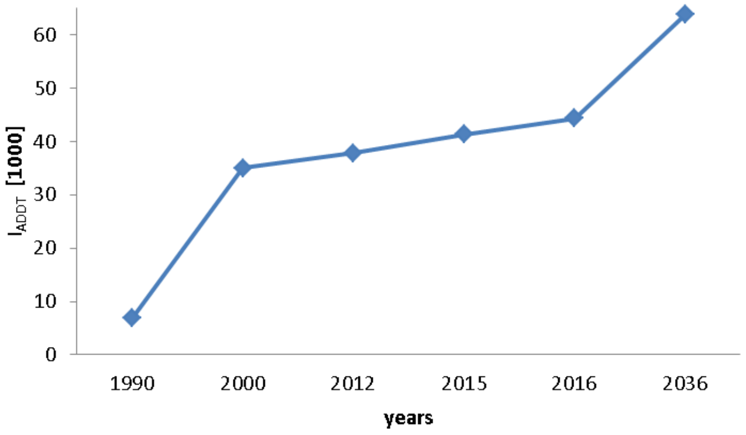

Chart 4 ADDT during the period 1990 -2036. Source: Author's work

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3.4 The evaluation of the intersection on selected criteria

The estimation of the intersection would determine required traffic engineering improvements to decrease the occurrence of TA.

3.4.1 The assessment of traffic quality

The assessment of traffic quality was conducted based on the analysis of motor vehicle capacity of intersection. Using online program EDIP-eL [32] delay time at traffic lights has been determined and respectively the level of traffic quality. The results are shown in the Table 3.

The leg of intersection	The number of a stream	Average residence time [s]	Designation
A	1	10	A
	2	10	A
	3	23	B
B	4	11	A
	5	21	B
	6	20	A
C	7	10	A
	8	3	A
	9	22	B
D	10	11	A
	11	20	A
	12	21	B

Table 3 The traffic quality for all streams of intersection. Source: Author's work

The total level for all legs of intersection is B, which means good level. According to the capacity analysis, this intersection is satisfactory.

3.4.2 The safety assessment

For assessment of road safety, the indicator of relative accident rate is usually used. Calculated values (Table 2) substitute to the formula (3):

$$R = \frac{90}{365 \cdot 44330 \cdot 5} \cdot 10^6 = 1.1$$

Values from 0.1 to 0.9 are normal, respectively 1.1 is a critical value for intersection and means that this intersection is not safe and needs draft measures to improve the situation.

In order to understand how much the indicator changed, a comparison was made with a five-year period before (4.10.2007-4.10.2012).

$$R = \frac{155}{365 \cdot 37800 \cdot 5} \cdot 10^6 = 2.3$$

Due to counted values, it is clear that the number of measures for improving safety have been taken, however, the current state of the junction still remains critical.

3.4.3 The assessment of environmental losses

For five years, 90 accidents happened on the selected intersection, which caused not only material damage but also brought environmental damage. In addition to the indirect effects of TA (the release of greenhouse gases, noise), police reported 4 cases by leaking fluids (oil, coolant). Unfortunately, showing direct loss is not possible, as the police reports do not identify specific type of pollution or the area or the number of its distribution.

For this intersection only indirect losses can be calculated which are connected with human health. Man is a part of the ecosystem and, accordingly, the consequences associated with a person are malicious to the environment. 16 accidents occurred with the effects on human health. As a result of serious injury accidents were with 2 passengers, light injuries – 21.

The following Chart 5 shows total environmental losses that were calculated using formula (1), the number of seriously injured and slightly injured occupants during the period from 2011 till 2016.

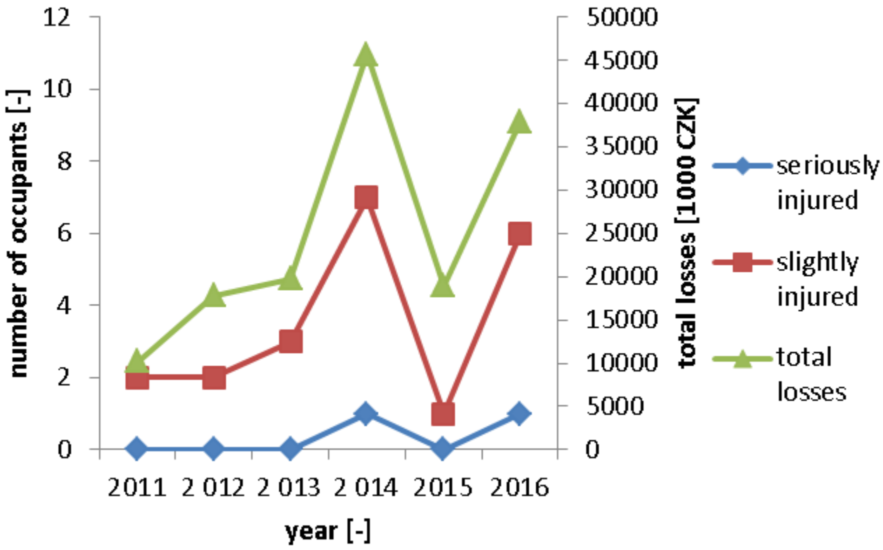

Chart 5 Total losses against the background of seriously and slightly injured.

Source: Author's work

As a result of accidents in more than five years material losses in the amount of CZK 150 470 289 were incurred, for this amount it would be possible to buy solar panels that producing electricity for 1500 houses without any additional cost [33].

4 Modelling of traffic situation in simulation software, proposal of precautions

At present time for the analysis and evaluation of particular section of road the software designed to create simulation of traffic is increasingly used. Creating a transport model can qualitatively and quantitatively assess the impact of the implementation of various development scenarios of the transport systems of cities and regions. Simulation allows to take into account different hypotheses of development of transport systems, and it is quite flexible tool for solving problems of transport planning and traffic management.

One of the leaders in the world among software developers is a German company PTV AG. The software package PTV Vision includes means for creating a macro-level transport models (predictive traffic models), and micro (transport simulation models). The next chapter is devoted to the creation of traffic model using the program PTV Vision VISSIM.

4.1.1 Creation of a traffic model using PTV VISSIM

PTV Vision VISSIM (hereinafter referred to as "VISSIM") is a microscopic, time step oriented, and behaviour-based simulation tool for modelling rural and urban traffic, pedestrian flows. The traffic flow is simulated under various constraints of vehicle composition, lane distribution, and signal control. Vehicles are moving in the network using Wiedemann traffic flow model. The basic concept of this model is that different driver behaviour is taken into consideration with distribution functions of the speed and distance behaviour. This model makes it possible to create realistic traffic flow.

That is why this program has been selected for more detailed research. A stochastic model made in the VISSION will help understand the causes of TA and evaluate safety of intersection.

In order to analyse, traffic model was created not only for the aforementioned intersection but also for the extension of legs B and D (up to 200 m) as well as for the exit onto minor collectors. The description of modelling area is in the Appendix 10.

The geometry of the intersection has been drawn on the basis of maps taken from the website mapy.cz [34]. Cars of different brands were used for 3D models, but for clarity all passenger cars were marked in blue, trucks – green, buses – yellow. The solid models of traffic lights, trees have been used for better visualization.

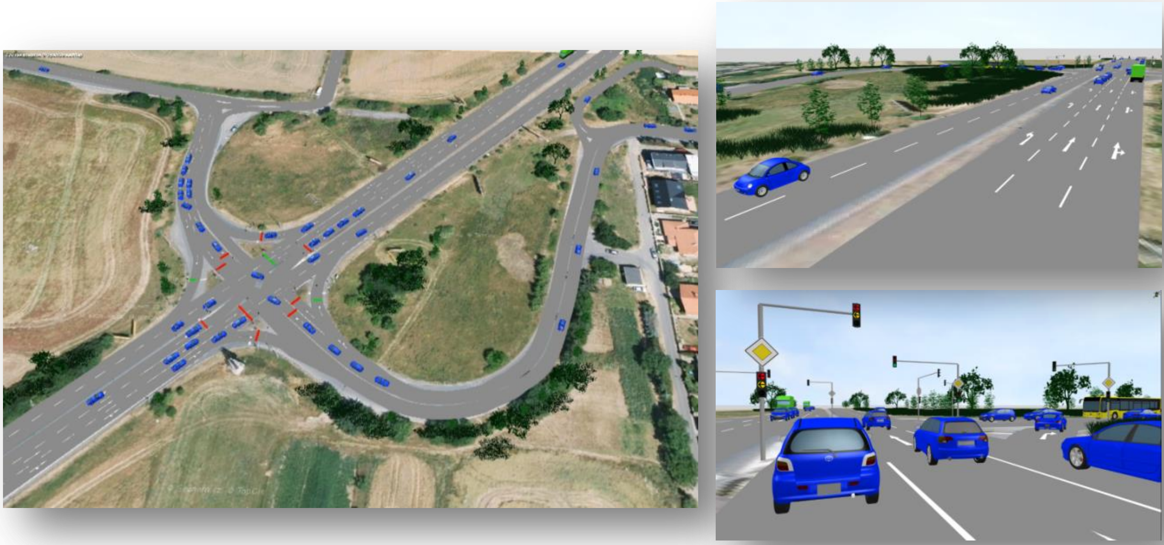

Figure 17 The view on created model (left – aerial view, right – panoramic views). Source: VISSIM

Quantitative and qualitative composition of the incoming streams and their directions of movement were created on the basis of the counted data (Table 2, Appendix 7). In addition to intensity and composition of traffic flow, cycles of traffic lights were also counted from traffic survey and displayed in Figure 18.

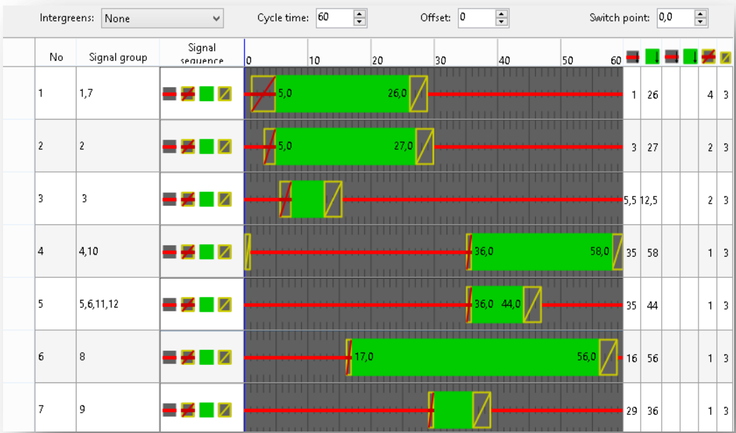

Figure 18 The traffic signal program. Source: VISSIM

4.1.2 Results of output

Wiedemann traffic flow model is an algorithm that most closely (at the moment) transmits the movement of vehicles, since there is practically no exact duplicate of the trajectories of the vehicle. While driving vehicles react to road signs: limitation in speed, driving ban, change light traffic signal. As a result of correct model the critical points are determined. Conflict points are represented in the program in the form of areas, as vehicle dimensions are not neglected. In this case, there are 54 conflict areas.

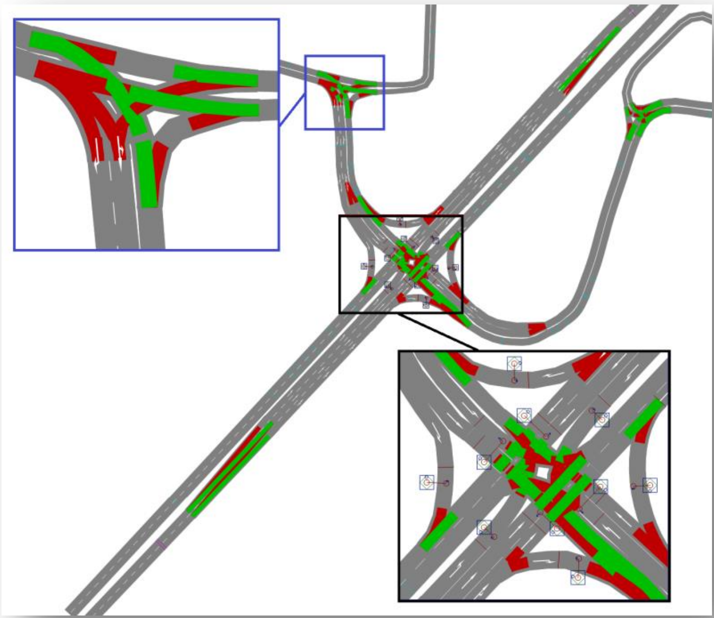

Figure 19 The areas of traffic conflicts[5]. Source: VISSIM

This amount includes not only the conflict area of three intersections (32 for cross-intersection and 9 for intersections with tree legs), but also the conflict zones which occur with a decrease or increase in the number of road lanes (4 areas).

VISSIM not only allows to see the movement of vehicles in "real-time", but also to obtain information about delay time, average speed, average number of stops per vehicle and even emissions (available only in the commercial version).

[5] Red and green lights are governed by priority rules (the green light means advantage in driving)

The leg of intersection	Simulation time [s]	Average delay [s/vehicle]	Average speed [km/h]	Average number of stops [1/vehicle]	Level of quality	
					modeled	calculated
A	12000	4	56	1	A	B
B	12000	27	35	2	B	B
C	12000	6	48	1	A	B
D	12000	52	15	3	D	B

Table 4 Results of vehicle network performance. Source: VISSIM

Table 4 presents a summary of the road model created on the basis of calculated data. It should be noted that the delay time in the model differs from the theoretically calculated as the level of traffic quality. It can be explained by the fact that the motion model is closer to the reality. Also the speed on the legs is not equal to the maximum possible value on the communications. The average vehicle speed is reduced, and the number of stops is increased because of the need to stop at a traffic light, slowdown in curves.

Another advantage of the program is the ability to analyse the trajectory of vehicles. Surrogate safety assessment model and validation (hereinafter referred to as “SSAM”) is add-on software which allows to predict possible collisions and their types on the basis of the trajectories. TA classification is based on the conflict angle (Appendix 11).

	SSAM	JDVM
Unclassified	0	11
Crossing	4	23
Rear-end	25	46
Lane change	12	10
Σ	41	90

Table 5 A comparative table of the actual TA with simulated.

Source: SSAM

Table 5 represents the data according to the type of collision accidents. The table contains data taken from two sources. One source of data is the police reports of TA that occurred, the second – the output of SSAM with the number of possible accidents.

The table shows that the expected number of accidents is almost twice less. This is due to the human factor, 57% of which is not possible to predict (Figure 7).

4.1.3 The decision on carrying out improvements at the intersection

Taking into consideration theoretical calculations of safety indicators, results of TA analysis for the selected period of time, the model created in the VISSIM, a number of safety measures are required.

The intersection “K Barrandovu - K Austisu - Ke Smíchovu” is regulated by traffic lights, markings and road signs comply with the standards, the condition of the roadway is good, the speed limit is available (Figure 12), but still this intersection can be attributed to the number of dangerous. It can be explained by so-called human factor, which cannot be controlled, but it is possible to reduce the number of factors that can directly or indirectly cause an accident. Since there are no complaints about maintenance of this part of the road, and weather conditions cannot be controlled at peak hours of traffic, then what can be done about this is only to make relevant changes in the road design.

Unfortunately, by the end of the year 2016 a pedestrian crossing (Appendix 4) was built at this intersection, which will only increase the accident rate of the site at the discretion of the author, and will lead in addition to the heavy and light injuries and even fatal cases.

It is necessary to change the selected intersection cardinally in design in order to remove the traffic lights because requirement to stop entails majority of TA. Reduced speed and stops lead to accidents due to human factor when the driver is not sensible to estimate the distance between the cars and the braking distance of his vehicle. Also absence of traffic lights will automatically lead to the disappearance of such causes of accidents as a “running red lights". Proper junction will reduce the number of accidents because of changing lanes.

Considered the changes in the structure of the intersection should not be regarded as an independent unit, but as a part of the way, it is necessary to take into account the continuation of minor roads. Inattention, bad weather can lead to losing control by driver and entering the oncoming lane, which happened in 21% of all cases. A similar, but less critical situation is for the continuation of the street Ke Smíchovu. The less number of accidents can be explained by the less traffic intensity (Appendix 7).

In addition, reducing accident rate of the site (removing traffic lights) will reduce damage on the environment. During the change of driving modes (by slowing down to stop and start) two times more fuel is consumed than maintaining the same speed [35]. The increase in fuel consumption entails the increase in the emission of harmful substances into the atmosphere and increases the need for extraction of exhaustible energy resources.

4.1.4 Creating a new geometry of the intersection

The main change of the intersection is the elimination of traffic lights. Since each leg have three lines providing turning left, turning right, and straight ahead, it was decided to change the number of levels (change from single-level to two-level). Also the surrounding area was taken into account. Updates should be cardinal, but with the least possible changes in the landscape.

A classic example of solutions would be the type of half-clover (Appendix 12), but this type of intersection reserves problematic zones BI and DI (Appendix 10), because it does not solve the problem of turning at almost right angles.

Based on the above mentioned requirements, a number of conclusions were made that have been used to change the geometry of the site:

- Create second level from minor roads;
- Reduce the number of lanes for decreasing change-lanes
- Use existing part of road (Appendix 10, numbers 2 and 3)
- Create roundabouts on problematic zones BI and DI.

Following the above parameters, changes have been made, which are shown in Figure 20.

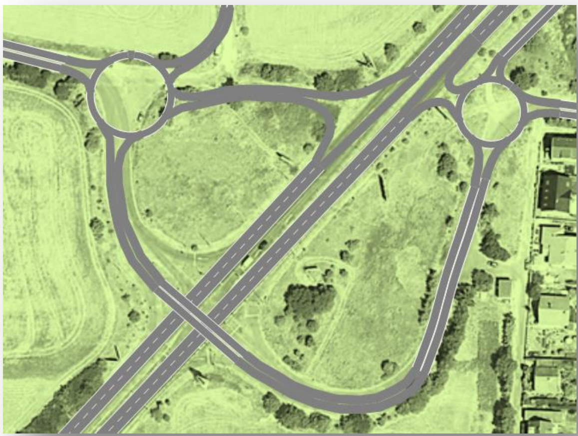

Figure 20 The new design of selected road site. Source: VISSIM

The selected area is shown schematically, without proper signs and markings because the aim was to show that this type of geometry decreases the number of the conflict areas. Carried out changes reduce their number from 54 to 16 (Figure 21).

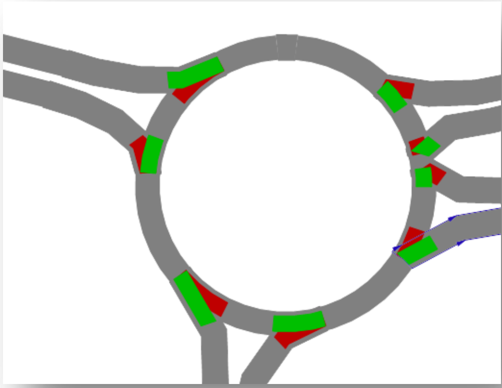

Figure 21 The conflict areas of roundabout in new model of the site.

Source: VISSIM

For confirmation of the reduction the number of accidents for selected site, analysis in SSAM was carried out again. The predicted intensity values for year 2036 (Appendix 9) were used for creation of the traffic model. The verification of this section of the road showed zero number of the expected accidents.

Such results can be explained by lack of the necessary stops (Table 6), increase in capacity due to lengthening of certain lanes.

Simulation time [s]	Average delay [s/vehicle]	Average speed [km/h]	Average number of stops [1/vehicle]
1200	0,5	64	0

Table 6 The output results of analysis after changes in the site.

Source: VISSIM

Assessing the new geometry of the selected section of the network, I can say that the proposed changes reduce the accident rate and, accordingly, the expected environmental damage.

5 Discussion and conclusions

TA as a part of environmental assessment were chosen as a subject of this thesis. The choice of the topic preconditioned by significance of the problem of environmental pollution by transport, in particular, due to the high level of TA.

Literature review, from which theoretical part of this paper starts, covers basic terms within TA topic, particularly types and causes thereof. Besides, method of environmental damage assessment was demonstrated. The importance of analysing the TA that already occurred was also shown to reduce their number in the future, and, accordingly, to reduce the negative impact on the environment. It was also suggested to ensure accidents prevention by implementing the road safety procedures.

Thus, the literature review led to understanding of the objectives of this paper, which consisted in analysing the selected part of the transport infrastructure, and finding out a causal connection between accidents' formation with the current state of the site and proposing design improvement to decrease occurrences of accidents.

The LFTA was chosen for analysis according the statistical data of police reports. The assessment of the selected part of the road infrastructure was carried out using three types of database. One source was JDVM application - data about TA already occurred, the second was my traffic survey for determination of traffic intensity and the level of traffic quality, the third one – is reflection of results of the created model in PTV VISSIM.

As a result of the analysis it was found that despite the good level of traffic quality of the chosen intersection, the value of the indicator of relative accident rate exceeds the norm, which means that this part of the road needs a number of changes. Considering the fact that at this precise moment the intersection is already regulated by traffic lights, the markings and road signs available in the required quantity and quality, it was decided to change the geometry of the intersection.

The geometrical changes were proposed with due account not only for safety, but also for minimal changes in the adjacent territories. The obtained model was tested using the data calculated for 2036 in the PTV VISSIM program. The results showed no possible TA. In reality, this value can be changed under influence of human factor that cannot be calculated.

The results of the analysis of the model with changed geometry can be considered as fulfilment of the tasks set afore. However, in addition to the main objective, I intended to show on a concrete example that a large number of TA are due to the influence of human factor. And in spite of the fact that it is impossible to remove it completely, one can reduce its influence by introducing multilevel intersections. The absence of intersections of roads with quite high intensity at one level will lead to significant decrease in TA, and as a result this will reduce the negative impact on the environment.

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Appendix 1 Typology of traffic accidents

All TA may be divided into main groups [2]:

- main group 0 – individual accidents;
- main group 1 – TA between vehicles in the same direction beyond the area of intersection;
- main group 2 – TA between vehicles in the opposite direction beyond the area of intersection;
- main group 3 – TA in the area of intersection during turning, reversing, rear impact in the direction of the same leg;
- main group 4 – TA in the area of intersection during turning, reversing, rear impact in the direction of the opposite legs;
- main group 5 – TA in the area of intersection during turning of vehicles when they enter from the adjacent leg or exit from the leg;
- main group 6 – TA involving pedestrians;
- main group 7 – TA with standing or parked vehicles;
- main group 8 – TA with wild animals and rail transport;
- main group 9 – other TA.

Appendix 2 TA during one year (1.01.14-1.01.15). Source: [30]

General overview of accidents in a given location		
The total number of TA		23
The number of accidents with consequences for the health		5
The number of accidents with killed	●	0
The number of accidents with severe injuries	●	1
The number of accidents with slight injuries	○	4

Appendix 3 TA during five years (4.10.11-4.10.16). Source: [30]

General overview of accidents in a given location	
The total number of TA	90
The number of accidents with consequences for the health	16
The number of accidents with killed	0
The number of accidents with severe injuries	2
The number of accidents with slight injuries	21

Appendix 4 Existing state of the intersection (20.02.2017). Source: Author's work

View from the leg A to the legs B and C

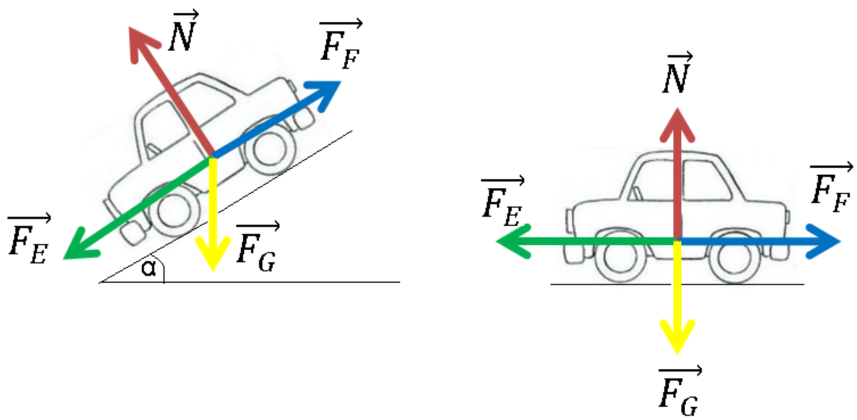
View from the leg B to the legs C and D

View from the leg C to the legs A and B

View from the leg D

Appendix 5 Changes in friction force according the road slope and braking distance

I. To compare friction force for two same cars, one moving on the road with 3% slope of the main road, another one with 0% slope.



α_1=11° - angle of 3% slope of the main street

α_2=0° - angle of 0% slope

F_{F1} – friction force of the first car that moves on 3% slope

F_{F2} - friction force of the second car that moves on 3% slope

$m_1 = m_2 = m$ - the same mass for both cars

$\mu -$ coefficient of friction is the same

$\frac{F_{F1}}{F_{F2}}$ - ?

$$\vec{F_G} + \vec{N} = \vec{0}, \vec{F_E} + \vec{F_F} = \vec{0}.$$

$$F_G \cdot cos\alpha - N = 0, F_E + F_G \cdot sin\alpha - F_F = 0.$$

$$F_G = m \cdot g,$$

$$N = m \cdot g \cdot cos\alpha,$$

$$F_F = \mu \cdot N,$$

$$F_F = \mu \cdot m \cdot g \cdot cos\alpha$$

$$\frac{F_{F1}}{F_{F2}} = \frac{\mu \cdot m \cdot g \cdot cos\alpha_1}{\mu \cdot m \cdot g \cdot cos\alpha_2} = \frac{cos\alpha_1}{cos\alpha_2}$$

$$\frac{F_{F1}}{F_{F2}} = \frac{cos(11°)}{cos(0°)} = 0.98$$

Conclusion: the friction force for 3% slope of the road is 2% less.

II. To compare the braking distance in normal weather conditions and during rain or snow.

$\mu_1 = 0.4$ – the coefficient of friction for wet road surface

$\mu_2 = 0.7$- the coefficient of friction for normal weather conditions

$\mu_3 = 0.15$ – the coefficient of friction for iced road surface

S_x- the braking distance for different weather conditions

v – the speed of the vehicle

$\frac{S_1}{S_2} - ?\ \frac{S_3}{S_2} -?$

Formula of braking distance for passenger car:

$$S = \frac{v^2}{254 \cdot \mu}$$

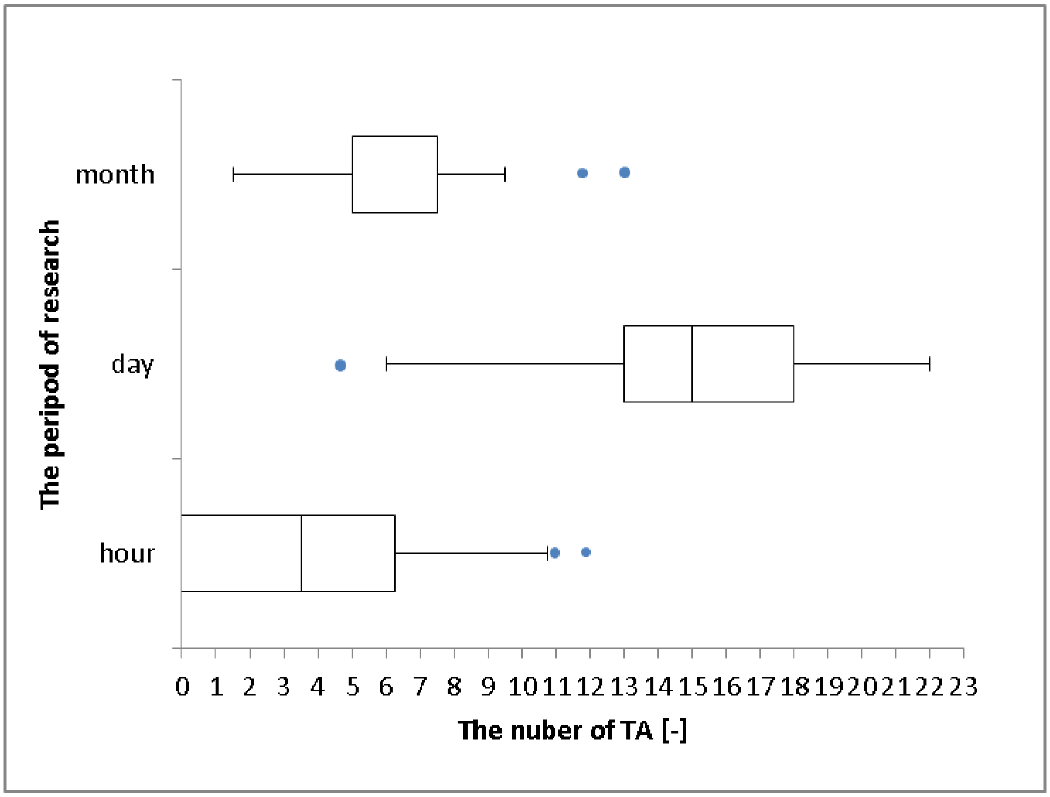
$$\frac{S_1}{S_2} = \frac{v^2}{254 \cdot \mu_1} \cdot \frac{254 \cdot \mu_2}{v^2} = \frac{\mu_2}{\mu_1}$$

$$\frac{S_1}{S_2} = \frac{0.7}{0.4} = 1.75$$

$$\frac{S_3}{S_2} = \frac{0.7}{0.15} = 4.7$$

Conclusion: the braking distance for wet surface is approximately 2 times longer than in normal conditions. For road surface with ice – 5 times longer.

Appendix 6 Statics method "Box-and-Whisker Plot". Source: [36]



Appendix 7 Processing of the measured data and calculation ADDT and TI_{50}

Technical condition number 189 is used to determine the intensity of the road transports [2] (next only TP 189). According to this methodology, traffic volume characteristics are calculated by the following formulas:

$$\mathrm{AADT} = \mathrm{TI_s} \cdot \mathrm{c_t} \cdot \mathrm{c_{s,d}} \cdot \mathrm{c_{d,w}} \cdot \mathrm{c_{w,ADDT}}$$

Where:

AADT – average annual daily traffic [vehicle/day];

$\mathrm{TI_s}$ – traffic intensity counted during the survey [vehicle/time of survey];

$\mathrm{c_t}$ – conversion factor according to the type of vehicles [-];

$\mathrm{c_{s,d}}$ – conversion coefficient of traffic intensity at the time of the survey on a daily traffic flow of the survey and was found from the tables [-];

$\mathrm{c_{d,w}}$ – conversion coefficient of daily traffic intensity at the time of the survey on a weekly average of daily traffic volumes was found from the tables [-];

$\mathrm{c_{w,ADDT}}$ – conversion coefficient of weekly average of daily traffic volumes on the annual average daily traffic volumes was found from the tables [-].

The coefficients for vehicles that are used in the work:

- for passenger $\mathrm{c_t} = 1$;
- for trucks and buses $\mathrm{c_t} = 1.5$.

$$\mathrm{TI_{50}} = \mathrm{AADT} \cdot \mathrm{c_{50}}$$

Where:

$\mathrm{TI_{50}} -$ the 50th highest hourly of traffic intensity value [vehicle/hour]

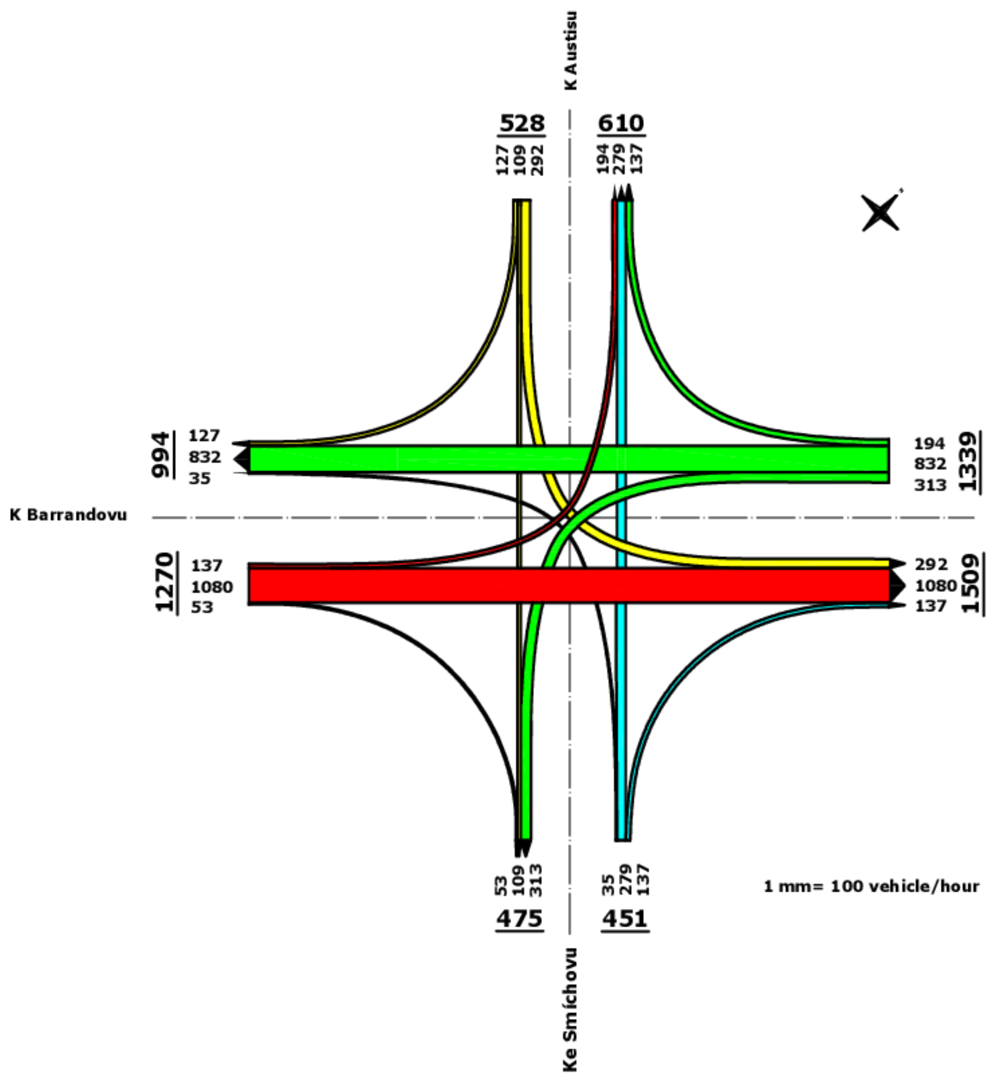
$\mathrm{c_{50}} -$ conversion coefficient peak hour of traffic intensity on a regular day at 50 hourly traffic volume [-]

AADT and TI_{50} were calculated for all streams using data from traffic survey and are shown below

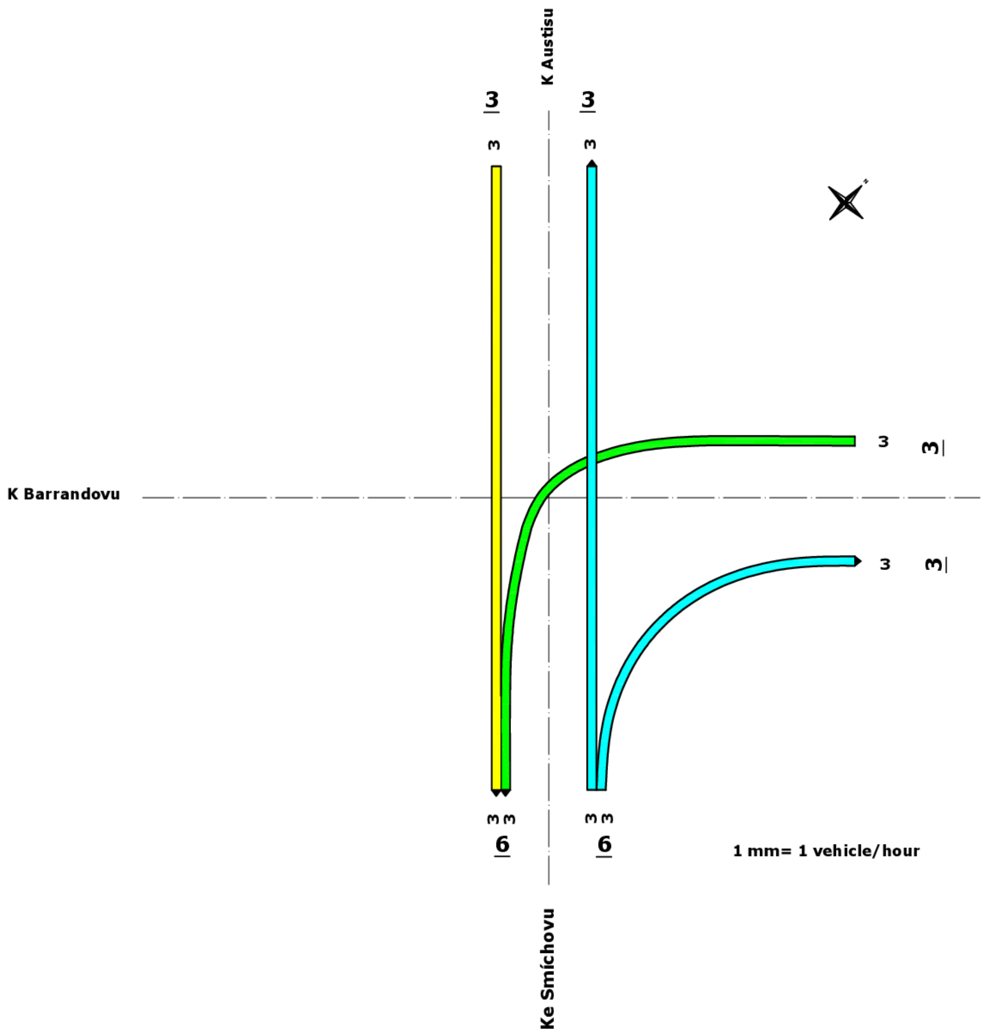
Location:	K Barrandovu-K Austisu-Ke Smíchovu 50°01'09.4"N 14°20'51.5"E				Date: 04.10.2016 Time: 7:00-8:00,16:00-17:00					
The leg of intersection	The number of a stream	Type of vehicle	TI_s [veh]	$c_{s,d}$ [-]	$c_{d,w}$ [-]	$c_{w,ADDT}$ [-]	**AADT [veh/day]**	δ [%]	c_{50} [-]	**TI_{50} [veh/h]**
A	**1**	*passenger car*	87	7,55	0,99	1,00	**651**		0,08	**53**
		truck	0	8,42	0,81	0,81	**0**		0,08	**0**
		bus	0	8,12	0,89	1,11	**0**		0,08	**0**
		Σ					**651**	± 20		**53**
	2	*passenger car*	1 760	7,55	0,99	1,00	**13 165**		0,08	**1 080**
		truck	45	8,42	0,81	0,81	**249**		0,08	**20**
		bus	0	8,12	0,89	1,11	**0**		0,08	**0**
		Σ					**13 414**	± 20		**1 100**
	3	*passenger car*	224	7,55	0,99	1,00	**1 676**		0,08	**137**
		truck	0	8,42	0,81	0,81	**0**		0,08	**0**
		bus	0	8,12	0,89	1,11	**0**		0,08	**0**
		Σ					**1 681**	± 20		**137**
B	**4**	*passenger car*	254	7,23	0,93	0,90	**1 543**		0,08	**127**
		truck	0	8,15	0,84	0,83	**0**		0,08	**0**
		bus	0	8,12	0,89	1,11	**0**		0,08	**0**
		Σ					**1 543**	± 20		**127**
	5	*passenger car*	218	7,23	0,93	0,90	**1 325**		0,08	**109**
		truck	0	8,15	0,84	0,83	**0**		0,08	**0**
		bus	4	8,12	0,89	1,11	**32**		0,08	**3**
		Σ					**1 357**	± 20		**112**
	6	*passenger car*	586	7,23	0,93	0,90	**3 560**		0,08	**292**
		truck	0	8,15	0,84	0,83	**0**		0,08	**0**
		bus	0	8,12	0,89	1,11	**0**		0,08	**0**
		Σ					**3 560**	± 20		**292**
C	**7**	*passenger car*	316	7,55	0,99	1,00	**2 364**		0,08	**194**
		truck	3	8,42	0,81	0,81	**17**		0,08	**1**
		bus	0	8,12	0,89	1,11	**0**		0,08	**0**
		Σ					**2 381**	± 20		**195**
	8	*passenger car*	1 356	7,55	0,99	1,00	**10 143**		0,08	**832**
		truck	35	8,42	0,81	0,81	**194**		0,08	**16**
		bus	0	8,12	0,89	1,11	**0**		0,08	**0**
		Σ					**10 337**	± 20		**848**
	9	*passenger car*	510	7,55	0,99	1,00	**3 815**		0,08	**313**
		truck	0	8,42	0,81	0,81	**0**		0,08	**0**
		bus	4	8,12	0,89	1,11	**33**		0,08	**3**
		Σ					**3 848**	± 20		**316**
D	**10**	*passenger car*	70	7,23	0,93	0,90	**425**		0,08	**35**
		truck	0	8,15	0,84	0,83	**0**		0,08	**0**
		bus	4	8,12	0,89	1,11	**32**		0,08	**3**
		Σ					**457**	± 20		**38**
	11	*passenger car*	560	7,23	0,93	0,90	**3 402**		0,08	**279**
		truck	0	8,15	0,84	0,83	**0**		0,08	**0**
		bus	4	8,12	0,89	1,11	**33**		0,08	**3**
		Σ					**3 435**	± 20		**282**
	12	*passenger car*	275	7,23	0,93	0,90	**1 671**		0,08	**137**
		truck	0	8,15	0,84	0,83	**0**		0,08	**0**
		bus	0	8,12	0,89	1,11	**0**		0,08	**0**
		Σ					**1 671**	± 20		**137**

Appendix 8 Graphic representation of TI_{50} for different types of vehicles

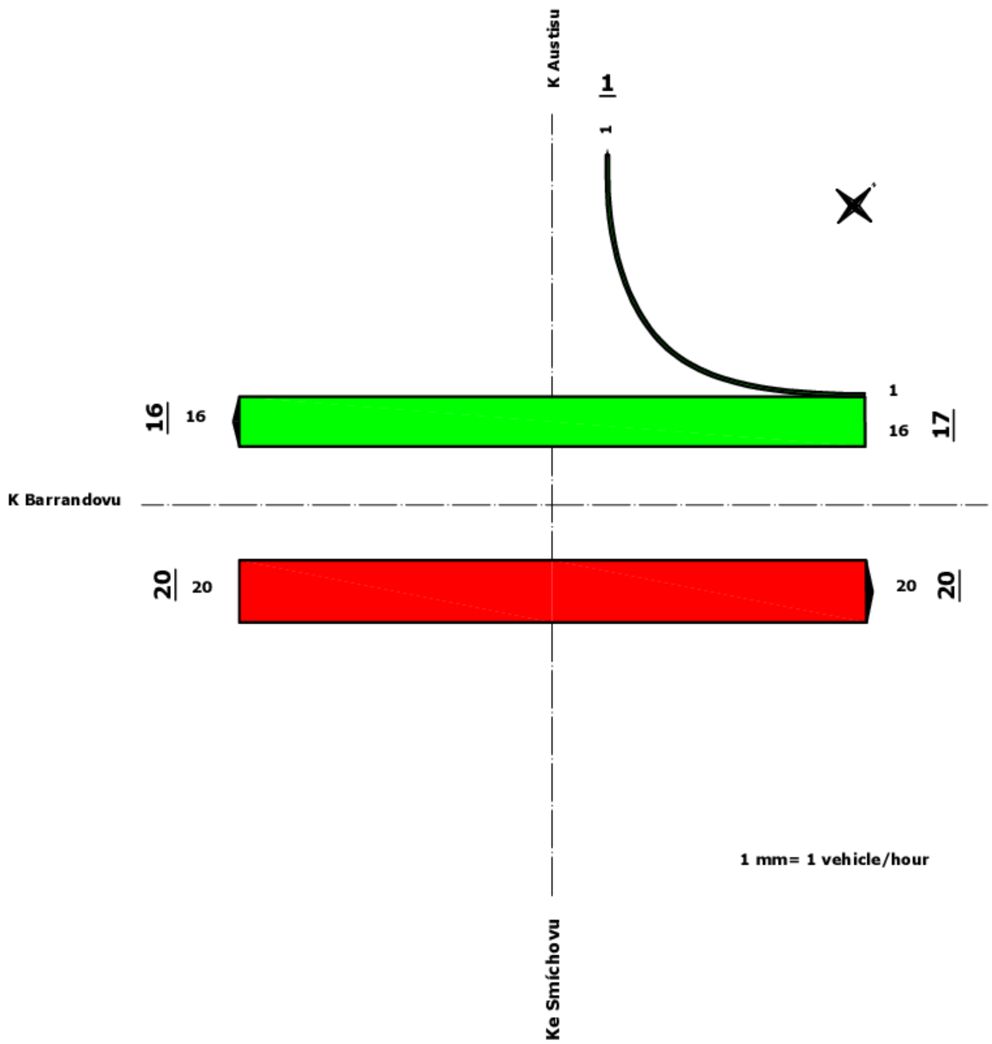
TI_{50} for passenger cars



TI_{50} for buses



TI_{50} for trucks



Appendix 9 Traffic Growth Prediction for 2036

Using TP 255 ”Forecast automobile traffic intensity” [3] the intensity for 2036 was calculated. The forecast intensity is calculated by uniform growth factor.

The leg of intersection	The number of a stream	Type of vehichle	TI_{50} [veh/h]	AADT [veh/day]	c_{2016} [-]	c_{2036} [-]	**TI_g [veh/h]**	**$AADT_g$ [veh/day]**
A	1	*passenger car*	53	651	1,11	1,56	**75**	**915**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	0	0,0	1,01	1,05	**0**	**0**
	2	*passenger car*	1 080	13 165	1,11	1,56	**1 518**	**18 503**
		truck	20	249,0	1,01	1,05	**21**	**259**
		bus	0	0,0	1,01	1,05	**0**	**0**
	3	*passenger car*	137	1 676	1,11	1,56	**193**	**2 356**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	0	0,0	1,01	1,05	**0**	**0**
B	4	*passenger car*	127	1 543	1,11	1,56	**179**	**2 169**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	0	0,0	1,01	1,05	**0**	**0**
	5	*passenger car*	109	1 325	1,11	1,56	**153**	**1 863**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	3	32,0	1,01	1,05	**3**	**34**
	6	*passenger car*	292	3 560	1,11	1,56	**410**	**5 004**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	0	0,0	1,01	1,05	**0**	**0**
C	7	*passenger car*	194	2 364	1,11	1,56	**273**	**3 323**
		truck	1	17,0	1,01	1,05	**1**	**18**
		bus	0	0,0	1,01	1,05	**0**	**0**
	8	*passenger car*	832	10 143	1,11	1,56	**1 169**	**14 256**
		truck	16	194,0	1,01	1,05	**17**	**202**
		bus	0	0,0	1,01	1,05	**0**	**0**
	9	*passenger car*	313	3 815	1,11	1,56	**440**	**5 362**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	3	33,0	1,01	1,05	**3**	**35**
D	10	*passenger car*	35	425	1,11	1,56	**49**	**598**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	3	32,0	1,01	1,05	**3**	**34**
	11	*passenger car*	279	3 402	1,11	1,56	**392**	**4 782**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	3	33,0	1,01	1,05	**3**	**35**
	12	*passenger car*	137	1 671	1,11	1,56	**193**	**2 349**
		truck	0	0,0	1,01	1,05	**0**	**0**
		bus	0	0,0	1,01	1,05	**0**	**0**
Σ			3 637	44 330	1,10	1,49	4 927	60 047

For calculation was used following formula:

$$TI_g(AADT_g) = TI_{50}(AADT) \cdot \frac{c_{2036}}{c_{2016}}$$

Where:

TI_g – growth prediction of traffic intensity for 2036 [veh/day]

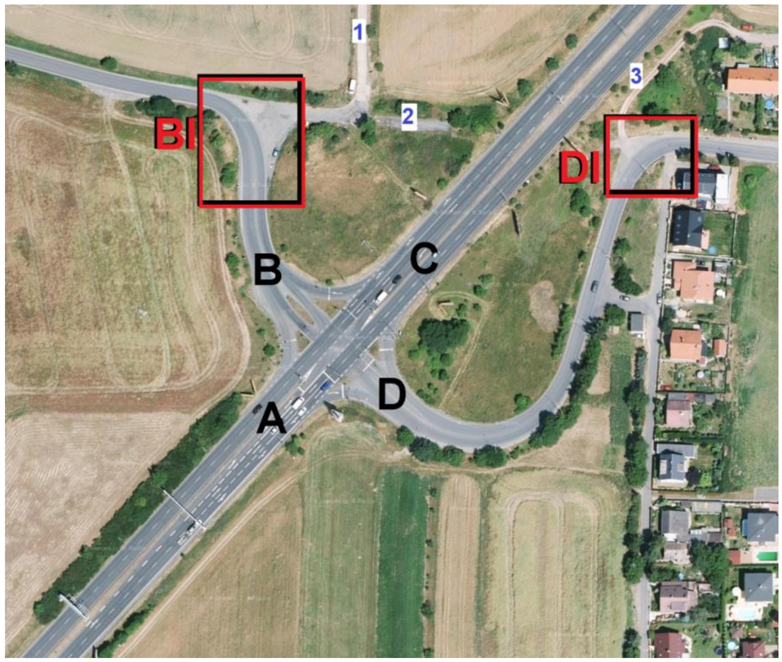
TI_{50} – the 50th highest hourly of traffic intensity value in 2016 [veh/day]

c_{2036} – coefficient of transport development for the 2036 year [–]

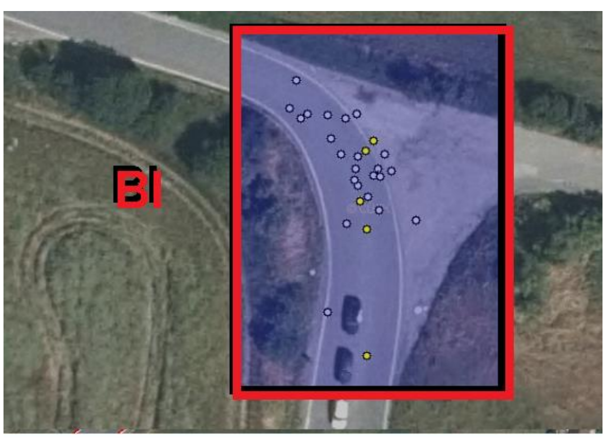
c_{2016} – coefficient of transport development for the 2016 year [–]

Using this formula, predicted intensities and AADI for all streams were calculated.

Appendix 10 Modelling area with designation of sections (A-D – legs of the intersection, BI and DI – critical zones,1-3 – parts of the road)



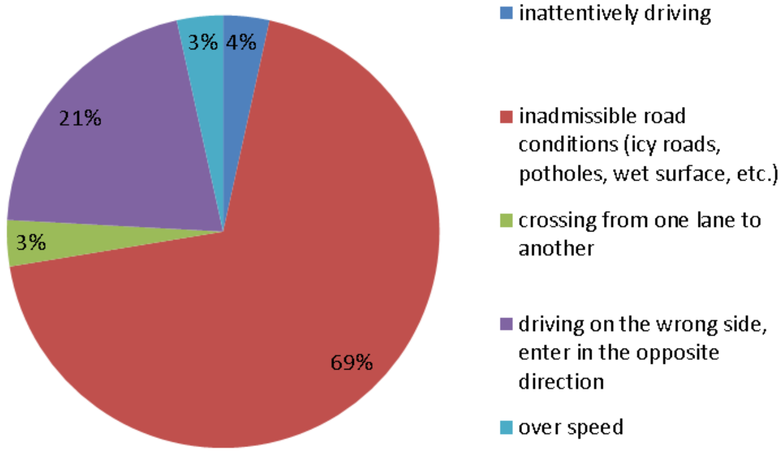
Zones BI and DI are not LFTA, nevertheless, a number of accidents were recorded. The statistics from JDVM [27] during the period 04.10.2011-04.10.2016 are shown below:



General overview of accidents in a given location	
The total number of TA	29
The number of accidents with consequences for the health	5
The number of accidents with killed ●	0
The number of accidents with severe injuries ●	0
The number of accidents with slight injuries ○	10

General overview of accidents in a given location	
The total number of TA	2
The number of accidents with consequences for the health	0
The number of accidents with killed ●	0
The number of accidents with severe injuries ●	0
The number of accidents with slight injuries ○	0

The causes of TA in zone BI are distributed as follows:



The causes of TA in zone DI0 are distributed as follows:

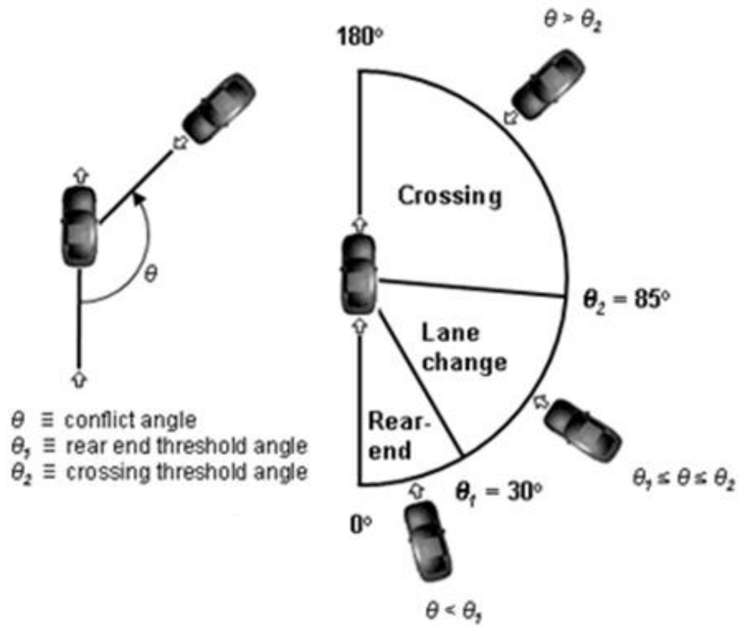
1 occupied because of bad weather conditions, 1 because of not maintaining a safe distance between vehicles.

Appendix 11 Conflict angle. Source: SSAM

The angle of the conflict is calculated for each pair of conflicting vehicles, based on the angle at which these vehicles converge to a hypothetical point of collision. The conflict angle is used for classification as follows:

- Unclassified: Conflict angle unknown or not a TA of moving vehicles.
- Crossing: || conflict angle || > 85 °.
- Rear-end: || conflict angle || < 30 °.
- Lane-change: 30 ° ≤ || conflict angle || ≤ 85 ° [37].

Threshold angle diagram is shown below:



Appendix 12 An example of half-clover intersection. Source: [34]