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An Analysis of Traffic Conflicts as a Tool for Sustainable Road Transport

Vladislav Krivda *, Jan Petru, David Macha, Kristyna Plocova and David Fibich

Department of Transport Constructions, Faculty of Civil Engineering, VSB-Technical University of Ostrava, 708 00 Ostrava-Poruba, Czech Republic; jan.petru@vsb.cz (J.P.); david.macha@vsb.cz (D.M.); kristyna.plocova@vsb.cz (K.P.); david.fibich.st@vsb.cz (D.F.)

* Correspondence: vladislav.krivda@vsb.cz

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Abstract: This paper presents an approach to partially solving an issue within the scope of sustainable road transport, specifically the issue of potential accidents, i.e., traffic conflicts. First, a method is introduced for the analysis of traffic conflicts using video equipment. The attention is focused on traffic conflicts that occur at turbo-roundabouts. Given the diversity of causes of traffic conflicts, the emphasis is placed on the correct identification of the cause, i.e., whether the conflict is caused only by the negligence of the road user, or whether the conflict is more or less influenced by an inappropriately designed turbo-roundabout or one or more of its specific building elements (e.g., unsuitable corner radius). The next part of the article presents a selection of results that were obtained from analyses performed at about 100 turbo-roundabouts in nine European countries. Illustrative diagrams show the courses of the emergence of traffic conflicts, the causes of which are then described in detail. The conclusions from these analyses confirm the main hypothesis that the evaluation of traffic conflicts should be an essential part of designing roads, in order to increase traffic safety and, importantly, contribute to sustainable transport.

Keywords: road transport; road traffic; traffic conflict; traffic safety; turbo-roundabout

1. Introduction

Sustainability is generally defined as an ability to satisfy the essential needs of current society, without having a significant negative impact on future generations, while also maintaining the standard of living. Sustainability is very closely linked to the issue of population growth. According to the US Census Bureau, nearly 7.8 billion people live on Earth [1] (various models estimate an increase to 10 billion people by 2050, after which the number is to likely decline). The growth of the population is placing increasing demand on all areas of human existence, and these areas must respond appropriately to these developments. For example, sustainable architecture minimizes the negative consequences of buildings by using more suitable materials, optimizing the use of space and energy, etc. Similarly, the sustainability of cities must address, inter alia, the issues of long-distance transmission of energy, water, food and waste [2–4].

The sustainability of architecture and, above all, the sustainability of cities, are closely linked to the sustainability of transport. In this regard, it is also a question of minimizing the negative impact on the environment. Therefore, the types of transport (pedestrian, bicycle, public transport, etc.) that have as minimal an impact as possible, or at least less of an impact than individual cars, are supported. Accidents are a significant negative aspect: they are responsible for over a million victims a year (e.g., according to the World Health Organization, 1.35 million people died in accidents in 2018 [5]). The above-mentioned population growth is also related to an increase in population mobility. This increase causes, among other things, greater demand on roads, and a need for interfigures with higher capacity. This is connected to space requirements, economic problems and the already mentioned negative environmental consequences, accidents, etc. Unfortunately, supply (in road transport, this means the variety of roads) exceeds demand (i.e., an increase in the number of vehicles on the roads), which, in turn, generates the need to increase supply, and then demand increases again; the conditions of such a system may become unsustainable [6].

Within sustainable transport, the objective is to suppress negative effects as much as possible. The classic approach to traffic planning primarily seeks to maximize the level of mobility. On the other hand, for sustainable development, transport should be the means and not the goal. It is necessary to plan cities and transport infrastructure so that unnecessary traffic is reduced. There are a number of methods for achieving sustainable transport [7], but it always depends on the specific type of transport, the given locality, local customs and possibilities (especially spatial and economic), etc.

The suggested solutions within the context of sustainable transport must also be reflected in the design of transportation constructions [8]. Technical standards are often outdated, and provide solutions that may not be compatible with sustainable transport. For example, when designing intersections on roads, designers often rely only on common types of intersections, but these do not have the capacity to meet the requirements placed on them. In general, the design of an intersection represents a number of activities, for example, the performance of traffic surveys, the drawing of the intersection, verification of the passage through the intersection using swept paths, verification of the capacity or the creation of a microsimulation transport model. Even if all design principles and technical standards are observed, dangerous behaviors by road users can occur at the intersection. However, drivers may not always be responsible for such behaviors. There exist certain hidden factors that even an experienced designer cannot predict in advance [9], as they do not become apparent until real traffic reveals whether the intersection is designed properly. Often, even a small detail can play an important role. For example, an improperly designed building element (insufficient corner radius, improperly located traffic island, etc.) can cause drivers to behave incorrectly. For example, with a small corner radius, the driver of a larger vehicle can either drive the rear wheel onto the curb of the corner or, in an effort to prevent driving onto the curb, leave the intersection in the opposite direction. Here arises the question of whether it is entirely the fault of the driver or whether the incorrectly designed corner (or the whole intersection) is also partially responsible for this situation.

To reveal these problems, an analysis of the behavior of road users—in other words, the analysis of traffic conflicts—can be performed, which is the main topic of this article. This analysis looks for details in the design of the intersection (or other places of transport) that may result in the inappropriate or even dangerous behaviors of drivers. It can be used, for example, to monitor dangerous overtaking, non-compliance with permitted speed [10] or wrong maneuvers while parking vehicles [11], or it can focus only on the behavior of a certain group of drivers, e.g., lorry drivers [12]. To a limited extent, such an analysis can be used to assess the suitability of the monitored place for the passage of oversized cargos [13,14].

The analysis of traffic conflicts can certainly be used in the so-called safety inspections of roads. The purpose of the safety inspection is to identify potential risks and safety deficiencies of an existing road and its immediate surroundings through systematic checking, which is performed by a trained team of certified safety auditors. The aim of the inspection is to prevent the occurrence of accidents or to reduce their consequences [15].

There are many ways to monitor traffic conflicts. For example, in [15], detailed descriptions of field observations, a computer vision technique and naturalistic driving are provided. In [16], traffic conflicts are monitored using so-called objective conflict indicators. It is not possible to describe all methods here, but in general, the monitoring of traffic conflicts can be divided into direct observation in the field and traffic analysis from video recordings. Each technique has its advantages and disadvantages. The analyses presented in this article are derived from videos of traffic conflicts, which is a widely used approach in the Czech Republic [9,11,17–20]. This method is described in more detail in the next chapter.

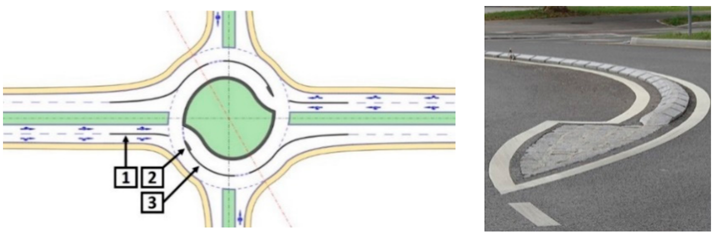
In this context, it is necessary to be aware of the following fact. The safety of transportation constructions is often assessed on the basis of the accident rate. However, relying on this statistic can be rather problematic. The accident rate shows relevant data only from a long-term perspective (in contrast, the usable results of an analysis of traffic conflicts are available in a relatively short time). It is not appropriate from a human or economic point of view to identify a dangerous traffic site only after accidents have occurred (it is worth mentioning that the value of human life lost due to an accident is large; e.g., according to [21], it is more than 2 million EUR). However, accident statistics do exist, while traffic conflict statistics do not, and it is the analyses of traffic conflicts that can prevent the above-mentioned problems. An interesting comparison of accidents and traffic conflicts is given, e.g., in [22].

It is also necessary to realize how the behavior of drivers is influenced by basic traffic engineering factors, such as the intensity of the traffic flow, speed and density. The distribution of speed in various traffic conditions in cities has been investigated in previous studies, e.g., [23]. The same authors also assessed the impact of different traffic conditions on the environment [24], where they analyzed the specific noise of traffic. Both of these articles describe the issue in detail using statistical methods. Similarly, the impact of education regarding the safety of road traffic on the behaviors of children and teenagers was studied in [25], and then the authors of [26] examined the relationship between organizational learning and training and accidents. Additionally, road safety analysis of urban roads was performed in [27].

The authors of [28,29] used very interesting statistical analyses to evaluate driver behavioral factors related to road safety using, among others, the best–worst method. In [30], a bivariate extreme value model was employed to integrate different traffic conflict indicators for road safety estimation. This model was validated with actual crash data and analyses of four conflict indicators, i.e., time to collision, modified time to collision, post encroachment time and deceleration to avoid a crash. Similar approaches were applied in [31,32] by the same authors.

However, our article does not aim to perform detailed statistical analyses but rather to highlight the importance of monitoring traffic conflicts in the analyses of the construction layout of turbo-roundabouts, security inspections, etc. The main goal is, as indicated in other parts of this article, to focus on the issue from a practical/application point of view. The described methods and procedures can be used tools for the analysis of problematic elements in scientific research activities and in the design of technical solutions (geometry analysis of intersections, development of new types of construction elements, etc.), and they can be used by transport designers who very rarely use statistical methods.

The present article focuses on the analyses of traffic conflicts at turbo-roundabouts, as depicted in Figure 1. A turbo-roundabout is a special type of roundabout that has two or more spirally constructed lanes on a circulatory roadway. The principle of the geometric arrangement of the turbo-roundabout is to ensure that vehicles can pass smoothly from the entrance of the roundabout, through the circulatory roadway, to the exit in one lane without the need to change lanes. One of the important elements of the turbo-roundabout is the possibility of physically separating lanes (Figure 1, nos. 1 and 3), whereas, at the beginning of the circulatory roadway, there may be a so-called spike (no. 2). This physical separation of lanes has a major impact on the safety of traffic at the turbo-roundabout, as described later in this article.



(**a**) (**b**)

Figure 1. (**a**) An example of the chosen type of turbo-roundabout; (**b**) an example of the physical separation of lanes on a circulatory roadway (3), including a spike (2).

A turbo-roundabout is a type of roundabout, which is generally considered to be a suitable solution for busy intersections in terms of both capacity [33,34] and safety [9,35,36]. In some European countries (e.g., the Netherlands, Poland, Hungary), this type of roundabout is quite common; in other countries (e.g., Austria, the Czech Republic, Slovenia, Slovakia), turbo-roundabouts are quite rare. However, Slovenia and other countries have a number of experts who address this issue from various professional perspectives [33,35–40], and as a result, the number of turbo-roundabouts is increasing.

As a part of this research, from 2014 to 2019, the authors of this article analyzed 105 turbo-roundabouts out of a total of approximately 600 turbo-roundabouts in Europe. The analyzed turbo-roundabouts were in nine countries (Great Britain, the Netherlands, Germany, Luxembourg, Austria, Poland, Slovenia, Hungary and the Czech Republic). Although most of the analyzed turbo-roundabouts complied with regulations, there were many traffic conflicts at these sites. These were attributed to both the mistakes of drivers and problems caused by improperly designed building elements. Research has shown that the video analysis of conflict situations is a suitable method for analyzing dangerous hidden factors that can cause accidents at turbo-roundabouts.

The aim of the presented article is to confirm the hypothesis that the analysis of traffic conflicts in road transport is of great importance in designing safer transportation constructions (the search for hidden dangerous factors), which can, to some extent, ensure the sustainability of transport in traffic-exposed areas. It can also be important during safety inspections, in cases where it is not possible to unambiguously decide on the dangers of the monitored place. This statement is supported by a selection of results from specific analyses performed at chosen turbo-roundabouts in European countries.

Another hypothesis is that turbo-roundabouts are certainly sophisticated solutions in the field of traffic safety, but even so, they may not always be completely without defects. Therefore, it is necessary to seek ways to identify these defects, learn from them and then introduce better solutions.

2. Materials and Methods

A number of methods were used to analyze traffic conflicts. The chosen methods that were used for the analysis of conflicts at turbo-roundabouts are described in this chapter. There are basically two main areas:

1. The measurement of traffic intensities using various technical devices, either directly (automatic counters) or indirectly (detecting intensities from videos recorded with various types of video equipment).
2. Video analysis of traffic conflicts (when using video recordings from which the intensity of the transport was also measured, in some cases).

Both approaches were used to determine the potential danger of the monitored turbo-roundabout, i.e., to determine comparative indicators of the relative conflict rate C_R or C_{RW} (the ratio between the number of traffic conflicts and traffic intensity), as detailed below.

First, however, it was necessary to select the appropriate turbo-roundabouts and choose the traffic survey method to apply to each of them. The restrictions were, among other things, given by the country where the surveys took place. In some countries, video recording of traffic (e.g., from a moving vehicle) or the use of a drone is restricted or directly prohibited. On the contrary, in some countries, this is not a problem, but it is necessary to have various permits. Automated measurement of traffic intensities using counting devices was carried out only in the Czech Republic, as some devices must be installed directly on the road or on structures such as a road sign pole or public lighting. Processing such a permit abroad would not be effective, especially in terms of time. In such a case, the traffic intensities were determined from video recordings (most often from a camera placed at an elevated location near the turbo-roundabout or from a drone) or, in rare cases, by the classic manual method (entry in the census sheet). Analyses were therefore carried out through a combination of different methods for counting traffic intensities or recording traffic conflicts.

2.1. Technical Equipment and Software for Adding Traffic Intensities and Video Analysis of Traffic Conflicts

2.1.1. Counter Devices for Traffic Intensities

For direct measurement of traffic intensities at turbo-roundabouts, the following automatic traffic counter devices were used (Figure 2). The first of these are NU-METRICS NC-200 counting cards, which are used to detect the number, speed and type of vehicles by using VMI (vehicle magnetic imaging) technology. The card allows vehicles to be divided into 13 length classification groups and 15 speed groups. It can detect a vehicle driving at a speed of 13–193 km per hour. The card is placed directly on the road and is encased by a special protective cover, which is screwed to the road. The card can only measure vehicles in the lane that passes over it.

(**a**) (**b**) (**c**) (**d**)

Figure 2. Automatic counter devices for measurement of traffic intensity: (**a**) NU-METRICS NC-200 counting cards; (**b**) special cover for NC-200; (**c**) VIACOUNT II counter device; (**d**) ICOMS-TMS-SA counter device.

The VIACOUNT II counter device was also used. This device records the speed of each vehicle, data proportional to the length of the vehicle and the time headway between two vehicles. ViaTerm software was used to set the parameters and transmission of the measured data. This software allows investigators to set the system parameters of the device, such as system time, measurement starting time, the direction of travel (arriving or departing vehicle, both directions), the correction factor (side, side–top, and top positions of the device) and the radar range. This device uses Doppler radar to detect vehicles. It is placed either next to the road at the required height (according to the correction factor) or above the road. It allows vehicles to be measured in multiple lanes (even in the opposite direction). During lateral measurements, however, there is a negative effect of the so-called radar shadow, when the closer vehicle covers the more distant one.

The last counter device for measuring traffic engineering characteristics was the ICOMS TMS-SA device. The device records the speed of vehicles, the traffic intensity and the composition of the traffic flow. The speed range of the vehicles to be measured is 10–255 km per hour. The method of measurement and installation is similar to that for VIACOUNT II.

Each of the mentioned types of equipment has its limits, which are specified in more detail, for example, in [6]. For these reasons, the analyses involved a combination of individual devices, which were subsequently installed on selected monitored turbo-roundabouts.

2.1.2. Video Technology for Recording Road Traffic

A number of devices were used to obtain video recordings of road traffic at turbo-roundabouts (and also to obtain the necessary photo documentation). At first, these were ordinary video cameras and cameras (Figure 3). However, the Sony DSC-RX10 III camera, for example, has a "super slow motion" shooting mode, i.e., it produces a slow-motion video recording (1000 fps). Slow motion at 1000 frames per second is sufficient for this type of measurement.

Figure 3. Examples of recording devices: Sony DSC-RX10 III camera on the left; Sony HDR-CX450 video camera on the right.

An elevated place near the intersection (embankment, building, etc.) was the most frequent place to mount the camera on a standard tripod. If necessary, a 7-m tripod with a rotating head was used (Figure 4). The camera itself was then controlled using a tablet with Wi-Fi.

(**a**) (**b**)

Figure 4. Use of a seven-meter tripod (**a**) with a rotating head (**b**).

In many cases, however, conventional video technology was not sufficient. Special GoPro and Lamax outdoor cameras were used for selected measurements because they offer high-quality recorded images (HD and 4K video resolution). These cameras were installed mainly in places where a wide-angle shot was needed (the so-called "fisheye"). The GoPro camera was also used to take detailed shots during traffic (installation on a so-called floating vehicle). A special fixture with a suction cup was used to install the cameras on the front of the vehicle, roof or other parts of the car body. This fixture withstood speeds of up to 70 km per hour. An example of the installation of the special outdoor cameras can be seen in Figure 5.

Figure 5. Examples of installations of special outdoor cameras for measurements at turbo-roundabouts ((1): position on the front of the vehicle; (2): use of a railing; (3): use of a public lighting pole; (4): position on the roof of the vehicle).

As mentioned above, recordings of traffic were not only obtained from static video cameras and regular cameras but also from a so-called floating vehicle. This is a vehicle equipped with a recording device for capturing the GPS position and a camera system (front and rear car camera), and it affords the ability to record the speed of the vehicle and other variables. The floating vehicle was also equipped with a device for monitoring instantaneous acceleration. For a more detailed measurement, a combination of several devices was used, as can be seen in Figure 6 (front and rear car camera + GoPro camera on the front of the vehicle).

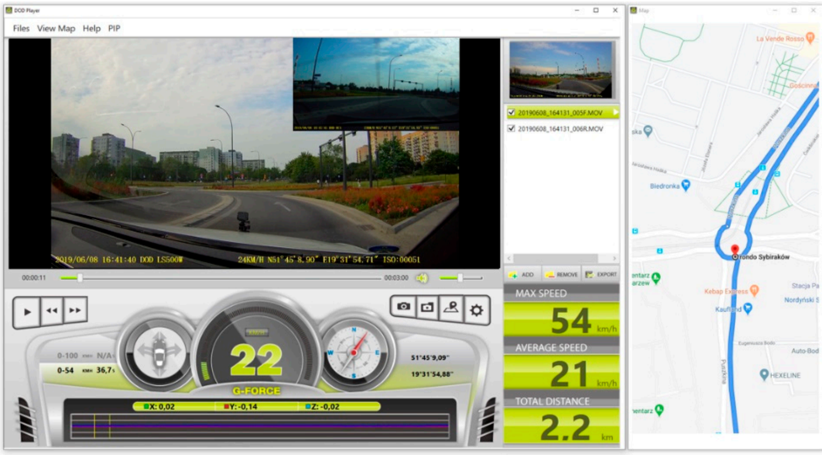


Figure 6. Fitting of video cameras in the so-called floating vehicle and the display of operating data in the DOD Player program.

For some measurements, 360° recording technology was used. The Insta 360 camera is able to take not only 360° photos, but also 360° videos. In photos and videos, it is possible to zoom in on the structural elements of the intersection, rotate the camera during video playback, select the type of display, etc. The undeniable advantage of the camera is the ability to record the situation in a broader context. An example of the use of the camera during vehicle passage in a turbo-roundabout in Poland is shown in Figure 7.

Figure 7. Use of the Insta 360 camera and a subsequent view of the recorded video in the Insta 360 Studio 2019 program.

2.1.3. UAV (Unmanned Aerial Vehicle)

Different types of UAVs (drones) were used for a more detailed analysis of turbo-roundabouts. Thus, it was possible to accurately analyze the construction layout of the roundabout and traffic engineering data. This information could not be obtained from ground measurements (better angle of rotation, larger viewing range, etc.). In order to use these devices for science and research, it is necessary to have tests and the necessary permits from the appropriate authorities of the given state. Drones, for example, were used to analyze turbo-roundabouts in the Czech Republic, England, Poland and Denmark. The following UAVs were used in the measurements (see Figure 8):

- DJI F450 quadcopter: equipped with a GORPO HERO 3 camera (the camera uses "fisheye");
- MAVIC 2 ZOOM: the drone has a camera with zoom (24–48 mm);
- DJI Matrice 210 RTK: the drone has a 4K camera, zoom camera with 30× zoom and RTK;
- Phantom 4 Pro V2: the drone has a camera for recording video in 4K.

(**a**) (**b**) (**c**) (**d**)

Figure 8. Used types of unmanned aerial vehicle (UAV): (**a**) DJI F450 quadcopter, (**b**) MAVIC 2 ZOOM, (**c**) DJI Matrice 210 RTK, (**d**) Phantom 4 Pro V2.

2.1.4. Software for Analysis of Image

Nowadays, image analysis tools are increasingly used in traffic surveys, and therefore, this technology was also used in the analyses described in this article. The acquired materials were analyzed for the purpose of measuring the speed of vehicles, intensity, acceleration, etc. Two programs were used for data analysis. This involved image analysis using the GOODVISION program [41] and tools from DATA FROM SKY [42].

Figure 9 depicts the GOODVISION program for one of the turbo-roundabouts in Ceske Budejovice, Czech Republic. A 4K video from the drone was uploaded to the web interface. After the analysis, the zones of interest were marked, and from these areas, paths for separately adding individual directions were created. Furthermore, lines were created at certain points of the roundabout so that it was possible to determine the speed of vehicles in a given profile of the roundabout. These data can be subsequently sorted. The web interface allows the data to be exported to MS Excel for further work and evaluation.

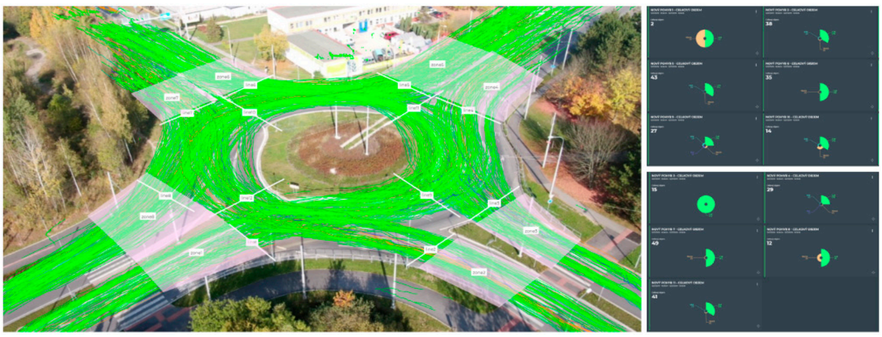


Figure 9. Example from the web interface of the program while working in the GOODVISION program (vehicle tracks are marked in green on the left, and graphs for individual directions are shown on the right).

Figure 10 depicts the DATA FROM SKY program for another turbo-roundabout in Ceske Budejovice, Czech Republic. The 4K video from the drone was uploaded to the web interface again.

After analyzing the video, a special file was downloaded and then uploaded to the application from DATA FROM SKY. Furthermore, all evaluation was performed directly from the computer. The program analyzed the movements of vehicles, their trajectories, their speeds at any point, the gap between vehicles, etc. For subsequent work, it is also possible to export data to Microsoft Excel or other database programs.

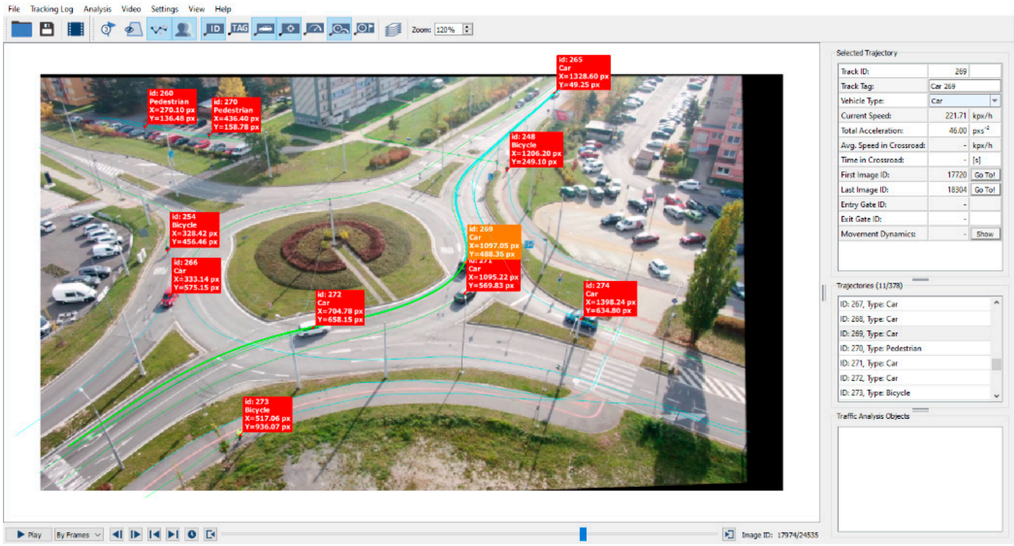


Figure 10. Working in the DATAFROMSKY program.

2.2. *Video Analysis of Traffic Conflicts: Description of Authors' Method*

The authors of this article have been studying the issue of traffic conflict analysis for many years. They have developed their own method, which is based on the original Folprecht method from the 1990s [43,44]. It is actually an innovated Folprecht method that takes into account new approaches and new experiences gained during about 20 years of analysis of traffic conflicts at VSB—Technical University of Ostrava. This innovated method is also described in the Czech certified methodology [18], which describes direct analyses of traffic conflicts at the monitored place (i.e., without video equipment) and the currently presented innovated method, which uses video equipment. It is apparent that each method has its advantages and disadvantages. The following text mainly focuses on an innovative video analysis of traffic conflicts. This method is described in more detail here for a better understanding of the results of the analyses.

2.2.1. The Term Traffic Conflict

There are many definitions of "Traffic Conflict". Even the name of the term varies, e.g., traffic conflict [18], conflict situations [17] and near-accident [45], but they describe the same issue. If we use the definition from [18], then a traffic conflict is an observable situation in which two or more road users approach each other in space and time, to such an extent that there is a risk of a collision if their movement does not change. Folprecht [43,44] defined a traffic conflict as such a moment or situation in road traffic in which a greater than usual level of danger arises (or may arise) for some participants. In the following text, the term traffic conflict is used.

Clearly, every accident must be preceded by a traffic conflict, or, on the contrary, every accident is a consequence of a traffic conflict in which the danger of a collision could not be averted. Therefore, traffic conflicts are potential accident situations, and their nature then determines the type of accident [17].

It is clear that traffic conflicts usually arise at the point of collision. However, it should be noted that the emergence of a traffic conflict can be caused by certain hidden factors (as mentioned above), whether operational, construction, weather-related or others. These hidden factors can be revealed by analyzing traffic conflicts. In other words, a transportation construction designer can never absolutely consider his/her transport solution to be completely safe and satisfactory unless he/she verifies it. Using the analysis of traffic conflicts, doubts about its safety can be avoided.

On the basis of the analysis of traffic conflicts, we can draw conclusions about the degree of danger of the monitored place and then take appropriate measures to increase safety. With the help of this analysis, measures can be taken to reduce danger before an accident occurs.

2.2.2. Classification Symbol and Division of Traffic Conflicts

Each traffic conflict can be described by a classification symbol (for example, 2r1-O1S). The original Folprecht symbol [43,44] contained only three characters (before the dash, i.e., "2r1-"). The upgraded symbol is complemented by additional characters (after the dash, i.e., "-O1S").

The first three characters before the dash (i.e., "2r1-") describe traffic conflicts according to

- Participants in the traffic conflict (in the example above, it is the number "2"): these are either individuals (pedestrians, vehicle, etc.) or pairs or groups of road users (pedestrian + vehicle, vehicle + vehicle, etc.), and it is possible to modify or supplement this category as needed (including the modification or addition of used characters);
- The method of the traffic conflict (letter "r" in the example): these are groups of traffic conflicts, which can be arbitrarily supplemented, for example, according to the purpose of the analysis or the type of monitored intersection, and the characters used are also optional (examples are given later in Section 3);
- The seriousness of the traffic conflict (number "1" in the example; before the dash): this division was maintained according to Folprecht's original proposals (see the next paragraph for details).

The seriousness of the traffic conflict (i.e., the third character) is divided into three basic types [44]:

- First level of seriousness: a situation in which traffic regulations are about to be violated at that time by a lone road user, i.e., without the presence of others who could be limited or endangered (it is a potential traffic conflict);
- Second level of seriousness: a situation in which a certain disruption of smooth transport can be observed, i.e., situations that do not provoke a violent reaction by other participants but rather hesitation or mild aggressiveness of single misconduct that results in a reaction of other participants;
- Third level of seriousness: a situation in which only a rapid evasive reaction (e.g., sharp braking or sudden deflection) prevents a collision (i.e., the accident);
- If an accident happens, we mark this situation with the number 4.

The upgraded classification symbol (see, e.g., [9]) contains three new characters after the dash (in the example above, these are the characters "-O1S"). This results in a further division of traffic conflicts, which is described in the following paragraphs.

Some traffic conflicts may not be caused by traffic at the monitored intersection, or not the intersection itself (i.e., its construction layout or driving). For example, a traffic conflict could result from a queue of vehicles at a nearby intersection that affects traffic at the monitored intersection or from drivers who perform a parking maneuver in a nearby parking lot that affects the exit from the monitored intersection. Therefore, these are conflicts that are affected by external influences.

According to the affiliation of the traffic conflict, conflicts were newly divided into two groups (in the brackets below, the character is used in the classification symbol):

- Own traffic conflicts (O): traffic conflicts that are directly related to the traffic at the monitored location, its construction layout, its management, etc.;
- Non-own traffic conflicts (X): traffic conflicts that are not directly related to the traffic at the monitored location, its construction layout, etc., but instead arise from outside the monitored location (however, they will affect traffic at the monitored location).

Other traffic conflicts arise as a result of another conflict and are unlikely to arise on their own. As an example, consider the case in which the driver of the first vehicle has to slow down unexpectedly and with force (e.g., before a pedestrian crossing, which is suddenly entered by a careless pedestrian) and the driver of the second vehicle brakes sharply to prevent a collision. The traffic conflict that the driver of the second vehicle becomes a part of would probably not have happened in the absence of the first conflict (between the first vehicle and the pedestrian).

According to the timing of the traffic conflict, we divide them into

- Primary traffic conflicts (1): traffic conflicts that are not caused by another situation;
- Subsequent traffic conflicts (2): traffic conflicts that are caused by other conflicts (usually by the primary or possibly another subsequent conflict).

Given that the reason for some traffic conflicts is not only the incorrect behavior of the driver (or another road user), but also factors such as the construction layout of the monitored location, it was necessary to divide traffic conflicts as follows.

According to the reason for the traffic conflict, we divide the traffic conflicts into

- Operational traffic conflicts: a traffic conflict caused only by the driver (or another road user);
- Construction traffic conflict: a traffic conflict caused not only by the driver but also (and mainly) by improperly designed building elements.

In the group of operational traffic conflicts, we can include not giving way, driving through a red light, tailgating, etc. These traffic conflicts formed the majority during surveys at various intersections, but as they are not directly related to the topic of this article, they are mentioned only marginally, especially in connection with the second group of traffic conflicts, i.e., construction traffic conflicts.

Construction traffic conflicts include driving in close proximity to curbs, entering the opposite direction when exiting the intersection, etc., but only if these conflicts also occur as a result of inappropriately designed building elements! Traffic conflicts that could have been avoided and therefore arise only from the incorrect behavior of the driver should be included in the group of operational traffic conflicts.

2.2.3. Procedure for Video Analysis of Traffic Conflicts in Order to Identify Inappropriately Designed Construction Elements at Intersections

For the monitoring and subsequent analysis of operational traffic conflicts, it is, in principle, sufficient to use a basic video recording from an observation location that is placed in the highest possible position. However, in order to monitor and analyze construction traffic conflicts, it is necessary to supplement the basic video recording with another video recording that is taken in the required vicinity of the problematic building element [17].

The procedure for the analysis of inappropriately designed building elements at intersections using video analysis of traffic conflicts is, therefore, as follows:

- On the basis of researchers' observations and experience, a problematic intersection is identified, traffic participants are suggested, the passage of the intersection is verified using swept paths, etc.
- The place is monitored by identifying features such as broken curbs, dark tracks on the curbs from the tires of passing vehicles, etc. However, it is necessary to note that not all of the mentioned features must be caused by improperly designed building elements (but may be due to winter maintenance, previous accidents, etc.).
- The video recording of the entire intersection (i.e., basic video recording) is retrieved to get an overall picture of the traffic at the intersection with the identification of problem areas. From the video, it is also possible to determine the basic characteristics of traffic flows (intensity of vehicles, composition of traffic flows and their direction, etc.). The most suitable location for the camera is at a certain height above the level of the intersection, e.g., from a building or bridge.

- Detailed video recordings are acquired from places where, according to the evaluation of the basic video recording, the danger of construction conflict situations is evident, or places where these situations can be expected. The camera is placed at the level of the intersection at the point with the best view of the given site. In any case, improper placement of the camcorder must not restrict the flow of traffic or endanger traffic safety.
- Video recordings are evaluated either in a standard way or by detailed analysis of the video recording by stepping through individual images and comparing various changes, e.g., the vertical position of the wheel that ran into the curb, towards the wheelhouse, etc.
- The results of the video analysis can then be recorded in tabular form, which states information such as the exact times of emergence of the traffic conflicts, the situations (denoted by a classification symbol), a brief description of traffic conflicts with a possible warning of important or special circumstances, etc. The tabular evaluation also includes data on the frequency of traffic conflicts and, if necessary, indicators of relative conflict (see below).
- Graphic evaluation is then performed by depicting traffic conflicts, e.g., in a ground scheme or in a photograph from a video recording. When using schemes, it is advisable to use two of them. In the first one, appropriate signs indicate the location of the traffic conflict as accurately as possible, and the number of these signs indicates the frequency of the conflict. The second scheme then shows a simplified course of the conflict, from which, among other things, the direction of travel of vehicles and the place of emergence of the conflict are clarified. The use of schemes is suitable for high frequencies of traffic conflicts. On the contrary, at low frequencies or to explain the course of the emergence of the conflict, the use of photography is sufficient (see the figures in Section 3).
- The collection of detailed photographic documentation and the creation of video sequences of specific traffic conflicts are a matter of course. If necessary, it is advisable to verify the passage of the given place using swept paths.
- In the end, a proposal of measures in order to improve the continuity of traffic and increase traffic safety at the monitored intersection should be made.

2.2.4. Weighted Relative Conflict Indicator

A quantity that gives us an idea about the degree of the danger of traffic at the monitored intersection is the relative conflict indicator C_R [TC/100 veh.]:

$$C_R = \frac{N_{TC}}{V} \cdot 100, \tag{1}$$

where N_{TC} is the number of traffic conflicts (TC) in an hour [TC/h], V is hourly intensity [veh./h] and veh. is vehicle. The relative conflict indicator C_R then indicates the number of traffic conflicts per 100 vehicles that passed in a given time of measurement.

However, this formula does not take into account the seriousness of traffic conflicts. It is therefore more efficient to use the weighted relative conflict indicator C_{RW}. The formula for calculating the indicator for a specific type of traffic conflict is then as follows:

$$C_{RW} = \frac{N_{TC} \cdot C_S}{V} \cdot 100, \tag{2}$$

where C_S is the coefficient of the seriousness of the traffic conflict [-]. This coefficient can be determined subjectively as needed. According to the experience of the authors of the article, on the basis of many analyses, a value that corresponds to the identified seriousness of the traffic conflict has proven successful (C_S = 1 corresponds to the traffic conflict of the first level of seriousness, etc.).

3. Results of Analyses

The following text describes selected traffic conflicts that were observed during the research at turbo-roundabouts. Emphasis is placed on the seriousness of traffic conflicts and the division of these conflicts into operational and construction (see above). Turbo-roundabouts are, in a way, a specific type of roundabout, which means that it is necessary to make a specific division of the types of traffic conflicts according to how the conflict arises (i.e., the second character of the classification symbol).

Tables 1 and 2 show the most common types of traffic conflicts that were observed at turbo-roundabouts in chosen European countries (see above). The situations are labeled with a classification symbol in accordance with the stated method. Specifically, situations that were caused by a lone traffic participant are labeled with a level of seriousness of 1, and traffic conflicts with two or more participants have a level of seriousness of 2 or 3. In the table, they are labeled in the place of the third character in this way: 2(3). It is only a matter of merging conflicts of two seriousness levels (i.e., second and third) into one symbol (for the simplification of the record). Details are clear from the texts in the following subchapters.

There were 105 turbo-roundabouts analyzed. Each was analyzed for a minimum of 2 h. However, some turbo-roundabouts did not show any of the traffic conflicts listed in Table 1, and thus, they were excluded from further analysis. Overall, for the estimation of the relative conflict indicator, 326 h of recordings were used.

Table 1. Examples of the most common traffic conflicts monitored at turbo-roundabouts (part 1).

Type of Traffic Conflict (TC)	2nd Character	Classification Symbols	Examples of the Most Common Causes of TC	C_{RW} [TC/100 veh.]
Not giving way (see Figure 11)	n	6n2(3)-O1P	Not respecting traffic signs at the entrance to the turbo-roundabout	0.74
Unwanted intertwining of vehicles (see Figure 12)	p	2p1-O1P 6p2(3)-O1P	Not respecting horizontal traffic signs, absence of physical separation of lanes	0.62
Unwanted change of direction (see Figure 13)	k	2k1-O1P 6k2(3)-O1P	Not respecting horizontal and vertical traffic signs, absence of physical separation of lanes	0.56
Unwanted guidance of vehicles (see Figure 14)	r	2r1-O1S 6r2(3)-O1S	Inappropriate design of geometry, absence of physical separation of lanes	0.44
Shortening the driving path (see Figure 15)	s	2s1-O1P 6s2(3)-O1P	Inappropriate geometry of the turbo-roundabout, absence of the "spike", unpredictable behavior of the driver	0.61
Dangerous approach to the turbo-roundabout (see Figures 16 and 17)	a	2a1-O1P 6a2(3)-O1P	Not respecting horizontal and vertical traffic signs	0.42
Driving in the opposite direction (see Figure 18)	x	6x3-O1P	Not respecting horizontal and vertical traffic signs, unpredictable behavior of the driver	0.09

Table 2. Examples of the most common traffic conflicts monitored at turbo-roundabouts (part 2).

Type of Traffic Conflict (TC)	2nd Character	Classification Symbols	Examples of the Most Common Causes of TC	C_{RW} [TC/100 veh.]
Turning of vehicles (see Figure 19)	o	2o1-O1P 6o2(3)-O1P	Not respecting horizontal and vertical traffic signs in an area where the turbo-roundabout does not allow turning	0.39
Unwanted driving on the circulatory roadway (see Figure 19)	d	2d1-O1S 6d2(3)-O1S	Inappropriate design of geometry, absence of physical separation of lanes	0.28
Stopping at the circulatory roadway (see Figure 20)	z	6z3-O1P	Behavior of the driver, connection to another traffic conflict	0.11

Individual traffic conflicts (TC), including an explanation of the classification symbol, are described in detail in the following text.

3.1. Not Giving Way (to Vehicles on the Circulatory Roadway)

Symbol 6n2(3)-O1P: 6—vehicle + vehicle; n—not giving way; 2(3)—seriousness of the second or third level; O—own TC; 1—primary TC; P—operational TC.

Unfortunately, this is a common traffic conflict that occurs at all types of intersections, including roundabouts. Common roundabouts have a legally preferred right of way in most countries for vehicles traveling on a circulatory roadway. The emergence of this traffic conflict can often have fatal consequences, especially if a higher maximum speed is allowed on the main road. Fortunately, vehicle speeds are lower at roundabouts, especially on a circulatory roadway. Drivers of these vehicles can then more easily react to the situation (i.e., reduce speed or change direction). Such a traffic conflict is shown in Figure 11, in which the light vehicle (Veh 1) arriving from the left leg of the intersection did not give way to the dark vehicle (Veh 2) on a circulatory roadway.

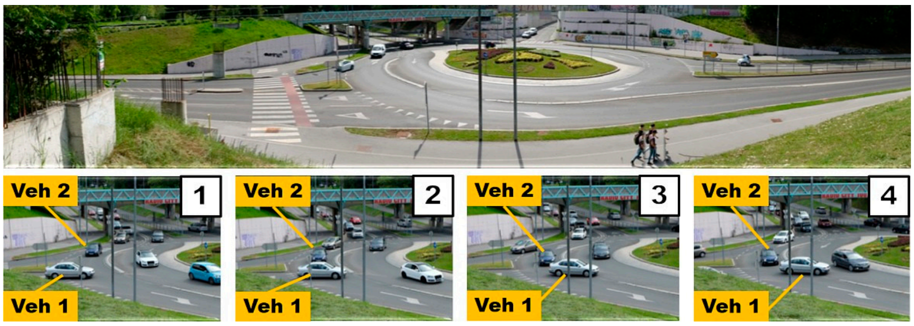


Figure 11. Not giving way (Maribor, Slovenia; GPS: 46.5510875 N, 15.6498817 E); (1)–(4): successive phases of the traffic conflict.

3.2. Unwanted Intertwining of Vehicles (Direct Passage)

Symbol 2p1-O1P or 6p2(3)-O1P: 2 or 6—vehicle or vehicle + vehicle; p—unwanted intertwining of vehicles; 1 or 2(3)—seriousness of the first, second or third level; O—own TC; 1—primary TC; P—operational TC.

If lanes are separated only by traffic signs (i.e., without the physical separation of lanes), then unwanted traffic conflicts can (and do) arise. In particular, this type of conflict involves the unwanted intertwining of vehicles between spirally arranged lanes on the circuit. Motorists drive in a straight line not only at lower vehicle intensities (see Figure 12, which graphically shows the passage of one vehicle). The passenger car arrives at the intersection position (1), stops in front of the circulatory roadway (2), then crosses into the inner lane (3), but does not continue in the inner lane of the circulatory roadway but crosses the traffic signs, i.e., the white line (4) and continues to the first exit of the intersection (5). The designation of the particular situation shown in this figure is 2p1-O1P (i.e., the first character 2), as this maneuver took place without the participation of another vehicle that could be limited or endangered. Here, however, it is necessary to realize that if another vehicle were driving in the inner lane of the circulatory roadway (or if one were approaching), then this situation would not have to occur. During traffic surveys at turbo-roundabouts, situations were also recorded in which an unwanted intertwining (direct passage) took place with the participation of vehicles traveling in the inner lane of the circulatory roadway (i.e., the designation 6p2 (3)-O1P).

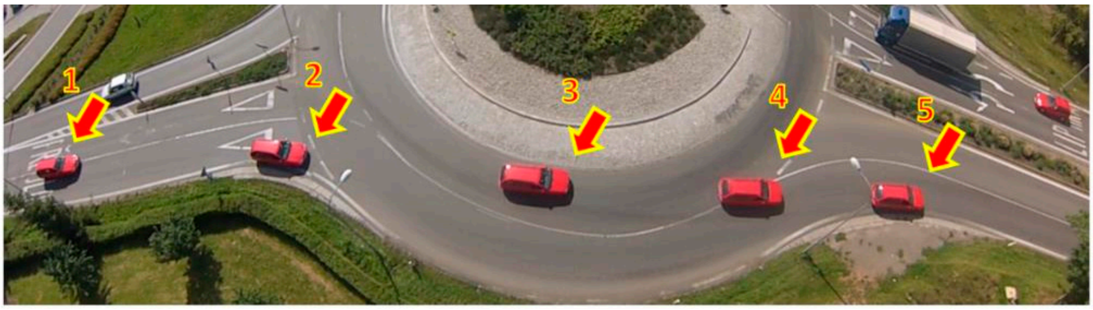


Figure 12. Not respecting traffic signs: direct passage via the turbo-roundabout (Olomouc, Czech Republic; GPS: 49.5890953 N, 17.3134856 E); (1)–(5): successive phases of the traffic conflict.

3.3. *Unwanted Change of Direction (Crossing of Paths)*

Symbol 2k1-O1P or 6k2(3)-O1P: 2 or 6—vehicle or vehicle + vehicle; k—unwanted change of direction; 1 or 2(3)—seriousness of the first, second or third level; O—own TC; 1—primary TC; P—operational TC.

Another negative conflict (partially similar to the previous one) with the absence of the physical separation of lanes on the circulatory roadway is unwanted passage through the turbo-roundabout (see Figure 13), when vehicles enter the inner lane on the circuit and then do not use the exit by the inner lane but the exit by the outer lane of the leg of the intersection. In such cases, there is a potential traffic conflict, i.e., the crossing of paths of vehicles. In the picture, the white van does not limit/endanger anyone when leaving the roundabout, so this situation would be marked 2k1-O1P. If the visible blue passenger car were closer to the camera, for example, then this scenario could already present a certain limitation/danger (then the situation would be marked 6k2(3)-O1P).

Figure 13. Not respecting traffic signs: crossing of paths (on the left Brno, GPS: 49.1832106 N, 16.6680133 E; on the right Prostejov, GPS: 49.4697986 N, 17.1177425 E; both in the Czech Republic).

3.4. Unwanted Guidance of Vehicles (Crossing Due to an Inappropriate Approach)

Symbol 2r1-O1S or 6r2(3)-O1S: 2 or 6—vehicle or vehicle + vehicle; r—unwanted guidance of vehicles; 1 or 2(3)—seriousness of the first, second or third level; O—own TC; 1—primary TC; S—construction TC.

Unwanted guidance of vehicles into the turbo-roundabout is shown in Figure 14. It shows the course of the passage of two heavy vehicles that enter the turbo-roundabout. There are no physical separation elements, and the lanes are divided only by traffic signs. The vehicle (1) approaches the paved part of the truck apron of the roundabout, because the vehicle in the outer lane goes across the traffic signs (2). The vehicle in the inner lane is then forced to stop (3), because the vehicle in the outer lane of the circulatory roadway goes between two lanes (4). This is followed by the gradual start of the vehicle (5) in the inner lane. The vehicle exiting the roundabout still interferes with the inner lane of the circulatory roadway (6). The vehicle in the inner lane leaves the roundabout at the next exit (7). During the measurements at this turbo-roundabout, this traffic conflict was repeated several times, and other road users were also negatively affected. The truck apron of the roundabout shows obvious damage to the paved cover from the frequent passage and braking of mainly heavy vehicles. The situation described here is a typical construction traffic conflict (i.e., label 6r2(3)-O1S, when it is obvious that the roundabout does not have the necessary geometric parameters (corner radius, etc.)). If a lone vehicle passed here incorrectly, the traffic conflict would be labeled 2r1-O1S. However, in other cases (or at other roundabouts), it could be an operational traffic conflict if the geometric parameters of the roundabout are designed correctly, but the wrong passage of the vehicle via the circulatory roadway would be entirely the intention or irresponsibility of the driver.

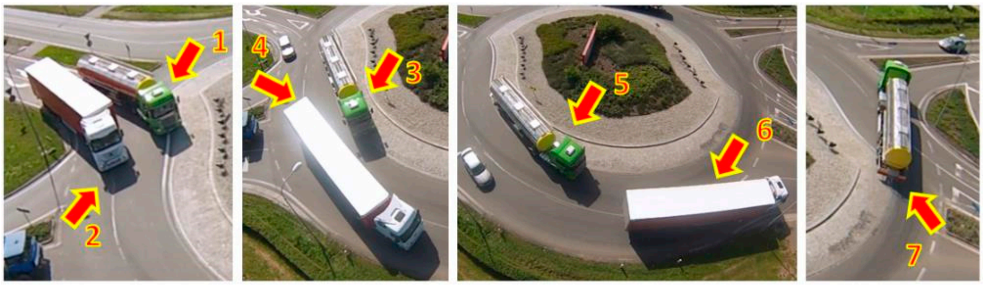


Figure 14. Unwanted guidance of vehicles: there is a subsequent crossing of the paths of the vehicles (Olomouc, Czech Republic; GPS: 49.5890953 N, 17.3134856 E); (1)–(7): successive phases of traffic conflict.

3.5. Shortening of Vehicle Path (Crossing from the Outer Lane to the Inner Lane at the Entrance to the Turbo-Roundabout)

Symbol 2s1-O1P or 6s2(3)-O1P: 2 or 6—vehicle or vehicle + vehicle; s—shortening the path; 1 or 2(3)—seriousness of the first, second or third level; O—own TC; 1—primary TC; P—operational TC.

Vehicles that are in the lane of a turbo-roundabout shorten their trajectory with a sharp maneuver. Unwanted path shortening is described (see Figure 15) in steps 1–3:

- Step 1: Vehicle 1 should continue in its lane as indicated by the dashed arrow. Vehicle 1 suddenly brakes and changes its trajectory to the inner lane. Vehicle 2 arrives at the entrance to the turbo-roundabout.
- Step 2: After suddenly braking, vehicle 1 passes by the front and rear axles' physical separation of the roundabout. Vehicle 2 slows down and changes its path to the inner lane.
- Step 3: Vehicle 1 continues in the inner lane and exits from the turbo-roundabout. Vehicle 2 continues in the inner lane and then exits the turbo-roundabout. After leaving the turbo-roundabout, both vehicles merge from the left to the right lane. If the vehicles remained in the outer lane, they would exit the turbo-roundabout directly from the right lane.

This is a big mistake by both drivers (i.e., operational traffic conflict), and both situations must be considered separately. From its action, the dark vehicle could influence the reaction of the driver of the light vehicle, which could have reacted with a dangerous maneuver. Therefore, this situation is referred to as 6s2 (3)-O1P. The light vehicle did not affect any other vehicle, and therefore, this situation is marked 2s1-O1P. The question arises as to whether the driver of the light vehicle was inspired to perform his/her action by the driver of the dark vehicle.

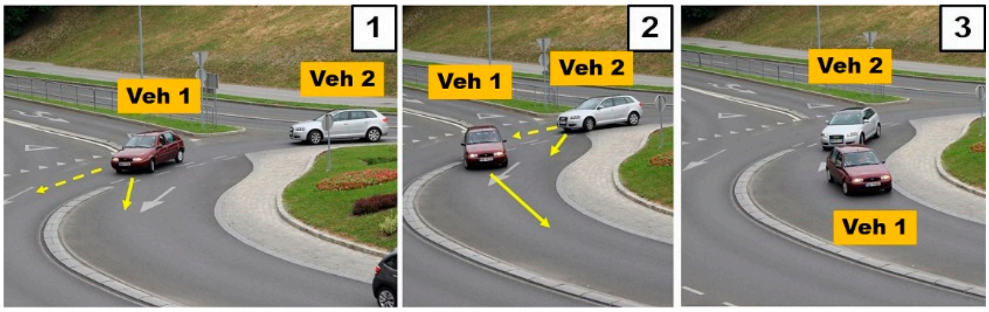


Figure 15. Unwanted shortening of the driving path: crossing from the outer to the inner lane at the point of entering the turbo-roundabout (Maribor, Slovenia; GPS: 46.5510875 N, 15.6498817 E); (1)–(3): successive phases of traffic conflict.

3.6. Dangerous Approach to the Turbo-Roundabout (Dangerous Entrance to the Circulatory Roadway)

Symbol 2a1-O1P or 6a2(3)-O1P: 2 or 6—vehicle or vehicle + vehicle; a—dangerous approach to the turbo-roundabout; 1 or 2(3)—seriousness of the first, second or third level; O—own TC; 1—primary TC; P—operational TC.

The dangerous approach of a vehicle to the turbo-roundabout is described in Figure 16. The vehicle in the right lane (Veh 2) is guided to turn right. The vehicle in the left lane (Veh 1) is guided into the inner lane of the turbo-roundabout to turn left. When approaching the roundabout, Vehicle 2 accelerates and enters the inner lane of the turbo-roundabout and crosses the path of Vehicle 1. Vehicle 1 is forced to brake suddenly when approaching the inner lane. This creates a dangerous traffic conflict in which Vehicle 2 unexpectedly crosses the track of Vehicle 1, which may become an obstacle in the lane for other vehicles in the turbo-roundabout due to unexpected braking. This is again an aggressive action by the driver (here, the van): thus, it is an operational traffic conflict. The situation in the figure is marked 6a3-O1P (here, specifically seriousness 3). If such a maneuver were performed by a lone vehicle at the given moment, the traffic conflict would be marked 2a1-O1P.

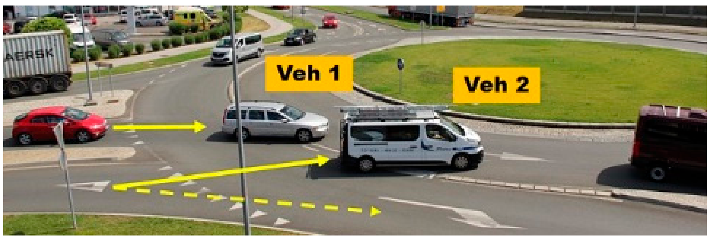


Figure 16. Dangerous approach to the turbo-roundabout: there is a subsequent crossing of the paths of the vehicles (Koper, Slovenia; GPS: 45.5451967 N, 13.7447347 E).

Another example of a dangerous approach to the turbo-roundabout is the situation shown in Figure 17. Vehicle 1 enters the inner lane on the circulatory roadway, signals a change of direction, slows down and leaves through the exit. At this moment, Vehicle 2 enters the inner lane. This vehicle is supposed to turn right according to the organization of the lanes in the turbo-roundabout (dashed line). Thus, Vehicle 2 suddenly crosses the path of Vehicle 1, which is forced to stop. Vehicle 3, which enters the inner lane in the gap, is forced to brake suddenly because Vehicle 1 has stopped. Vehicle 4, which goes along the outer lane of the circulatory roadway, is affected by Vehicle 3: it brakes and suddenly changes its direction to avoid Vehicle 3. The whole situation ends without an accident, but the risk of an accident was high because of the dangerous driving of Vehicle 2. The designation of these traffic conflicts is identical to that of the previous case.

Figure 17. Dangerous driving into the roundabout: there is a subsequent crossing of paths of vehicles on the circulatory roadway (Koper, Slovenia; GPS: 45.5414922 N, 13.7355831 E).

3.7. Driving in the Opposite Direction (Dangerous Approach of the Vehicle to the Opposite Direction)

Symbol 6x3-O1P: 6—vehicle + vehicle; x—driving in the opposite direction; 3—seriousness of the third level; O—own TC; 1—primary TC; P—operational TC.

The dangerous approach of a vehicle driving in the opposite direction is described in three steps (see Figure 18):

- Step 1: Vehicle 1 arrives at the turbo-roundabout. It stops at the entrance to the circulatory roadway. The vehicle should continue in the direction of the dashed arrow. Vehicle 1 stands at the entrance for approximately 4 s, and there are no vehicles on the circulatory roadway.
- Step 2: Vehicle 1 suddenly turns left (in the opposite direction). The arriving vehicles that are on the circulatory roadway cannot be seen through the central island of the roundabout. The vehicle stops at the point of dashed traffic signs.
- Step 3: After three vehicles pass, Vehicle 1 continues to drive in the opposite direction through the entrance to the roundabout. It joins its lane via the lane of the opposite direction. The trajectory of the vehicle is marked by a solid red line. The dashed yellow line indicates the correct passage via the turbo-roundabout.

This was a case of a very gross violation of traffic rules (i.e., operational traffic conflict). This is, of course, a unique case; however, it raises the question of whether, from the point of view of the driver, the relevant entrance to the turbo-roundabout does not appear to be a standard intersection with two-way traffic on the main road or whether there are insufficient traffic signs, among other possibilities. Then, it would be a construction traffic conflict. However, this is not the case here, which is why the traffic conflict is marked 6x3-O1P. As a result of the uniqueness of this case and also its seriousness, it is not necessary to elaborate on the possible designation of the situation with a milder degree of seriousness (even if no other vehicles are limited/endangered).

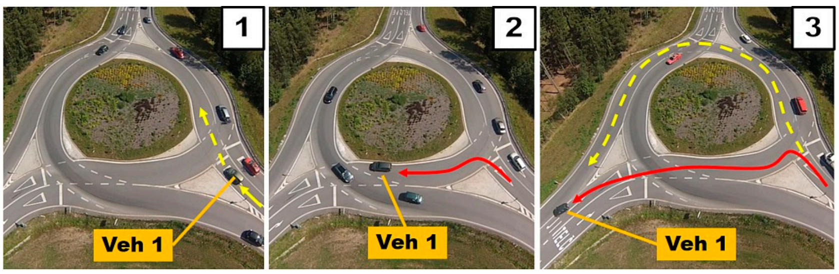


Figure 18. Driving in the opposite direction: dangerous entrance of the vehicle in the opposite direction (Jihlava, Czech Republic; GPS: 49.3809189 N, 15.5125189 E); (1)–(3): successive phases of traffic conflict.

3.8. Turning of the Vehicles (Turning of the Vehicle in a Place Where the Lanes Do Not Allow Turning) and Other Traffic Conflicts

Symbol 2o1-O1P or 6o2(3)-O1P: 2 or 6—vehicle or vehicle + vehicle; o—turning of vehicles; 1 or 2(3)—seriousness of the first, second or third level; O—own TC; 1—primary TC; P—operational TC.

Standard roundabouts quite commonly allow vehicles to turn safely or return to the direction from which they originally came. This is one of the significant advantages of this type of intersection. However, this is not always the case at a turbo-roundabout due to its type.

Figure 19 shows the turning of a vehicle (Veh 2: white passenger car) in the turbo-roundabout in places where this maneuver is not allowed. The vehicle on the circulatory roadway enters the inner lane and, after crossing the central island, exits through the same leg of the roundabout from which it arrived. The maneuver of turning the vehicle at the turbo-roundabout can be marked with the summary symbol 2o1-O1P in the absence of other road users or 6o2(3)-O1P in the presence of other vehicles.

However, the picture in this figure also shows other traffic conflicts that occurred in this time period:

- Vehicle 1 (green-red lorry) (steps 1–4) does not respect the traffic signs "undesirable intertwining of vehicles", and the vehicle shortens the driving path (designation 2p1-O1P, or 6p2(3)-O1P);
- Vehicle 3 (white lorry) (step 1) does not respect the traffic sign "unwanted driving to the circulatory roadway" (sign "d"), and the vehicle crosses the traffic signs (designation 2d1-O1S, or 6d2 (3)-O1S);
- Vehicle 4 (blue passenger car) (steps 2–4) performs an "unwanted change of direction", and the vehicle crosses into the inner lane on the circulatory roadway and then changes direction again to exit through the outer lane of the circulatory roadway (designation 2k1-O1P or 6k2(3)-O1P);
- Vehicle 5 (gray passenger car) (steps 3–5) performs an "unwanted change of direction", and the vehicle crosses to the inner lane on the circulatory roadway and then changes its direction again to exit through the outer lane of the circulatory roadway (designation 2k1-O1P or 6k2(3)-O1P).

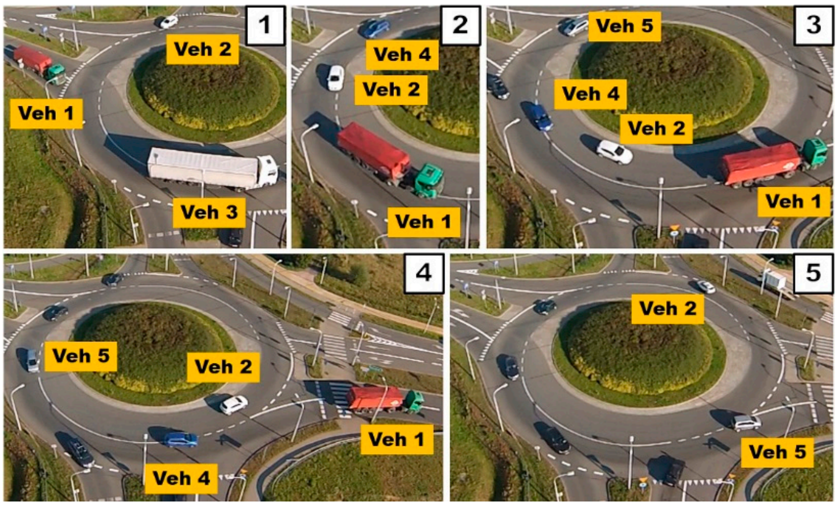


Figure 19. Turning of the vehicle and other traffic conflicts (Zory, Poland; GPS: 50.0614958 N, 18.6630994 E); (1)–(5): successive phases of traffic conflict.

3.9. Stopping at the Circulatory Roadway

Symbol 6z3-O1P: 6—vehicle + vehicle; z—stopping at the circulatory roadway; 3—seriousness of the third level; O—own TC; 1—primary TC; P—operational TC.

This observed situation is unusual at first sight; however, the panic of drivers can make this a relatively common situation. In Figure 20, Vehicle 1 suddenly stops at the exit of the turbo-roundabout, i.e., at the moment when he/she probably realized that he/she was going in the wrong direction. Other vehicles (2 and 3) are affected here and are forced to stop completely. It is interesting that

Vehicle 2, which moves similarly to Vehicle 1, also leaves the given exit according to photo 2, but in photo 3, it returns to the circulatory roadway and exits from the turbo-roundabout at another exit. Vehicle 1 eventually does so as well, passing over a physical island (see photo 5). This situation (similar to the situation above, i.e., driving in the opposite direction) is again designated by the symbol 6z3-O1P due to its seriousness.

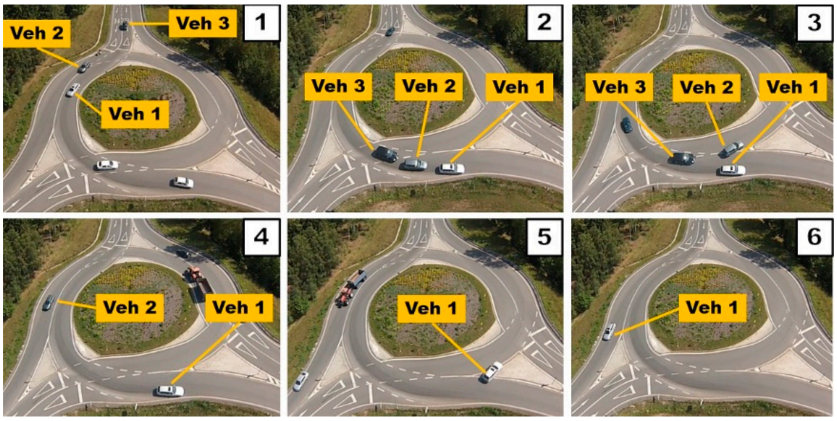


Figure 20. Stopping of the vehicle on the circulatory roadway (Jihlava, Czech Republic; GPS: 49.3809189 N, 15.5125189 E); (1)–(6): successive phases of traffic conflict.

3.10. Other Traffic Conflicts

There were a number of other traffic conflicts at the monitored turbo-roundabouts, for example,

- Driving to the curb or outside of the paved part of the road (the reason may be a faulty geometry of the turbo-roundabout, the absence of a "spike" or only the unpredictable behavior of the driver);
- Risky parallel driving on a circulatory roadway, when the vehicle in one lane is affected by a vehicle traveling in a parallel lane (usually, this is due to a lack of respecting horizontal traffic signs or the absence of the physical separation of lanes);
- Passing over the physical separation of lanes on the circulatory roadway because of a change of direction or turning of a vehicle in an arrangement that is not allowed by the turbo-roundabout (this is usually a mistake of a driver who does not respect vertical and horizontal traffic signs).

4. Discussion and Conclusions

The presented article addresses very specific issues of turbo-roundabouts. However, with a more global view of this issue, we realize the connection to sustainable transport. Incorrectly designed infrastructure can cause or intensify the negative consequences of transport on the environment, the health of the population, etc. Even a small detail that is not precisely finished can have immense consequences. If, for example, we look at the last-mentioned figure (Figure 20), it may seem at first sight that the driver of the white vehicle (Veh 1) only panicked and that this situation is unique. However, the cause may be a poorly designed roundabout, such as a poorly designed orientation of road signs (which may be the case in Figure 20) or an overall problematic construction layout of the turbo-roundabout (this could have resulted in the situation in Figure 18). These details could have caused serious accidents in these cases.

Therefore, the designer of road structures has to consider whether his/her intersection project can cause any of the traffic conflicts mentioned in this article. He/she does not have to conduct such detailed research but could learn from the conflicts mentioned here, as these are the most frequent conflicts at turbo-roundabouts.

Therefore, this article describes chosen traffic conflicts that were observed within the scope of the conducted research at turbo-roundabouts in Europe. Construction traffic conflicts (denoted by the symbol S) were analyzed to assess the effectiveness of the geometry of turbo-roundabouts and their building elements (the impact of physical separation of lanes, the effectiveness of the spike element, the passage of the vehicle over the truck apron or outside truck apron, etc.). Further, there were operational traffic conflicts (P), which can be helpful in the analysis of traffic signs (i.e., whether the situation that was observed had any connection to traffic signs, i.e., if it was due to the wrong guidance of the driver into the roundabout, ambiguous traffic signs, missing horizontal or vertical traffic signs, etc.).

The presented method of video analysis of traffic conflicts and the results stated here confirm certain hypotheses. The analysis of traffic conflicts in road transport is of considerable importance in designing safer roads and can be a suitable tool for more comprehensive safety inspections. It was further confirmed that turbo-roundabouts, which are considered by many experts to be a highly sophisticated and safe solution to intersections, can be a cause of often very serious traffic conflicts, even if all technical standards and principles for the design of intersections were met during the design.

Finally, we present the following summary. As mentioned, for example, in the Introduction of this article, the issue of road safety is a very broad topic that receives much attention. Therefore, it can provoke a number of other discussions on how to monitor, analyze and approach this issue. The main aim of the presented article was to introduce the practical/application use of the method developed by the authors. The method has been used in the analysis of road traffic at turbo-roundabouts in selected European countries for several years. The article's concept is focused mainly on public roadway experts who use practical methods in their activities that can improve their work. These are mainly designers of transport constructions, as mentioned above. They are certainly interested in designing only safe constructions. However, they do not always succeed, even when in compliance with applicable regulations (and it may not always be the fault of the designer). The method mentioned in the article, including the presented examples, can prevent subsequent problems (i.e., accidents). It is quite obvious that it is always better to eliminate these problems or reduce them to the smallest possible degree than to deal with their consequences, which can be and usually are relatively serious (death, injury, property damage).

Traffic conflicts caused by an inappropriately designed intersection can be solved by its appropriate modifications. However, it is always necessary to keep in mind that any change, even a positive one, may result in another problem or problems (which are often more serious). For example, converting a classic two-lane roundabout to a theoretically (and mostly practically) safer turbo-roundabout can cause drivers to behave with uncertainty due to the lack of clarity of this type of roundabout, especially for drivers who pass it for the first time. There are certainly more examples like this.

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