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ANALYSIS OF CONFLICT SITUATIONS IN ROAD TRAFFIC ON ROUNDABOUTS

ABSTRACT

The wrong behaviour of road traffic participants is a permanently discussed issue in many countries with advanced road transport. Such behaviour does not always result in traffic accident, but only in restriction or danger to the culprit or other participants. For monitoring the behavioural problems it is possible to apply the video-analysis of the conflict situations. The methodology of the conflict situations monitoring with the video-apparatus application is described in the paper presented. There are also results of the conflict situations analysis on the selected roundabouts in the Czech Republic. The paper refers to the suitability of the conflict situations video-analysis application not only for monitoring the wrong behaviour of drivers and other road traffic participants, but also for monitoring the inappropriately designed building elements (this hypothesis has been confirmed by the results of research, which are shown in this paper).

KEY WORDS

road transport, conflict situation, roundabout, video-apparatus

1. INTRODUCTION

Road transport brings many advantages to human society, but unfortunately numerous problems as well. One of the major problems in road traffic is often dubious, arguable, doubtful or otherwise problematic behaviour of the road traffic participants. Such behaviour can eventually cause a traffic accident and it is questionable whether this accident could or could not be averted. The accident may be caused partly by the driver's or other traffic participant's inattention and partly by the "wrong" infrastructure (for example inappropriately designed road, intersection, pedestrian crossing, etc.) causing wrong driver's behaviour and other subsequent problems, i.e. a conflict situation or a traffic accident.

The traffic accident statistics provides a certain overview of numbers and causes of traffic accidents. The statistics of conflict situations is logically non-existent and therefore, if necessary, one should carry out their own observation of the road participants' behaviour on the monitored place in real traffic.

And how is the term "Conflict Situation" defined? It is a moment or a situation in road traffic in which a higher than usual degree of risk [1] arises or can arise for some traffic participants. A conflict situation naturally precedes each traffic accident. On the contrary it can be stated that each traffic accident is a result of such conflict situation when the risk of collision was impossible to be averted. Thus, conflict situations are potential accident situations and their types then predetermine the types of traffic accidents.

It is evident that conflict situations usually arise at the place of collision points. However, it is necessary to realize that conflict situations can be caused by the influence of some hidden factors (e.g. operating, building, meteorological ones, etc.). These hidden factors can be discovered by the analysis of conflict situations. In other words, the transport construction designer can never regard their transport solution as absolutely safe and suitable [1]. *Using the analysis of conflict situations the doubts about their harmlessness can be avoided.*

Pursuant to the conflict situations analysis the designer can draw conclusions about the degree of danger of the monitored place and then perform relevant precautions for the increase of safety [1]. With this analysis it is possible to take precautions for the reduction of dangerousness before an accident occurred.

The use of video-apparatus is a very good contribution to the conflict situations analysis. The monitored conflict situation can be evaluated collectively and primarily repeatedly or in slow motion. This paper describes the methodology which has been used by the staff of the Department of Transport Constructions (Faculty of Civil Engineering, VSB – Technical University of Ostrava, the Czech Republic) for monitoring of the behaviour of participants involved in road traffic. Furthermore, the text provides the most important results of road traffic surveys on the selected roundabouts in the Czech Republic which have been conducted within the research project [2]. The task of this project was partly to define the conclusions for the design of roundabouts on the basis of comparison of roundabout geometry and relative accident frequency [3] and partly to verify the applicability of video-analysis of conflict situations for the evaluation of inappropriately designed building elements on roundabouts. This hypothesis was certified.

2. VIDEO-ANALYSIS OF CONFLICT SITUATIONS

Monitoring of the conflict situations through application of the video-apparatus was introduced in the Czech Republic by the associate professor Jan Folprecht, Ph.D. in the 1970s. In 1998 the author of this paper started to co-operate closely with the associate professor Folprecht and they were developing the methodology of conflict situations video-analysis together. At present, the author of this paper and his other colleagues keep utilizing and developing this method within the professional activity of the Department of Transport Constructions (VSB – Technical University of Ostrava, Faculty of Civil Engineering). It is impossible to describe the whole methodology in this paper, so the text below is limited only to essential facts [1, 4] (see also *Figure 1*).

First, it is necessary to get a video record of the selected locality where the road traffic should be analyzed (situated on the highest observation point, if possible). It is also useful to use an audio record, i.e. verbal comments that can help in orientation during analyzing the video record (it is possible to make remarks about the situation in road traffic out of camera record for example). A statistically evidential complex of conflict situations can be obtained as early as on the basis of a one-hour video record. The video record has to be evaluated by more people at the same time. On the one hand, the evaluation itself is sped up and on the other hand, the results are more objective than in case of monitoring carried out by one person only.

The main advantage of the video analysis consists in the possibility to stop, slow down or replay the video record. Last but not least, it is advantageous that all data recorded can be retrospectively supported (for control, repeated or more precise analysis). From the video recording it is furthermore possible to obtain other road traffic characteristics of the place monitored, e.g. volume and structure of traffic flow etc.

Each conflict situation is marked by a symbol exactly describing the given situation – see *Figure 2*.

The first part of the symbol (see *Figure 2* – the 1st mark) marks the participant or participants of the conflict situation, for example:
- 1..... pedestrian,
- 2..... vehicle,

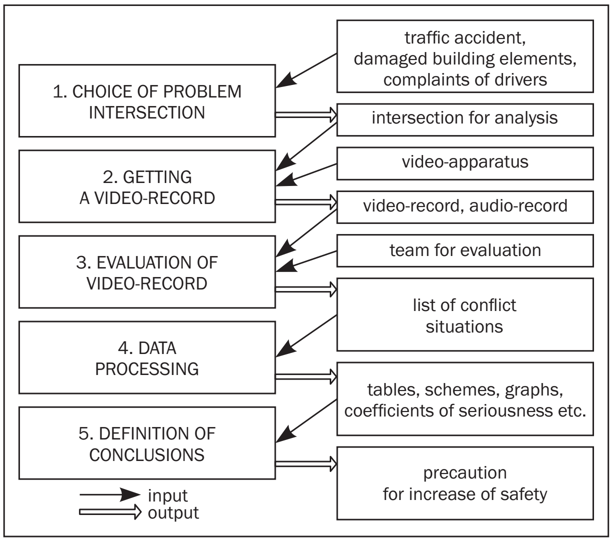

Figure 1 - Procedure of video analysis of conflict situations on intersections

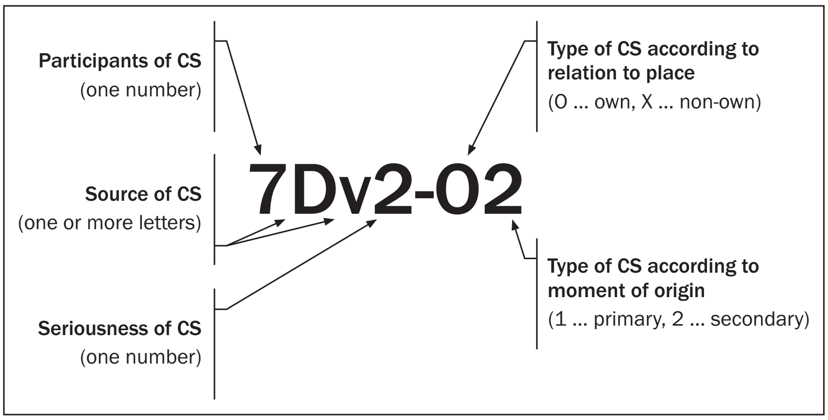

Figure 2 - The symbol for the conflict situation marking (CS) [3, 4]

- 3..... tram,
- 4..... pedestrian x vehicle,
- 5..... pedestrian x tram,
- 6..... vehicle x vehicle,
- 7..... vehicle x tram,
- 8..... tram x tram,
- 9..... another participant.

The second part of the symbol (see *Figure 2* – the 2nd and 3rd mark) marks the source of conflict situation, for example:

- c ..... cyclist's fault,
- D .... danger of rear-end collision,
- f_k .... influence of near intersection,
- f_p .... influence of pedestrian crossing,
- g..... giving priority against rule,
- j ...... wrong way of driving (generally),
- j_o..... wrong way of driving (very near the curb),
- n..... violation of rule "yield to ...",
- o..... restriction or danger in driving during change of the lane or during exiting the roundabout,
- r...... motorcyclist's fault,
- v ..... driver's fault.

The above-mentioned marks are followed by marking of seriousness of the conflict situation (see *Figure 2* – the 4th mark):

- 1..... 1st level – potential conflict situations (mere breaking of road traffic rules by a single participant),
- 2..... 2nd level – conflict situations when one or more participants are restricted by another participant,
- 3..... 3rd level – conflict situations when one or more participants are endangered by another participant,
- 4..... 4th level – traffic accident.

According to the relation to the place of origin the conflict situations are divided as follows: (see *Figure 2* – the 5th mark):

- "own" conflict situation – a conflict situation which is related to traffic on the monitored place (roundabout etc.), its structural arrangement, etc.,
- "non-own" conflict situation – a conflict situation which is influenced by other conflict situation in the vicinity and which is not related to the monitored place (for example, influence of near intersection).

Numerous situations were of such an extent that they caused other conflict situations (often different ones) that would not have normally happened. For this reason it was necessary to divide the conflict situations as follows (see *Figure 2* – the 6th mark):

- "primary" conflict situation – a conflict situation which is not caused by other conflict situation,
- "secondary" conflict situation – a conflict situation which is caused by other conflict situation (usually by primary or another secondary conflict situation).

The conflict situations observed are then drawn into the ground plan of the monitored place (see e.g. *Figure 3*). In this way the places of their accumulation as well as their causes are very well elucidated. Then, it is also possible to deduce a method of possible measures to avert these conflict situations. On the basis of mere assessment of these results the designer of transport constructions is able to carry out a responsible design for modification of the monitored place with the aim of improving the traffic safety.

As a magnitude giving a certain picture on the traffic danger rate on the place monitored it is possible to apply the so-called coefficient of relative conflict rate showing the number of conflict situations per 100 vehicles (or 100 pedestrians). The relative conflict rate coefficient c_R is determined as follows [1]:

$$c_R = \frac{N_{CS}}{V} \cdot 100 \qquad (1)$$

where:

c_R – relative conflict rate coefficient [CS/100 veh],

N_{CS} – number of conflict situations (CS) per hour [CS/h],

V – hourly traffic volume [veh/h].

In this simple way it is possible to determine the relative conflict rate coefficient not only for a whole monitored place but also for a certain type of the conflict situation. The comparison of these coefficients from different places implies the traffic danger rate of these localities in question.

However, the above-mentioned relation does not take into consideration the seriousness of the conflict situations. Thus, it is more practical to use the so-called weighted coefficient of the relative conflict rate c_{RW}. The equation for concrete type of the conflict situation has the form as follows [6]:

$$c_{RW} = \frac{N_{CS} \cdot C_S}{V} \cdot 100 \qquad (2)$$

where:

C_S – coefficient of seriousness of conflict situations [-], i.e. for example:

- for seriousness of conflict situations of the 1st level ... $C_S = 1$,
- for seriousness of conflict situations of the 2nd level ... $C_S = 3$,
- for seriousness of conflict situations of the 3rd level ... $C_S = 6$.

The equation for all conflict situations has the form as follows [6]:

$$c_{RW} = \frac{\sum_{i=1}^{n} N_{CSi} \cdot C_{Sj}}{V} \cdot 100 = \frac{N_{CS1} \cdot C_{Sj} + N_{CS2} \cdot C_{Sj} + \ldots + N_{CSn} \cdot C_{Sj}}{V} \cdot 100 \qquad (3)$$

where:

- *i* – number of conflict situations of the same type ($i = 1, 2, \ldots, n$),
- *j* – seriousness of conflict situations ($j = 1$ or 2 or 3), $C_{S1} = 1$, $C_{S2} = 3$, $C_{S3} = 6$ – see above.

3. CONFLICT SITUATIONS OBSERVED ON ROUNDABOUTS

Sixteen selected roundabouts in the Czech Republic were monitored under the research project of the Ministry of Transport "The Influence of Structural Elements Geometry on the Safety and Fluency of Operation in Roundabouts and Possibility of Rise

Table 1 - The list of conflict situations (CS) – N_{CS} [CS/h]; V [veh/h]; c_R [CS/100 veh]

No.	Town / Number of legs/lanes on circulating roadway	V / c_R (total)	CS:	6n2, 6n3	6g2	$4f_p2$	$6f_k2$	6D3 (6D4)	9jc1, 9jc2, 9jc3	$2j_o1$	6o2, 6o3
1	Novy Jicin	1,547	N_{CS}	5	2	4	6	1	3		
	4/1	0.96	c_R	0.32	0.13	0.26	0.40	0.06	0.19		
2	Novy Jicin	1,506	N_{CS}		1	21		3	5		
	3/1	2.13	c_R		0.07	1.39		0.20	0.33		
3	Novy Jicin	1,630	N_{CS}	3		16		1	14		
	4/1	1.59	c_R	0.18		0.98		0.06	0.86		
4	Novy Jicin	1,926	N_{CS}	8	2	42		4	1		
	4/1	3.74	c_R	0.42	0.10	2.18		0.21	0.05		
5	Novy Jicin	1,094	N_{CS}	6	1	14		3	7		
	4/1	2.91	c_R	0.55	0.09	1.28		0.27	0.64		
6	Valasske Mezirici	1,290	N_{CS}			1	5			23	
	3/1	2.41	c_R			0.08	0.39			1.78	
7	Valasske Mezirici	1,648	N_{CS}	10	2				3		
	4/1	0.90	c_R	0.60	0.12				0.18		
8	Valasske Mezirici	2,141	N_{CS}	17	2	5			2		
	4/1	1.16	c_R	0.79	0.09	0.23			0.10		
9	Valasske Mezirici	1,942	N_{CS}	16	7	12		2	15		
	4/1	2.30	c_R	0.83	0.36	0.62		0.10	0.77		
10	Valasske Mezirici	2,115	N_{CS}	12	5	45			5		
	4/1	3.13	c_R	0.56	0.24	2.13			0.25		
11	Havirov	3,747	N_{CS}	10	19	1		1 (6D4)			11
	6/2	1.89	c_R	0.27	0.51	0.03		0.03			0.30
12	Havirov	1,648	N_{CS}	4	11	4	14		1		
	4/1	2.18	c_R	0.24	0.67	0.24	0.85		0.06		
13	Frydek-Mistek	2,762	N_{CS}	12				1			16
	4/2	1.05	c_R	0.43				0.04			0.58
14	Ostrava	1,590	N_{CS}	1	3	26	10		2		
	4/1	4.97	c_R	0.06	0.19	1.64	0.63		0.12		
15	Kolin	2,722	N_{CS}	28	10	23		4	5		
	5/1	3.19	c_R	1.03	0.37	0.84		0.15	0.18		
16	Praha (Prague)	2,884	N_{CS}	6							2
	4/2	0.55	c_R	0.21							0.07

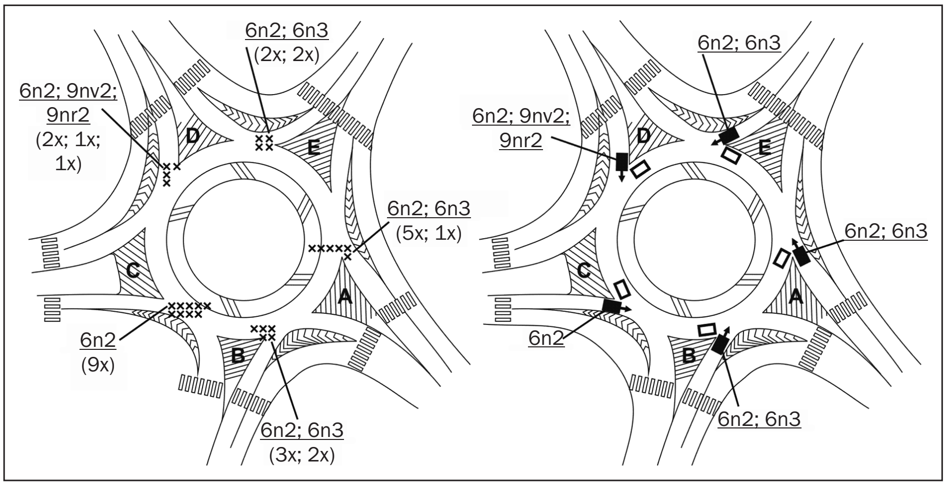

Figure 3 - Scheme of conflict situations 6n2 and 6n3 (roundabout No. 15 – see Table 1); the black vehicle caused the conflict

Crashes Prediction" [2]. Three roundabouts were double-lane circulating roadways (all others were of single-lane only). Most of the monitored roundabouts had four legs, with the exception of two which had three legs, one roundabout had five legs and one had six legs. The list of selected monitored conflict situations, including their numbers and coefficients c_R, is in *Table 1*.

3.1 Violation of the rule "Yield to ..." (6n2-01; 6n3-01)

It is a very frequent conflict situation (see *Figure 3*) when a vehicle entering the roundabout does not yield to a vehicle on the circulating roadway. This situation occurred almost on all monitored roundabouts.

This situation can be caused either by aggressive behaviour of a driver on a minor road or by wrong appraisal of the distance between vehicles on a major road (on roundabout it is usually a circulating roadway). Determining of the so-called critical distance between vehicles on a circulating roadway for performing of the manoeuvre (i.e. entering of the vehicle from a minor road into a circulating roadway) is relatively complicated and a lot of specialists deal with this problem (for uncontrolled intersections topically e.g. V. Bogdanović, I. Dadić, Z. Papić and N. Ruškić [7]).

3.2 Giving priority against the Rule (6g2-01)

It is a conflict situation (see *Figure 4*) when a vehicle on a circulating roadway yields to a vehicle entering the roundabout (against the rule). The driver of the vehicle on the circulating roadway slows down (or even stops). The driver of the second vehicle following behind the vehicle slowing down might not expect such a reaction.

Moreover, the behaviour of a driver on the entry can be chaotic, because they might not accept the priority to drive immediately for fear of collision, but they might accept this priority later, i.e. at the moment when the driver on the circulating roadway decides to continue driving and then they can collide.

This situation also occurred almost on all monitored roundabouts. This can occur either out of excessive "chivalry" of the driver on the circulating roadway or due to their ignorance of the traffic rules (the driver on circulating roadway wrongly supposes that they

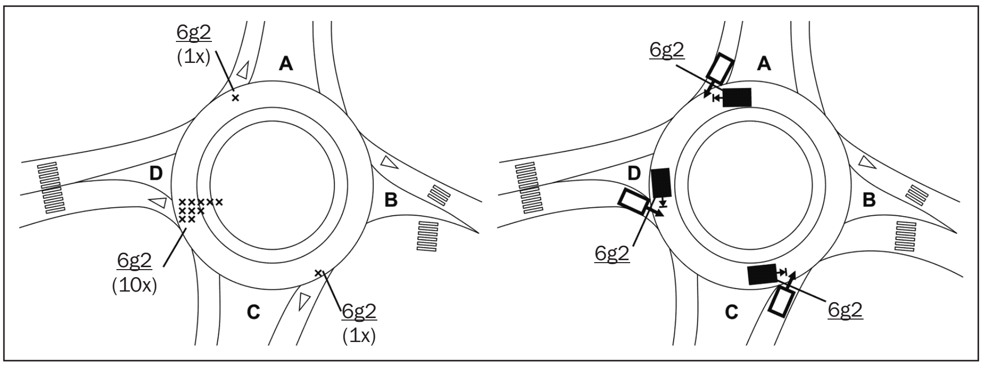

Figure 4 - Scheme of the conflict situation 6g2 (roundabout No. 12 – see Table 1); the black vehicle causing the conflict

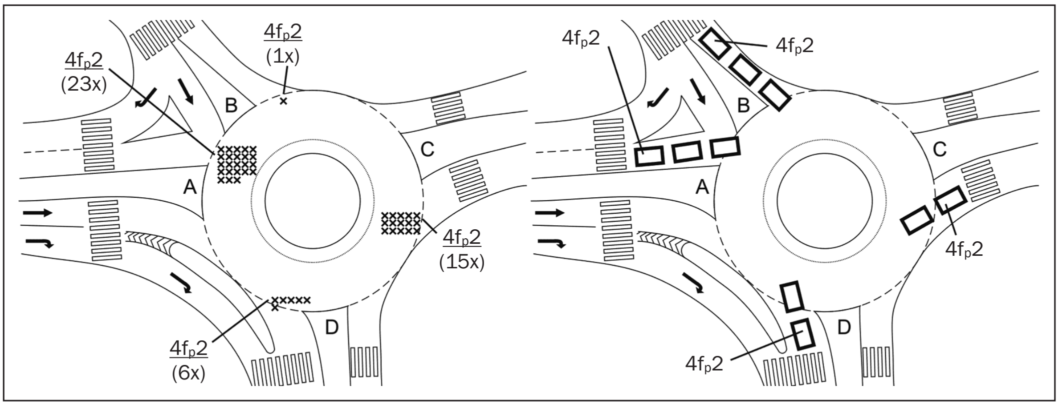

Figure 5 - Scheme of conflict situation $4f_p2$ (roundabout No. 10 – see Table 1)

Figure 6 - Photographs of conflict situation 4fp2 (roundabout No. 15 – see Table 1) and details of damaged curb of the central island (the same place at an interval of approx 1.5 years)

must yield to the vehicle coming from the right). In both cases, the drivers probably do not realize that they can cause secondary conflict situations which can result in the traffic accident.

3.3 Influence of pedestrian crossing ($4f_p2$-O1)

It is a conflict situation (see Figures 5 and 6) when the traffic on the circulating roadway is slowed down or stopped due to the queue of vehicles in front of the pedestrian crossing. This situation occurred on all monitored roundabouts with pedestrian crossings near the circulating roadway. Some vehicles go round the stationary vehicles using the central island truck apron, which can damage at the same time the truck apron or the curb of the central island.

Although this problem can be solved by moving the pedestrian crossing to a larger distance from the circulating roadway, it would generate other problems, because the pedestrian path would then be extended and the drivers at that point (at a longer distance from the crossing) might achieve higher speeds which can lead to other dangerous situations. Therefore, it is necessary to take into account the particular conditions of the monitored roundabout.

3.4 Influence of near intersection ($6f_K2$-X1)

It is a conflict situation (see *Figure 7*) when the traffic on the circulating roadway is slowed down or stopped due to a queue of vehicles on a farther adjacent intersection (signal-controlled intersection or another roundabout). This situation occurred on roundabouts No. 1, 6 and 12 (see *Table 1*), where the adjacent intersection is also a roundabout, and on roundabout No. 14, where the adjacent intersection is an intersection controlled by traffic lights.

This example clearly shows an unsuitable combination of two different types of intersections, situated close to each other. A signal-controlled junction would be a better type of intersection instead of a roundabout. However, it is evident that the use of precisely a roundabout at this place has a rather aesthetic reason – an interesting view from the viewing tower of the New City Hall in Ostrava-City (see *Figure 8*).

3.5 Danger of rear-end collision (6D3-O2; 6D4-O2)

These conflict situations usually arise as secondary situations and they are generally caused by inattentive

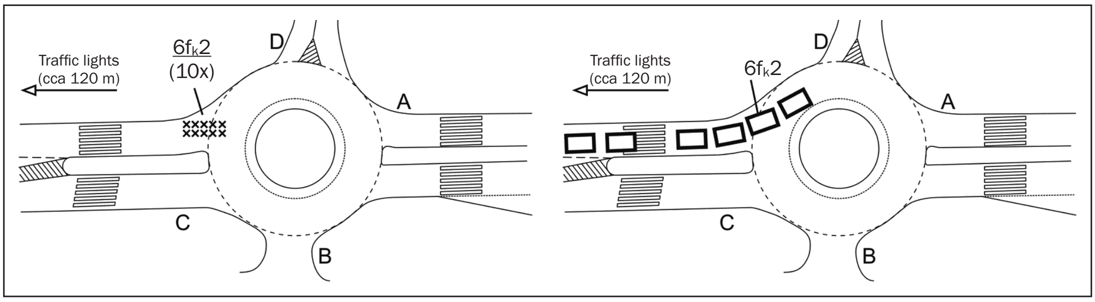

Figure 7 - Scheme of conflict situation $6f_k2$ (roundabout No. 14 – see Table 1)

Figure 8 - Photograph of roundabout No. 14 (see Table 1) from the viewing tower of the New City Hall in Ostrava-City

drivers who do not manage to stop behind the vehicle that has slowed down or completely stopped. These situations can be caused by situations as follows: 6n3, 6g2, $6f_k2$, $4f_p2$, 6o3 etc. (see *Figure 13*).

These situations can be prevented only by drivers themselves through their responsible behaviour and respecting the safe distance between vehicles.

3.6 Wrong riding of the cyclist (9jc1-01; 9jc2-01; 9jc3-01)

It is a situation (see *Figure 9* – top), when a cyclist does not cycle near the right edge of the circulating roadway, but go near the truck apron or the roadway middle. In case of situations 9jc2 and 9jc3 the cyclist restricted the vehicle running behind them. Marking the reserved cycle track on a circulating roadway (see *Figure 9* – right), guiding the cyclist traffic outside the circulating roadway etc. can be the right solution.

3.7 Driving near the curb ($2j_o1$-01)

It is a conflict situation when a vehicle (usually a truck) exiting the roundabout drives very close to the right curb which can be damaged (see Figures 10 and 11). During this conflict situation nobody is restricted or endangered, but mounting the curb might result in a serious traffic accident.

The cause of the situation described is partly a wrong manoeuvre of the driver and partly wrongly designed exit from the roundabout (probably badly veri-

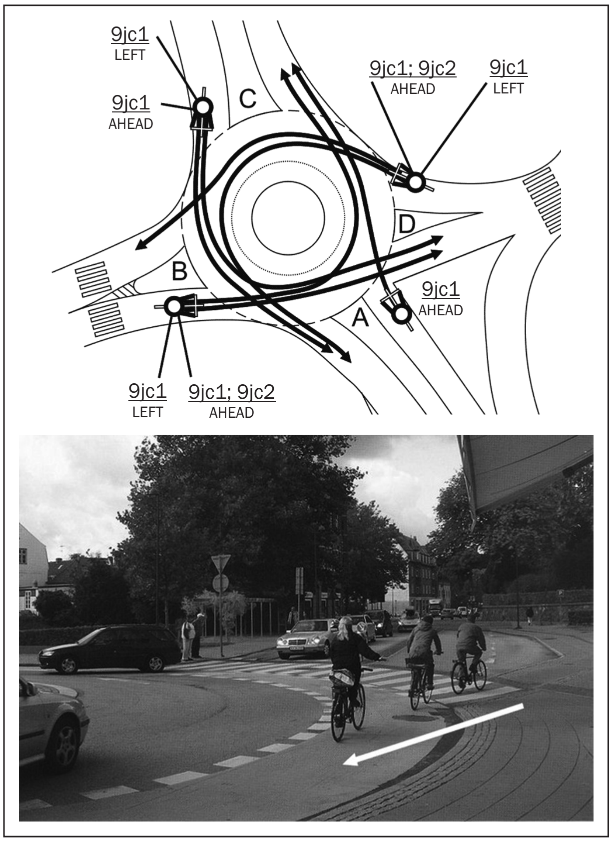

Figure 9 - Scheme of conflict situations 9jc1 a 9jc2 on roundabout No. 15 (left) and reserved cycle track on circulating roadway [8] (right)

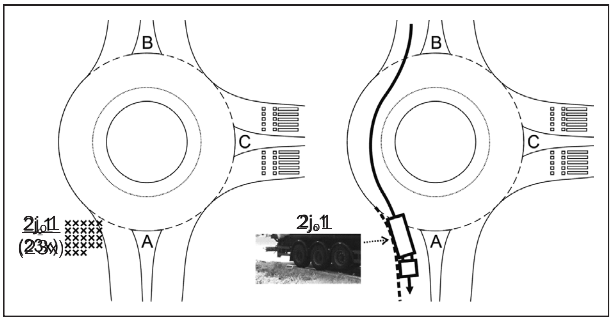

Figure 10 - Scheme of conflict situation $2j_o1$ (roundabout No. 6 – see Table 1)

fied by the rupture curves). This problem can be solved with the help of the so-called hard sickle-shape shoulder (see *Figure 12*).

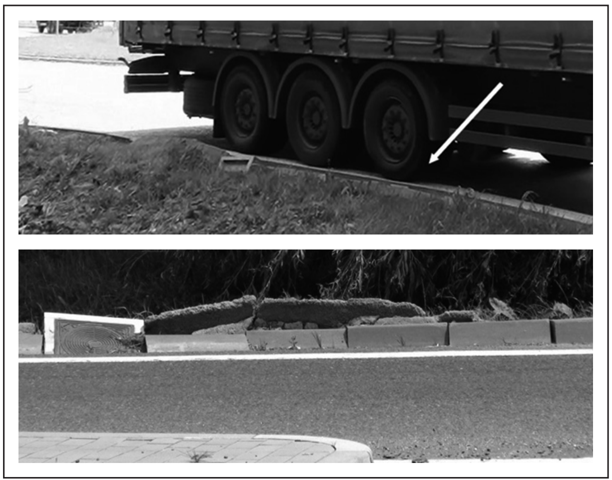

Figure 11 - Photograph of conflict situation $2j_o1$ and details of damaged curb (roundabout No. 6 – see Table 1)

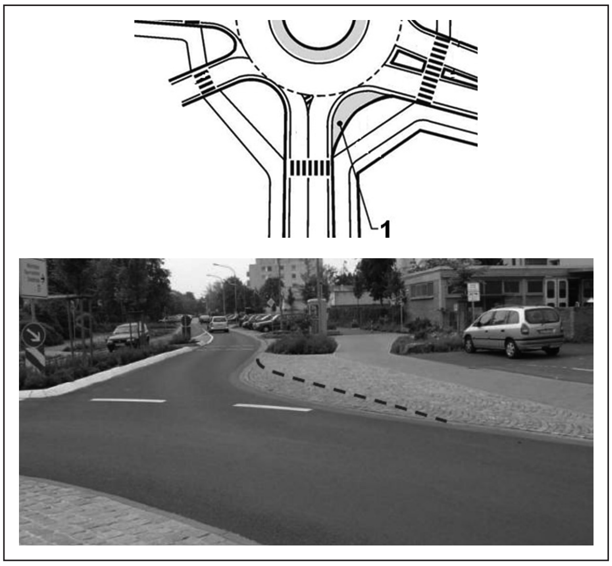

Figure 12 - Use of the hard sickle-shape shoulder (1) on the roundabout [9, 10]

3.8 Restriction or danger in driving when changing lane or during exiting the roundabout (6o2-01; 6o3-01)

These conflict situations usually arise on roundabouts with double-lane circulating roadway. It is a restriction or danger in road traffic during change of the lane or during exiting the roundabout. There may be several situations of this type – see *Figure 13*.

Conventional double-lane roundabouts are already obsolete. They are currently being replaced by different alternative types, so-called turbo roundabouts.

4. CONCLUSION

Road transport safety is a complex system which combines movement of various entities (i.e. means of transport, pedestrians, cyclists and other participants of road traffic) in the precisely determined space and time dimension [11]. Each of the entities, with their different properties, sets different requirements for the road traffic system. Due to a large number of traffic participants and their characteristic requirements, their interaction results in extremely complex relations which determine the behaviour of the road traffic system which can cause various types of conflicts [11].

The issue of how to address the conflict situations in road traffic is very complicated. It can be said that considerable part of conflicts is caused by the drivers' irresponsibility. However, there are also conflict situations for which the driver is not directly responsible, but they are rather caused by wrong infrastructure. This article shows both categories and it can be said that the video analysis of the conflict situations can separate these categories relatively precisely. In both cases using the video-apparatus is absolutely essential for the possibility to stop, slow down or replay the part of the video record in order to evaluate the monitored conflict exactly and objectively.

Conflict situations caused only by the driver's wrong behaviour (e.g. situations marked as 6n2, 6g2, 6D3, 9jc2 etc.) can be solved for example by better educa-

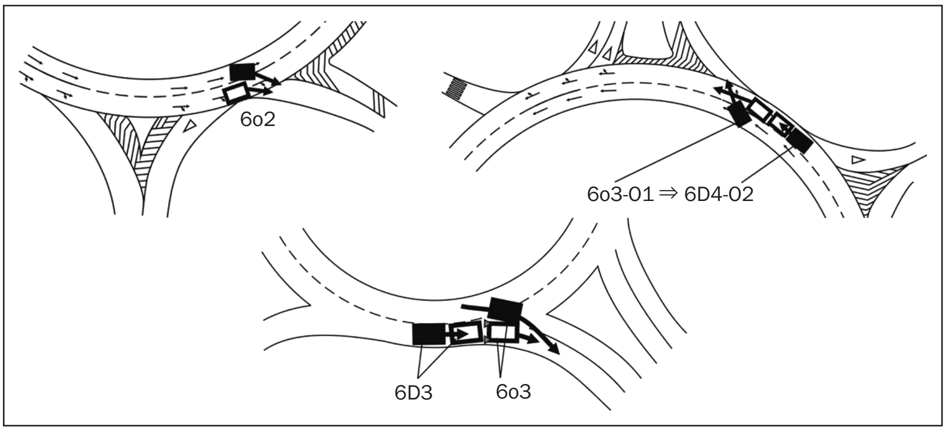

Figure 13 - Scheme of conflict situations 6o2, 6o3, 6D3 and 6D4 (roundabouts No. 11 and 13 – see Table 1); the black vehicle caused the conflict

tion explaining the correct way of driving and behaving of the drivers at roundabouts. However, this education cannot be aimed only at new drivers (i.e. at the driving school), but also at already experienced drivers who are informed of news in the road traffic regulations in this way.

Conflict situations caused by wrongly designed roundabout (e.g. situations marked as $4f_p2$, $6f_k2$, $2j_o1$, 6o2 etc.) can be solved by its modification, *but it is always necessary to keep in mind that whichever change (even a positive one) can lead to another problem or several problems (which are often much more serious)*. For example, moving a pedestrian crossing further from the circulating roadway (to avoid situations described in Section 3.3) can on the contrary make the movement of pedestrians more difficult and cause their inappropriate behaviour (e.g. walking outside the pedestrian crossing).

Use of the hard sickle-shape shoulder (see *Figure 12*) can cause risk connected with the misuse by the passenger car drivers. Rebuilding of conventional double-lane roundabout to turbo roundabouts can cause doubtful behaviour of drivers due to poor arrangement of this type of roundabouts (especially for drivers who are passing through such a place for the first time).

The process of monitoring the conflict situations in road traffic has certainly its well-founded importance. *It is always better to prevent problems (i.e. traffic accidents), than to handle their consequences later, when they can be (and usually are) of relatively serious character (death, injury, damage).*

ACKNOWLEDGMENT

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ANALÝZA KONFLIKTNÍCH SITUACÍ V SILNIČNÍM PROVOZU NA OKRUŽNÍCH KŘIŽOVATKÁCH

Chybné chování účastníků silničního provozu je stále diskutovaným problémem v řadě zemí s vyspělou silniční dopravou. Takové chování ne vždy skončí dopravní nehodou, ale dojde pouze k omezení nebo ohrožení samotného viníka nebo jiných účastníků. K odhalování problémového chování lze s výhodou použít například právě videoanalýzu konfliktních situací.

V předloženém příspěvku je popsána metodika sledování konfliktních situací s využitím videoaparatury a výsledky analýz konfliktů na vybraných okružních křižovatkách v České republice.

V článku je poukázáno na to, že videoanalýza konfliktních situací se velmi dobře hodí nejen pro sledování nevhodného chování řidičů a jiných účastníků provozu, ale také (což zde uvedené výsledky průzkumů dokazují) pro sledování nevhodně navržených stavebních prvků.

KLÍČOVÁ SLOVA

silniční doprava, konfliktní situace, okružní křižovatka, videoaparatura

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