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Cycling transport safety quantification

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Abstract. Dynamic interest in cycling transport brings the necessity to design safety cycling infrastructure. In las few years, couple of norms with safety elements have been designed and suggested for the cycling infrastructure. But these were not fully examined. The main parameter of suitable and fully functional transport infrastructure is the evaluation of its safety. Common evaluation of transport infrastructure safety is based on accident statistics. These statistics are suitable for motor vehicle transport but unsuitable for the cycling transport. Cycling infrastructure evaluation of safety is suitable for the traffic conflicts monitoring. The results of this method are fast, based on real traffic situations and can be applied on any traffic situations.

1. Safety of cycling transport

The trend in the last years shows clearly the growth of cycling transport popularity.
People discover the advantages and uniqueness of this kind of transport again.
The return to the cycling transport is realized because of several reasons. The main reason is the users are aware of the advantage of bicycle as a mean of transport within the public transport.
The increase of the bicycle users as a mean of transport brings the necessity of building a cycling infrastructure. The valid legislative and the development of integrational elements for cyclists may not adequately react to the tempo of cycling transport development. The integrational elements for cyclists in the main transport flow are the most frequent ways, how to support the bicycle users.
The development of integrational elements for the cyclists is the long-term issue which brings many difficulties. Very often, the solution that appears as suitable at the first sight may bring the decrease of cyclists safety later on. Certain element can work under specific circumstances only and it cannot be automatically and without consideration brought to other projects.
The main target of cycling transport infrastructure suggestions is the safety. The safety is the relative term, not easy to grasp. Every participant has his subjective sense of safety within the public transport and its ways. The subjective feeling influences the decision of users, when deciding which mean of transport to use and also the behaviour in it.
The objective view on the public transport safety is throughout the statistical data. These statistical data of accident rate have its clear values and are able to evaluate the safety, too.
The evaluation of cycling transport safety with the help of statistical data about the accident rate has its deficiencies. The deficiencies can lead to the completely wrong interpretation of these data.

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The common statistics about the accident rate does not consider the size and quality of constructed cycling infrastructure, which is, according to the safety, crucial. Furthermore, the share of the transport labour division on the cycling infrastructure, is not considered. We call it a modal split.
According to this, it is essential, to create the safety evaluation methodology for the cycling transport, which will consider its web, the cyclists share on the total transport labour and which will evaluate the safety in real time.

2. Safety in numbers hypothesis

Safety in numbers is a hypothesis based on the idea, that if the individual is part of a big group, it is less probable, that he/she will be part of an accident, will be killed or will die due to the heart attack. Some relevant theories bring the argument, that if the individual is part of some big group, his/her behaviour is more predictable and there are less accidents.
Safety numbers hypothesis can be well applied on the cycling transport safety. Long-term researches show, that the bigger the transport labour share on the total share of transport is, the lower is the accidental rate of cyclists. It is remarkable, that the increased interest in the cycling transport "takes out" the users from the other transport types. The number of potential conflicts with motorised as well as pedestrian transport decreases.
Last but not least important fact (considering the safety of cycling transport) is that with the increased interested in cycling transport, the investments expended on building of cycling infrastructure and cycling transport itself, grow as well.

2.1. Accident rate of cycling transport in selected EU countries

Safety in Numbers methodology was used to determine accident rate of cyclists, with the modal split consideration in selected EU countries.
In the Table 1, there is a number of cyclists killed in the given year, according to selected EU countries and linked to the modal split. It is obvious, that the bigger the share of cycling transport on the total labour of transport is, the lower is the accident rate of cyclists. According to the following data, we can see that the accident rate in Netherlands is approximately 6 times lower than in United Kingdom.

Table 1. The number of cyclists killed in year per 1 million inhabitants in EU countries with a link to modal split of cycling transport, converted to 1 percent modal split [1]

Country	The number of cyclists killed in year per 1 million inhabitants a link to modal split of cycling transport			
	Modal split	2007	2008	2009
Netherlands	27	0,3	0,3	0,3
Denmark	18	0,5	0,5	0,3
Finland	11	0,4	0,3	0,3
Sweden	10	0,4	0,3	0,2
Germany	10	0,5	0,6	0,6
Belgium	8	1,0	1,0	1,0
Switzerland	6	-	0,6	1,1
Austria	5	0,9	1,5	0,9
France	3	0,7	0,8	0,8
Italy	3	2,0	1,6	1,7
Ireland	2	1,7	0,8	1,4
UK	1	2,2	1,9	1,7

The Table 2 shows the number of cyclists killed per one million inhabitants. In 2009, in Netherlands, there were 8.4 killed cyclists per 1 million inhabitants. Technically the same amount of killed per 1 million inhabitants was in Belgium 2009. The difference is in the fact, that in Netherland there is a 3 times bigger share of cycling transport on the total labour share of transport.

Table 2. The number of cyclists killed in year per 1 million inhabitants in EU countries [2]

Country	The number of cyclists killed in year per 1 million inhabitants			
	Modal split	2007	2008	2009
Netherlands	27	8,9	8,8	8,4
Denmark	18	9,8	9,8	4,5
Finland	11	4,1	3,4	3,8
Sweden	10	3,6	3,2	2,2
Germany	10	5,2	5,6	5,6
Belgium	8	8,4	8,0	8,3
Switzerland	6	-	3,4	6,7
Austria	5	4,4	7,4	4,7
France	3	2,2	2,3	2,5
Italy	3	5,9	4,8	5,0
Ireland	2	3,3	1,5	2,9
UK	1	2,2	1,9	1,7

Fig. 1 shows the distribution of the number of killed cyclists according to number of inhabitants and modal split of cycling transport. It is clear, that the bigger the share of cycling transport on the total transport labour share is, the lower the accident rate.

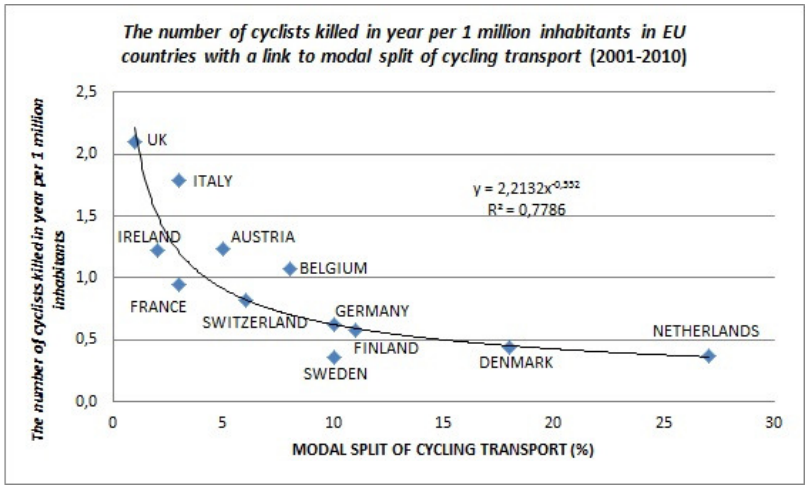

Figure 1. The number of cyclists killed in year per 1 million inhabitants in EU countries with a link to modal split of cycling transport

2.2. Accidental rate of cycling transport in the Czech republic in comparison with the other EU countries

For the methodology proposal of the cycling safety evaluation, which is being prepared in the Czech rep., is necessary to determinate current safety rates. This will be the initial for the evaluation itself. It is necessary to determine the quantification value for the evaluation of individual types (kinds) of cycling infrastructure or individual sections of communication.

To bluntly identify the position of the Czech rep. in the Fig. 1 is not easy because of the missing data about the share of cycling transport on the total transport labour. Providing that Czech rep. will have similar statistics as for example UK, Austria or France.

There were three basic premises to determinate the position of Czech rep. in Fig. 2 of cycling safety with the help of Safety in Numbers hypothesis: the share of cycling transport on the total transport labour is 2 %, 3 % or 4 %. We can gain an approximate image, what is the position of the Czech rep. (according to cycling safety) in the EU is. The logical result would be the position with the high value of accident rates.

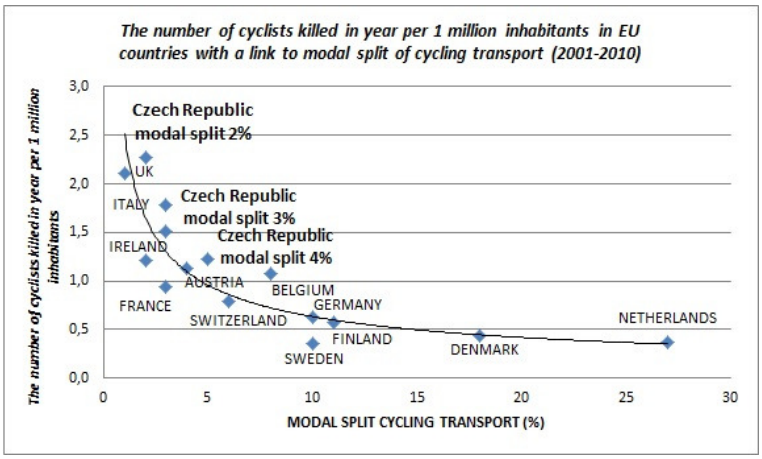

Figure 2. Anticipated ranking of the Czech rep. in the frame of Safety in numbers evaluation, according to the various shares of total transport labour.

Fig. 3 shows number of killed cyclists per 100 million kilometer. For further calculations is used number of killed cyclists per number of inhabitants.

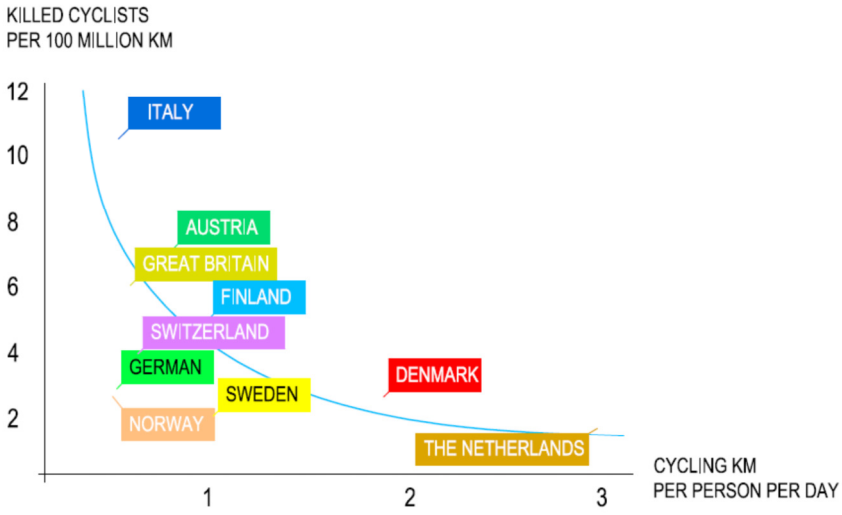

Figure 3. Killed cyclists per 100 million kilometer [1]

3. Evaluation of cycling transport safety

Evaluation of cycling transport safety with the help of monitoring methodology and evaluation of transport conflicts has unquestionable advantage in gaining the results very quickly (it is not necessary to wait for the accidents). The next unquestionable advantage is ability to monitor the real situations (conflicts) and their evaluation in real time. This can easily ang quickly affectivity of newly created integrational elements, designed for the cyclists, to increase their safety.

The next unquestionable advantage is its punctuality and the range of monitored conflicts. The statistics of accidents record only the accidents, according to the legislative of the given country. Many accidents do not appear in the statistics at all. There are relatively few accidents and thus they do not have high statistical value. What more, the statistical data react with the years delay until the data are collected to the statistical file.

With the monitoring of transport conflicts ("almost accidents") it is easy to gain much better and bigger statistical file in a split of time in comparison with current accident statistics. Thanks to this method, the cause is solved, not the result. This can be applied directly to the suggested transport safety infrastructure.

3.1. Methodology of monitoring and transport conflicts evaluation

Monitoring methodology and evaluation of transport conflict is the basic output of project "Conflict", project of public competition "Support of applied research and experimental development of ALFA", released by Technological agency of Czech republic [3].

Traditional attitude for the safety on way evaluation is monitoring of quantitative and qualitative characteristics of individual accidents. This attitude is very demanding from the financial and time-consuming point of view.

The less method used in the Czech republics is the monitoring of transport conflicts. This method monitors and evaluates individual conflict situations in given transport section.

The conflict situation is the situation very close to the accident (almost accident, but is diverted in time by i.e. changing of speed, stopping, changing the direction and so on.

The advantage is that the conflict situations are almost instantly available (after the video is recorded and analysed, it is not necessary to wait for the accident itself. The next advantage is that conflict situations without an accident are more frequent than the accident itself. Thus it is possible to grasp the more dangerous situations and locations with the help of transport research.

After the measure for the safety improvement is applied it is possible to obtain the data immediately and it is possible to analyse the individual measure. Fig. 4 shows safety pyramid, which is used in Monitoring methodology and evaluation of transport.

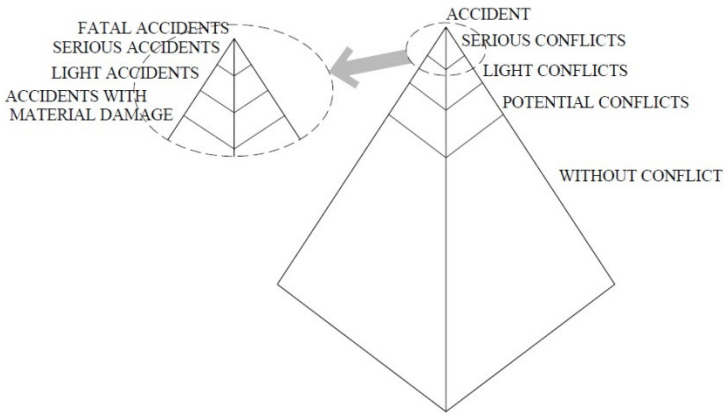

Figure 4. Safety Pyramid [4]

The conflicts are divided into five basic grades according to rules violation and jink. The conflict is defined as the situation, when the move has to changed and/or the speed of vehicle. These are two possible maneuvers to avoid the collision.
Grade "0" represents the rules violation, but with no further effects. The behaviour can have negative influence on safety (for example turning/stopping at crossing/ no respect to STOP sigh, red signal and so on). The rules are in grade "0" violated without any effect, which means there is no need of a jink or sudden speed change.
Grade "1" represents the rules violation with the reserve to handle the jink. In example it is bypassing the vehicle by the pedestrians or controlled decrease of speed of a vehicle coming to the crossing via the major road.
Grade "2" represents sudden reactions which lead to unexpected maneuvers. For example it is sudden avoidance to a vehicle.
Grade "3" represents abrupt reactions which lead to unexpected maneuvers as to try to avoid the collision in last moment.
Grade "4" represents conflict with collision (clash) result.
The seriousness is not defined by the guilt of the element which is responsible. It is the rate of the damage no matter who is guilty.

3.2. Safety in numbers hypothesis – basic safety determination

To determine the basic safety of cycling transport the Safety in Numbers hypothesis is used. On basis of the statistical file of accidents the basic rate of safety will be determined in given country. The rate of safety will be gained by the calculation of accidents followed by death.
The individual grades of accidents seriousness will be multiplied by the frequency rate coefficient according to frequency of individual accident types.
This will show the basic safety rate will be obtained. This will be initial value to be able to consider the safety, according to the monitoring of transport conflict methodology. The basic rate of safety can be determined not only for the state or country but also for the city/town or even for the given section.

4. Methodology of monitoring and evaluation of cycling transport conflicts

Methodology of monitoring and evaluation of cycling transport conflict must evaluate the behaviour of cyclists, drivers of vehicles and analyse their mutual affect.
Grade "0" represents the rules violation, but with no further effects. The rules were violated only slightly, which means the cyclists do not ride in ideal track or the car (vehicle) rides in the cycling safety lane. The next grade "1" represents the rules violation with no further effects, but the cyclist rides outside of his safety lane or dedicated location and/or the vehicle driver rides in the space dedicated for cyclists. Grade "2" represents the situation when the rule is violated. Result is the easily mastered maneuver. The next grade "3" represents the rule violation which results in sharp maneuver. The next step "4" represents the rules violation which results in sharp maneuver and avoiding the conflict in last moment. The last grade "5" represents the conflict resulting in collision.
It is expected that majority of transport conflicts will be defined as grades "0" to "2". Following assumption is, that majority of all conflicts will be defined as grade "0".
According to the recorded conflicts it is possible to obtain frequency rate/distribution of individual conflict grades. It is possible to set an assumption about how many conflicts and transitions of motor vehicles are there before the grade "5" conflict. The grade "5" conflict represents the traffic accident which ends up in material damage, health aftermaths – conflict is recorded via the Safety in Numbers hypothesis.

5. Example of using

Within the preparation of evaluation methodology of cycling transport, the transport researches were carried out. These were evaluated with the help of transport conflict methodology. As an example of cycling transport solution, two measurements gained in town "Hradec Kralove" were used.

5.1. Input data

Hradec Kralove is a very important regional city with almost 100 thousand inhabitants. Thanks to its geographical location and morphology, bike is a very popular mean of transport. Modal split is more than 16%. Hradec Kralove has a very good, nevertheless not finished, transport infrastructure network. In the city, there is a combination of elements in associated but also in the main transport space. These are frequently used. Table 3 shows number of accidents in the time period 1. 1. 2017 – 31. 10. 2015. Accidents are divided in to number of accidents, number of deaths, serious injuries and slight injuries.

Table 3. Cyclists accident frequency in the time period 1. 1. 2007 – 31. 10. 2015 in chosen cities [5]

City					
	Modal split	Accidents total	Deaths	Serious injuries	Slight injuries
Olomouc	6,2	391	2	18	312
Hradec Kralove	16,2	262	3	26	161
Ceske Budejovice	11,3	321	0	18	270
Pardubice	18,3	443	4	27	373
Opava	10,6	273	4	31	211
Frydek-Mistek	4,1	99	1	14	64
Prerov	14,7	150	0	27	100
Mlada Boleslav	4,2	83	0	16	55
Prostejov	22,8	167	1	17	124
Trinec	5,8	98	2	8	77

5.2. Safety in Numbers (SiN)

In Hradec Kralove has happened 262 accidents in almost 9 years. In the statistics, there are 3 accidents resulted in deaths, 26 accidents resulted in serious injuries and 161 accidents resulted in slight injuries. If we compare these data with Ceske Budejovice (city with modal split of transport cycling over 11%), we find that, in Ceske Budejovice, there are 22% more traffic accidents. Modal split is approx. 5% lower than in Hradec Kralove.

$$SiN\ (Hradec\ Kralove) = \frac{\frac{262}{94{,}242}}{16{,}2} = 0{,}17$$

$$SiN\ (Ceske\ Budejovice) = \frac{\frac{321}{93{,}883}}{11{,}3} = 0{,}30$$

$$SiN\ = \frac{\frac{Number\ of\ Accidents}{Number\ of\ Inhabitans}}{Modal\ Split}$$

This calculation can be specified with the help of statistical data in time period. It is necessary to consider use of the data about the share of cycling transport on the total transport labour share. The value Safety in Numbers is not fixed, it changes, depending on the size of statistical file. It is necessary to work with the same time period as the file is the same for all locations.

In Fig. 5, we can notice, that Hradec Kralove, with the result 0.17, ranks among the safest cities in given Modal Split. For approx. 16% Modal Split is the value of Safety in Number round 0.24.

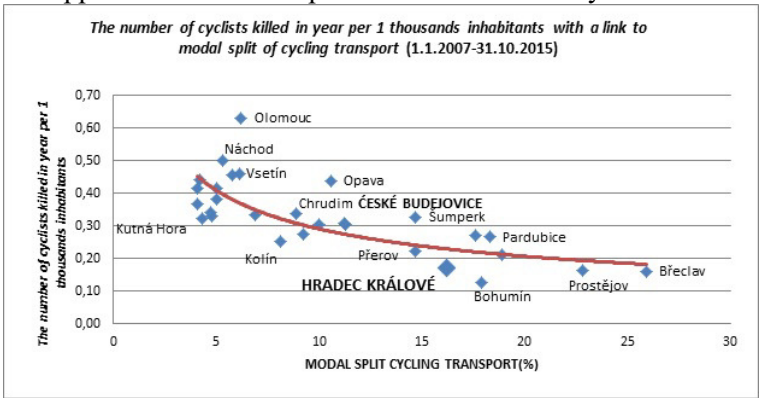

Figure 5. The number of cyclists killed in year per 1 thousands inhabitants with a link to modal split of cycling transport (1.1.2007-31.10.2015)

5.3. Monitoring methodology and traffic conflicts evaluation

Within the traffic research in Hradec Kralove, more than 11 hours in 12 sections had been recorded. In 11 hours period, there were 228 situations of mutual influence between cyclists and motor vehicles drivers. Cyclists violated the rules in 48 cases, without consequences (it means grade "0" and "1"). Motor vehicle drivers violated the rules in 19 cases in "0" and "1" grade. Out of the 228 situations, there were 67 cases of rules violations (grade "0" and "1"). During the research, 301 cyclists and 6795 motor vehicles transited the location. There were 683 situations without mutual influence between cyclists and motor vehicle drivers (grade "0" and "1"). According to the results it is evident, that 1/3 of cyclists do not ride in ideal track, or even they ride outside of reserved space. In case of motor vehicle drivers, the ratio is 1/10. These are indications, which can lead to grade "5" conflicts.

The traffic accident with the cyclist happens in Hradec Kralove once a 14 days. Modal Split considers the maximal length of cycling transport track 12km. Measured sections had recorded length of 0.1km. The total transport labour in Hradec Kralove is 23500 inhabitants, while 3800 are cyclists. Measured data represent approx.. 8% of cyclists, which participate on total transport labour share. During one day, there are 1250 cases of grade "0" and "1" caused by cyclists, with no motor vehicle interaction, 840 cases of rules violations (grade "0" and "1") caused by cyclists and motor vehicle drivers with their mutual influence.

We can expect that the grade "5" occur once in two weeks (according to statistical data). In 14 days, 17500 cases of grade "0" and "1" occur (rules violation by cyclists) and 11760 grades "1" and "0" (rules violations of cyclists and motor vehicle drives with their mutual influence). We can assume that the one traffic accident will happen out of 17500 cases, respectively 11760 according to traffic conflicts monitoring and evaluation methodology. 17500 grades (type "1" and "0") represent more than 53200 cyclists´ traffic routes. The cyclists´ traffic route is considered in Modal Split not more than 12km. Within the calculation, the average route length considered is 7km. One traffic accident of a cyclist happens after every 372400 kilometres rode. This represents the whole results for Hradec Kralove. Now, these results should be compared with the measured values on specific route profile.

5.4. Use of results

Within the bounds of methodology preparation, suitable for the cycling safety transport evaluation, individual elements of cycling infrastructure will be compared with various road profiles. Road parameters are: width of main traffic corridor, width of traffic lane and intensity of cycling, as well as motor vehicles´ infrastructure. According to these data, it will be possible to design cycling infrastructure of maximal safety.

6. Conclusion

As previously mentioned, the main and the most important essence of transport infrastructure proposal is the proposal of safety transport. Transport infrastructure is suggested according to norms, methodology and experience. With its specifications, cycling transport exceeds the common idea of transport infrastructure designs. It is due to its fast development and especially due to new elements for cyclists, growing share on the total transport labour and due to mutual influence of cyclists and motor vehicle drivers.

Cyclists´ safety evaluation with the help of traffic conflicts methodology can predict the accident rate which results in injury or death in real time. It is also able to analyse the safety of newly designed elements for cyclists and is also able to check their efficiency in a very short period of time.

On the grounds of accident rate and its data inputs, it is possible to design and suggest the most suitable and safest elements for cyclists, already in the stage of project preparation.

Within the creation of traffic conflicts methodology, the local sections of infrastructure had been observed. These were of various width of main transport corridor, intensity of motor vehicles and type of cycling infrastructure.

Methodology will be published in year 2018 within dissertation work, written by Jiri Drbohlav, student of postgraduate programme on Czech Technical University in Prague, Faculty of Civil Engineering.

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