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PRELIMINARY SAFETY ASSESSMENT OF POLISH INTERCHANGES

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Abstract:

Interchanges are a key and the most complex element of a road infrastructure. The safety and functionality of interchanges determine the traffic conditions and safety of the entire road network. This applies particularly to motorways and expressways, for which they are the only way to access and exchange traffic. A big problem in Poland is the lack of comprehensive tools for designers at individual stages of the design process. This applies to guidelines or other documents regarding the location, choice of interchanges type and selection of design parameters. This does not provide sufficient material for designing safe and functional interchanges. This situation results in numerous hazards that occur on existing interchanges and errors that are still being made at all stages of the design process. Consequently, there is a risk of accidents in the area of interchanges, which often have serious consequences.
The purpose of the research presented in the article is to identify main groups of hazards on the interchanges and to classify them based on field tests and audits of project documentation. The prepared classification uses the results of analyzing data on road accidents. As part of the research, a database was built that includes information on road accidents and traffic, as well as data on all existing interchanges on motorways and expressways in Poland. These data includes: interchange type, length of exit and entry lanes, total interchanges length, type of cross-section on main roads and ramps. The number and type of ramps occurring at a given interchange as well as the type of intersections, if any, were also taken into account.
Based on the assessment, the level of safety was determined for individual types of interchanges. Then, the impact of selected road and traffic factors on safety was presented. The critical elements of interchanges are entries, exits, weaving sections and intersections. Assumptions were also adopted for the classification of identified hazards.
A comprehensive safety assessment for interchanges allowed the development of assumptions for their design guidelines. On the basis of database exploration and field research, the main problems and hazards regarding the functioning of interchanges were identified.

Keywords: *road safety, road infrastructure, interchanges*

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1. Introduction

1.1. General characteristics of road interchanges

A road interchange can be defined as an engineering structure that provide connecting roads in more than one level, with full or partial choice of direction (Krystek, 2008). Defining a interchange alone is insufficient, since such a definition refers to a point, and the interchange should be considered as an area category. The area of the interchange includes sections of intersecting or connecting roads together with ramps and collecting and distributing roads. This area is limited by changes in the cross section of the main roadways caused by additional lanes, including the turn off and turn on lane or intersections that are part of these interchange. What is extremely important, the area of the interchange includes intersections that are elements of this interchange (for selected types) and sections between intersections.

The basic division of interchanges distinguishes three types that occur in Poland (Krystek, 2008; MIC, 2016) and in many countries around the world (RAA, 2008; Austroads, 2015; AASHTO, 2018) and which meet the functional and technical requirements of the interchanges (Fig. 1):

– type WA, crossing-free - on which there is no crossing of driving paths, and turn relations are implemented only as maneuvers for deceleration, acceleration and weaving,
– type WB, partly crossing-free - on which intersection of driving paths occurs on some of the routes; at this interchange there is a intersection or a set of intersections on this road, however, relations with the dominant volumes are conducted without collision,
– type WC - on which only the main road intersects at different levels, while the turn relations on both roads take place at the intersections.

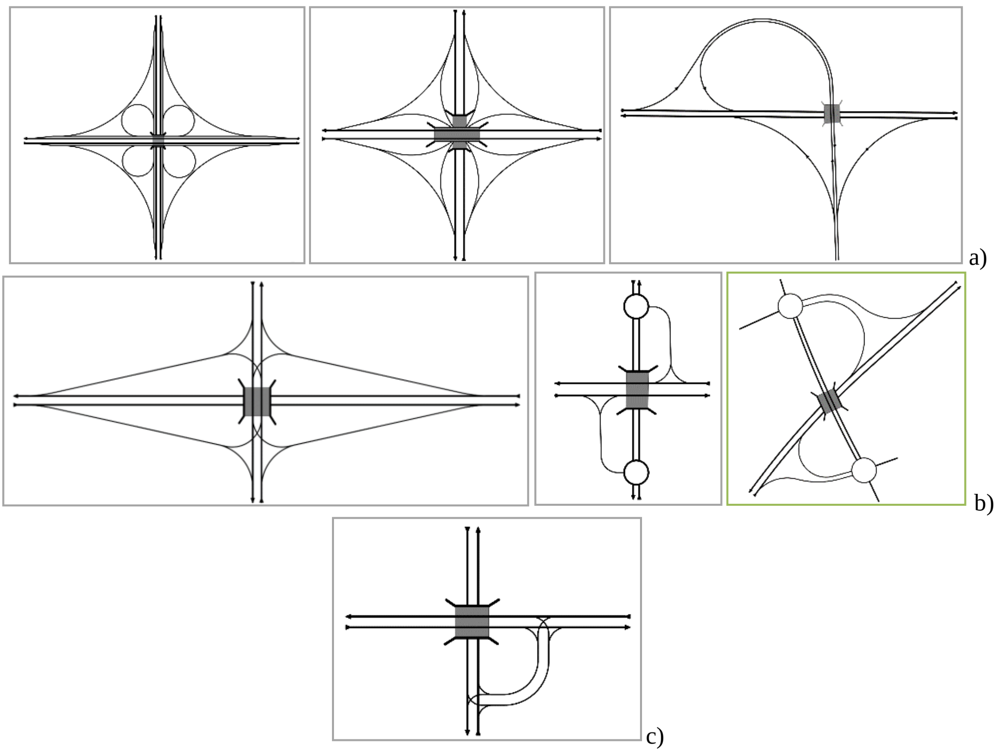
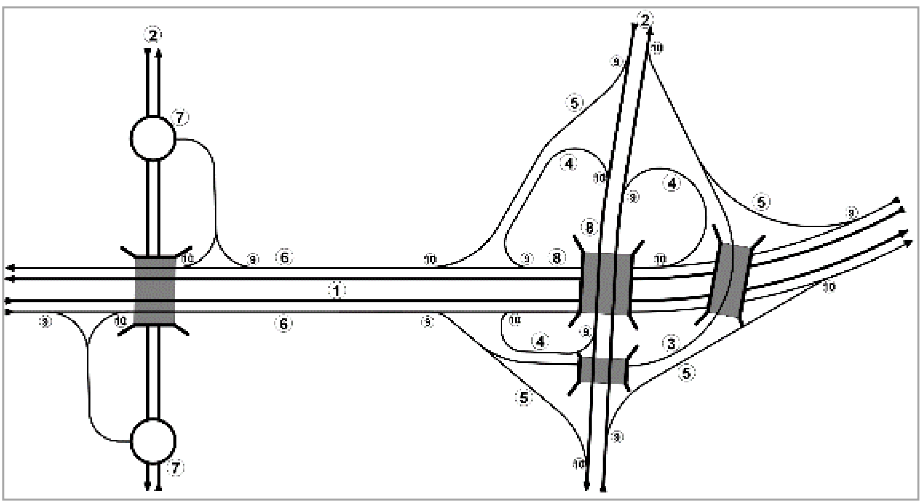


Fig. 1. Type of interchanges: a) WA, b) WB, c) WC

In the area of the interchange, the following elements, which should be assessed in terms of functionality and safety are (Krystek, 2008) (Fig. 2):

– main roadways, crossing at different levels (these are mainly roadways that lead traffic on straight relations),
– exits, places where the traffic flow diverging from the main road, a collecting and distributing road or a ramp,
– entries, places where the flow of traffic joins to the main road, a collecting and distributing road or a ramp,
– deceleration lanes, additional traffic lanes, enabling speed reduction and diverging from the main road, a collecting and distributing road or a ramp
– acceleration lanes, additional traffic lanes, enabling to increase speed and merge into the main roads, a collecting and distributing road or a ramp
– ramp, sections of additional roadways, connecting exits with entries, which are divided into indirect, semi-direct and direct (depending on parameters and a shape),
– sections of weaving, in which vehicle streams intersect: oncoming and exiting vehicles and moving straight ahead on the main road, a collecting and distributing road or the ramp,
– collecting and distributing roadways, enabling the entrance and exit of traffic flows outside the main road,
– engineering objects, enabling crossing of traffic flows at different levels,
– intersections (in selected types of interchanges), enabling the possibility to choose the direction of travel,
– additional equipment (road safety devices, such as road barriers, lighting, drainage, traffic organization, infrastructure for pedestrians, cyclists and public transport), necessary for the efficient and safe functioning of interchange.

Road interchange, besides being a traffic exchange point, are important elements of the road network. Their location and number on the road determine the function and weight of the road in the network. For A class roads (motorways) and S class (express roads), interchange are the only traffic exchange points, their location along these roads determines accessibility. Road interchange, besides being a traffic exchange point, are important elements of the road network. Their location and number on the road determine the function and weight of the road in the network. For A class roads (motorways) and S class (express roads), interchange are the only traffic exchange points, their location along these roads determines accessibility. The exception to this rule are



1– main roadways, 2 – subordinate roadway, 3 – semi-direct ramp, 4 – indirect ramp, 5 – direct ramp, 6 – collecting and distributing roadways, 7 – intersection with subordinate road, 8 – weaving section, 9 – exits, 10 – entrance

Fig. 2. Diagram of a complex interchange with highlighting of its detailed elements

single carriageway of S class roads, where there are intersections, but this is an extremely dangerous solution and in the new regulations currently being developed for road design, this class of roads will be designed only as dual carriageways. On the other road network, including sections of city roads, the occurrence of interchange significantly increases the rank of a road. Unfortunately, in Poland there are not enough tools to support the design process in the planning and design of interchanges. The only documents available are part of the Regulation on technical conditions (MIC, 2016), where the basic technical parameters of the interchange design are given, taking into account the criteria for choosing the interchange type and its parameters, including safety, to a very small extent. There are no guidelines for the design of interchange, with an indication of possible solutions in difficult design conditions (due to e.g. development, accessibility requirements). This applies not only to interchange, but to the entire road infrastructure. Therefore, it is necessary to develop new regulations in the field of road design (technical conditions - level I regulations and design guidelines - level II). Very important issue is also the assessment of traffic conditions (Romanowska et al., 2019).

1.2. Safety at interchanges -review

1.2.1. General studies

Rudyk et al. (2019) emphasized that prevention is a key factor in improving safety. An important element of this prevention is properly prepared road infrastructure. The selection of transport infrastructure parameters is preceded by the development of a transport needs forecast. Depending on the accuracy of the forecasts created, restrictions and bottlenecks of the built infrastructure may appear at different times (Jacyna et al., 2011). Interchanges can be classified as the most complex elements of the road network, both in terms of design and use. For this reason, they are sensitive to mistakes made in the design process, from the planning stage, through the concept, construction project to maintenance. One of the basic functional features of interchanges, like the entire road infrastructure, is user safety. Analyzing only the network of high speed roads (motorways and expressways roads) it can be concluded that a significant proportion of road accidents concentrates on interchanges, while on stretch between interchanges sections they are dispersed and rarely occur in a larger number in one location (Abatan and Savolainen, 2018). Research work in the area of safety assessment of interchanges focuses on the analysis of hazards and the possibilities of their mitigation (Bonneson et al., 2012). As part of the research work, recommendations are made for the design of interchanges in terms of improving safety, related to areas of traffic exchange (sections of the traffic flow exit, entry and weaving). Attention is paid to the importance of distance between interchanges, proper marking and traffic control within interchanges (Layton, 2012). Green et al. (2010) compared the accident rates in traffic exchange areas and in neighboring areas. Areas of traffic exchange due to the occurrence of conflicts, the need for drivers to make quick decisions and often complex geometry, showed significantly higher values of these indicators. A distinction should also be made between the specificity of the design and use of interchanges in urban agglomeration areas where there is very high pressure on road accessibility (Kiattikomol, 2008).

1.2.2. The influence of ramps parameters on safety

The ramps are the sections where the exit and entry to the main roads take place. The ramps have curves with very different parameters. Entrances and exits from the main road cause variations in vehicle speeds, and all this creates potential conflict situations (Chimba et al., 2006). Traffic conditions on ramps have an impact on safety, in the event of their deterioration, the risk of road accidents increases (Hu et al., 2017). Some studies show the impact of the length of the ramps on the level of safety - when the length of ramp increases, the risk of accidents decreases (Bauer and Harwood, 1998; Chen et al., 2011; Li et al., 2012). But when assessing the impact of the length ramp on motorcyclist accidents, long ramps negatively affect the level of safety (Chen et al., 2014), Some studies, however, do not show the impact of the length of the ramps on the level of safety, but indicate the influence of other parameters (Garnowski and Manner 2011; Wang et al., 2015). When analyzing the situational plan for road sections, one of the methods for assessing the ramps of interchanges may be research using floating car data (Ambros et al., 2019).

1.2.3. Entry and exit lane

Entry lane (accelerating) and exit lane (decelerating) sections are places where the risk of accidents significantly increases (FHWA, 2010). The selection of the length of these sections depends on the speed on the main roads and on the ramps, and on the acceleration and deceleration values desired from a safety point of view. Based on the review of the test results, the safety effect of these parameters cannot be clearly determined. Research results concluding that increased lengths of acceleration and deceleration lead to a reduction in the number of accidents, it can be found in (Bared et al., 1998; Sarhan et al., 2008; Wang et al., 2009). However, some studies indicate the opposite effect (Chen et al., 2009, 2011; Garnowski and Manner, 2011). In studies conducted by (Garcia and Romero, 2006), it was found that long sections of exit will encourage drivers to maintain high speeds before leaving the main road. Test results generally indicate that above certain values for the length of the on and off sections the level of safety can get worsen.

1.2.4. Weaving sections

Weaving sections are very important elements in the area of the interchange that affect safety (Golob et al., 2004). Weaving sections research focuses on various aspects related to a safety impact: analysis of road accident risk factors (Rundmo and Iversen, 2004; Havârneanu and Havârneanu, 2012), characteristics of the distribution of road accidents (Plug et al., 2011; Yeung and Wong, 2013), forecasting of road accidents (Abdel-Aty and Radwan, 2000; Dinu and Veeraragavan, 2011), identification of road accident risk points (Loo, 2009; Martín et al., 2014), road safety assessment (Minderhoud and Bovy, 2001) and prevention of road accidents (Salvarani et al., 2009).

1.2.5. Others

An example of a comprehensive study of the impact of interchange types and its individual elements on road safety is the ISAT project (FHWA, 2007; Torbic et al., 2009). As a part of the project, a tool was built to assess the impact of changing interchange parameters on user safety. Studies on the impact of selected elements of road infrastructure on expressways, including interchanges, were presented in the study of Ambros et al. (2018). Traffic exchange points, marking, number of lanes and parameters of ramps (type, length, radii of horizontal curves) were analyzed. One of the very important aspects of interchanges safety research is the assessment of traffic incident types, their location and severity (Sun et al., 2016). Identification and classification of sources of hazards and hazards is the basis for implementing corrective actions (Budzynski et al., 2017).

2. Data and method

2.1. Safety on motorways and expressways in Poland

The state of safety on motorways and expressways should be related to the length of the road network and to the general level of safety on all roads. In the years 2010 - 2018, the number of accidents on the entire road network in Poland decreased from nearly 39,000 to nearly 37,000, and the number of fatalities dropped from 3,907 to 2,862. At the same time, the number of fatalities on expressways increased from 65 to 107 (Figure 3). However, this should be analysed in the context of the significant increase in the length of fast roads during this period. In the years 2010 - 2018, the length of motorways in Poland doubled (in 2018 - more than 1,600 km) and the length of expressways increased more than threefold (in 2018 - almost 2,000 km). Therefore, the change in the number of accidents and fatalities on expressways should be assessed by density, i.e. calculated on the length of this network (measure of social risk). Based on Figure 4, it can be estimated that the number of fatalities per 100 km of motorways and expressways remains stable, which is not a favourable phenomenon and shows that despite the high technical standard in force in these road classes, it is still necessary to take action to improve road safety. Another measure for assessing the level of safety is the value of individual risk (number of accidents or fatalities per 1 mln vehkm). Unfortunately, the lack of data from the General Road Traffic Measurement for 2020 (traffic surveys are carried out every 5 years) makes such an assessment impossible in 2010-2015. Based on the comparison of the value of the individual risk for accidents IR_a and fatalities IR_f in 2010 and 2015, the following results were obtained:

- The IR_a for motorways in 2010 was 0.038, and in 2015 - 0.025,
- The IR_a for express roads in 2010 was 0.032, and in 2015 - 0.023,

– The IR_f for motorways in 2010 was 0.0038, and in 2015 - 0.004,
– The IR_f for expressways in 2010 was 0.008, and in 2015 - 0.0037.

The above data indicate that the IR_a value for motorways and expressways decreased by about 30%, the IR_f value for express roads decreased by nearly 50%, while the IR_f value for motorways remained at a similar level (slightly increased) for the entire period under study. It follows that in the analyzed period the safety level on express roads improved, while on motorways there was no such improvement in relation to fatalities.

2.2. Characteristics of interchanges on motorways

Interchanges are a critical element of the high-speed-way network. As a part of the construction of a method for assessing the safety of interchanges, in the first stage of work, which is the basis of this article, the authors focused on highway interchanges. Based on the review of interchange types at 1705 km (end of 2019) of motorways, 155 interchanges were identified, of which 66 are WA and 89 are WB interchanges. The average distance between interchanges was 11 km (Table 1), but there were large discrepancies here, the shortest distances between junctions on motorways were from 2 km to 25 km (measured between the axis of the interchanges).

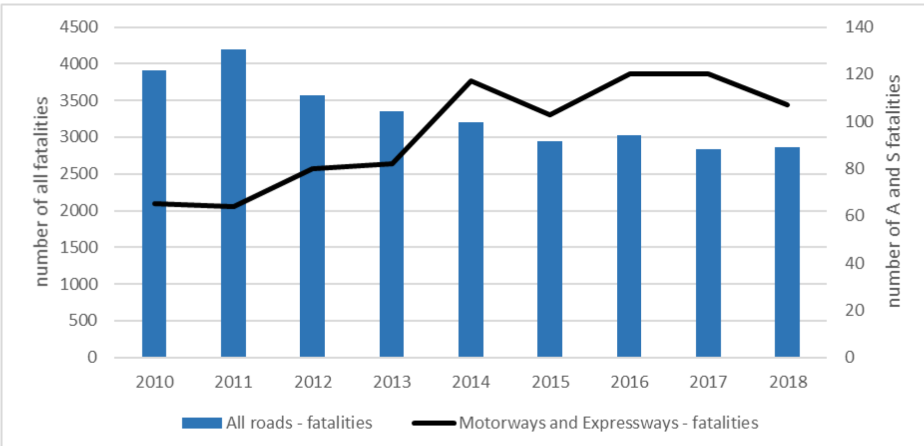


Fig. 3. Number of fatalities in 2010 – 2018 years

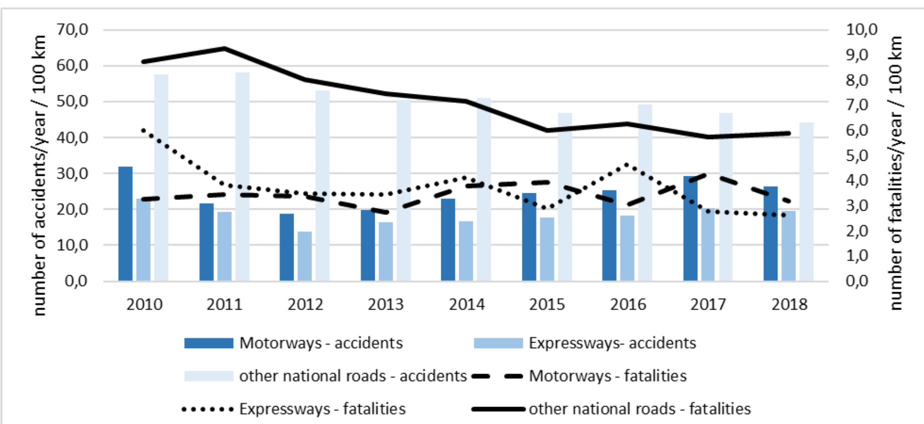


Fig. 4. Density of accidents and fatalities in 2010 – 2018 years

Table 1. General data about interchanges on motorways in Poland

Motorway	Length [km]	Number of interchanges	Number of interchanges WA type	Number of interchanges WB type	Average distance between interchanges [km]
A1	503	45	35	10	11,2
A2	475	27	9	18	17,6
A4	673	73	17	56	9,2
A6	26	3	1	2	8,7
A8	22	6	4	2	3,7
A18	6	1	0	1	6,0
Sum	1705	155	66	89	11,0

By analysing the types of interchanges, the following solutions can be identified on motorways:

- trumpet type WB (three-way interchange, with crossroads located on the transverse road at a distance of up to 500 m from the beginning of the exit lane or the end of the entry lane) - 50 interchanges (fig. 5a),
- half-cloverleaf - 37 interchanges (fig. 5b),
- trumpet type WA (three-way interchange, with crossroads located more than 500 m from the beginning of the exit lane or end of the entry lane) - 36 interchanges (fig. 5c),
- double trumpet (connection of two trumpet interchanges at the four-port interchange) - 12 interchanges (fig. 5d),
- cloverleaf – 8 interchanges (fig. 5e),
- directional interchanges - 2 three-way and 2 four-way interchanges (fig. 5f and 5g),
- incomplete (no turn relationships selected) - 4 interchanges (fig. 5h),
- diamond - 2 interchanges (fig. 5i),
- individual interchanges: 1 scissors, 1 pear (fig. 5j and 5k).

The diverse selection of interchange types on individual motorways is noteworthy. Trumpet interchanges dominate on the A1 motorway (over 70%), trumpet interchanges (55%) and half-cloverleaf (19%) stand out on A2 motorway, and trumpet interchanges (38%) and half-cloverleaf (32%) stand out on A4.

2.3. Safety on motorway interchanges

Due to the completed and verified data on the location of accidents on motorways the 2012-2016 time interval was analysed. Analysis of the level of safety at interchanges based on available databases is difficult and time consuming. Deficiencies and inaccurate localization of accidents are reflected in databases. This requires verification of each accident so that its location can be assigned on the section between interchanges or on the interchange. For the purposes of constructing assumptions for the interchange safety assessment method, the authors adopted, as accidents on interchange (assigned to the motorway), those which were located on main roads, collecting and distributing roadways and ramps near the highway road. Therefore, the number of accidents at interchange is actually much higher, but they are assigned to the second road (the same elements as on the highway and additionally intersections in the case of WB interchanges).

Accidents within the motorway interchange were located on the basis of reference sections from the General Road Traffic Measurement of 2015 (as points on the motorway sections). Based on the measurements of the length of the inclusion and exclusion lanes, the range of the interchange area was determined and then accidents were assigned to the interchange area according to their mileage. For this purpose, available GIS tools were used (e.g. openstreetmap.org, google.com/maps). Table 2 presents the safety characteristics for motorways interchanges. The results presented in Table 2 do not take into account the impact of traffic volume due to the general nature of the analysis. The preliminary analysis showed that the WA interchanges were more loaded with road traffic than the WB interchanges. This is consistent with the conclusions set out below. There are four aspects to note:

- Very high severity of accidents on interchanges, almost every second accident ends in the occurrence of a seriously injured or fatal victim.
- The severity of accidents on WA interchanges is clearly higher than the severity of accidents on

WB interchanges, which can be explained by higher speeds on ramps and by the occurrence of weaving sections, including on main units. There is also a serious problem of interchange type WA (trumpet), which is often not adapted to high access speeds to the interchange.

– The number of accidents in relation to the number of interchanges is clearly higher in the case of WB interchanges, which can be explained by the worse parameters of these interchanges.

– The number of fatalities in relation to the number of interchanges is similar, with an indication of WB interchanges.

Summing up this part, it should be emphasized that from the point of view of operational parameters, WA interchanges will be more favourable to users, while from the point of view of road safety the interchange type is not a sufficient assessment criterion.

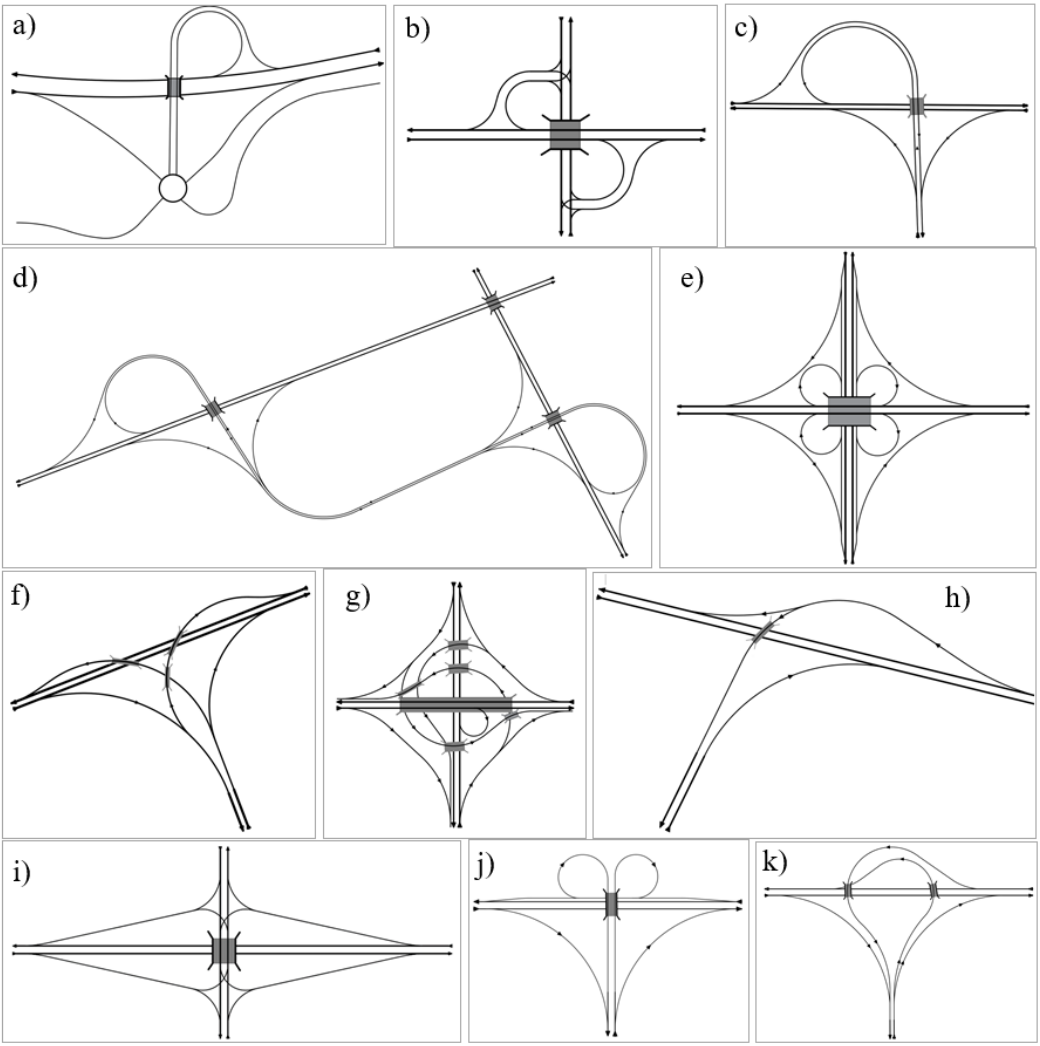


Fig. 5 Diagrams of interchanges on motorways in Poland

Table 2. Safety characteristics of highway interchanges

Parameter	Interchanges WA type	Interchanges WB type
share in the total number of interchanges [%]	43	57
accidents [%]	32	68
injured victims [%]	32.0	68.0
seriously injured victims [%]	39.0	61.0
fatalities [%]	32.0	68.0
severity of accidents [number of fatalities and seriously injured / 100 injuries]	54.0	42.1
number of accidents to the number of interchanges [in the year]	0.30	0.48
number of fatalities to the number of interchanges [in the year]	0.16	0.20

2.4. Identification of typical accidents on interchanges

The most common accidents within interchanges include:

- Head-on collisions - intersections, ramps and main roads. The most common reason is 'upstream' driving as a result of a driver error - often due to incorrect geometry and marking.
- Side-swipe collisions - at the intersections of ramps with subordinate roadway (WB and WC interchanges) and at the inclusion and weaving sections. The most common reasons are restrictions on visibility, forcing priority.
- Rear-end collision - main roadways and ramps. The most common causes are not keeping a safe distance, too high speed in the area of interchanges.
- Run off the road accidents - colliding with an obstacle or the vehicle falling over off the road or ramp. The most common cause is excessive speed, incorrect geometry, incorrect shaping of the road surface
- Collision of pedestrians, cyclists - main roads, ramps. The most common reason is for pedestrians and cyclists crossing the main road and interchange in unauthorized places (lack of appropriate infrastructure or crossing next to designated places, e.g. under the footbridge).

Figure 6 shows an illustration of typical accidents that occur on ramps and within acceleration and deceleration lanes.

3. Results

3.1. Identification of typical accidents on interchanges

Accidents that occur on interchanges are a consequence of driving errors on the one hand, but very often these errors are generated by hazards related to incorrect characteristics of interchanges, which results from design errors.

The authors analyzed reports on road traffic safety audit, design documentation for motorways and expressways, and road traffic safety inspection reports. On this basis, they identified the main errors that could result in road accidents at interchanges. Additional data was obtained as part of the courses of road safety audit and periodic courses for auditors and road safety inspectors. In total, about 40 different design variants and about 20 existing solutions were assessed. The most common interchange design errors that threaten users safety are:

- lack or incorrect protection of the "nose" of the novice ramp (the exit ramp from the main road or collecting and distributing roadways (about 40%),
- design of ramps enabling the development of high speeds, with the need of reducing this speed at the ends of the ramps, including in the case of simultaneous reduction in the cross-section of more than one lane (about 35%).
- incorrect selection of the cross-section of the ramps, a lack of collecting and distributing roadways on weaving sections of main roads (at speeds above 80 km/h) (about 30%),
- too short sections of exit ramps from on interchange (about 25%),
- incorrect location of infrastructure for pedestrian, bicycle and public transport in the area of the interchange (about 25%),
- lack of visibility of signing on indirect ramp (about 20%),
- too short lengths of visibility sections to stop against obstacles on ramps (about 20%),
- lack of coordination of plan geometry and grade lines on ramps (about 10%),
- starting deceleration lanes behind the object, which causes too late visibility of leaving the main road (about 10%).

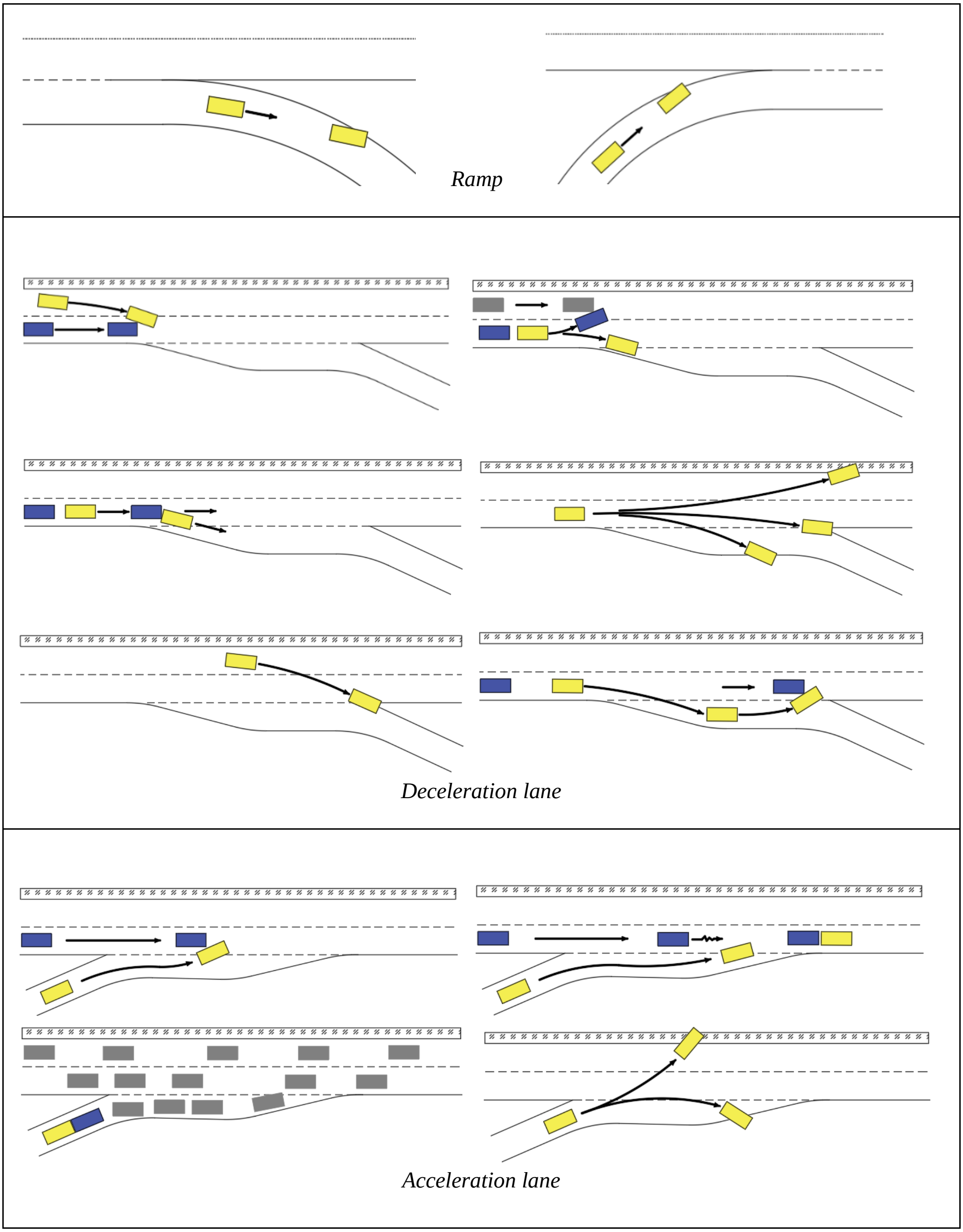


Fig. 6 Typical accidents in the area of interchange (source: own study based on Sun et al., 2016)

3.2. Impact of selected factors on interchange safety

To assess an impact of selected road and traffic factors on interchange safety, first of all it is necessary to identify the significance of the impact of selected factors on road safety (the number of fatalities and seriously injured in the area of the interchange, which are assigned to the highway in the SEWIK police database). Based on research carried out in the USA (Pilko et al., 2007), model (1) was used, for which $R^2 = 0.58$ was obtained. Model (1) was used to analyze the impact of selected parameters, based on the example of A1 motorway interchanges (45 interchanges). The STATISTICA program was used for the analyzes. Table 3 shows the values of the calculation factors.

$$NV = e^{\left(\alpha+\beta_1\cdot\ln\left(\mathrm{AADT/NL}\right)+\beta_2\cdot(\mathrm{L})+\beta_3\cdot(\mathrm{DR})+\beta_4\cdot(\mathrm{WS})\right)} \quad (1)$$

where: NV – number of fatalities and seriously injured per year in the interchange area, AADT/NL – traffic volume across the main road / number of lanes [vehicle / day/number of lanes], L – distance between interchanges [km], DR – occurrence of collecting and distributing roads (0 – absent, 1 - present), WS – occurrence of the weaving section on the main road (0 – absent, 1 - present).

Table 3. Parameter estimates of the crash prediction models of Eq. (1)

Coefficients		Value	p-Value
Intercept	α	-6.32	< 0.001
AADT/NL	β_1	0.75	< 0.001
L	β_2	-0.24	< 0.001
DR	β_3	-2.73	< 0.001
WS	β_4	3.65	< 0.001

On the basis of the obtained results, it is possible to confirm the influence of the analyzed factors on the number of seriously injured and fatalities at the interchanges. This impact should be assessed positively in the case of increasing the distance between interchanges and the presence of collecting and distributing roads. On the other hand, the impact of the weaving sections on the main roadway is assessed negatively. In order to increase the reliability of the analysis, it is necessary to increase the research sample and take into account other parameters, e.g. speed in the interchanges area and parameters of ramps.

3.3. Criteria for assessing interchanges safety

It should be emphasized that presented in chapter 4.3 model is based only on selected parameters for which a significant effect on LO measure has been determined. In further work, the model will be developed, taking into account the length of the sections entry and exit, and the inclination of the ramps. It is also necessary to expand the scope of collected data to include information on the entire interchange area, not just the section within the motorway. Preliminary analyses have shown a positive impact on the safety of greater distances between interchanges and the occurrence of collecting and distributing roads. However, the weaving sections on the main road have a negative impact on safety. Review of hazards identified at interchanges, errors in design documentation and preliminary analytical work allow defining criteria and sub-criteria for the road safety assessment. Figure 7 presents five main criteria and 24 sub-criteria. For selected sub-criteria, a more detailed analysis is needed, which should address the impact of interchange geometry parameters. The proposed set of criteria and sub-criteria can be used for the purposes of multi-criteria analysis. In this analysis, in addition to safety, the main criteria for the assessment of interchanges will be used: impact on the natural and social environment, efficiency (traffic conditions) and life-cycle costs.

4. Discussion

The results presented in point 3 are the result of preliminary analyzes of the impact of the interchange type and the selection of its geometrical parameters on road safety. On the basis of reviews of audits related to road safety (BRD Audits), threats resulting from design errors were identified. Similar threats are also indicated in other studies, e.g. too short sections of exit ramps from on interchange. Studies (Chen et al., 2011) indicated a reduction in the number of accidents with increasing the length of the ramps. However, other studies (Li et al., 2012) indicate an increase in the effects of accidents when the length of the ramps is increased. Therefore, it is necessary to relate these analyzes to types of nodes. In the case of WB interchanges, short exit ramps from expressways pose the risk of increasing the impact of the queue of vehicles in front of the intersection on the interchange area. Another example of an identified treat is acceleration and deceleration lane of an invalid length.

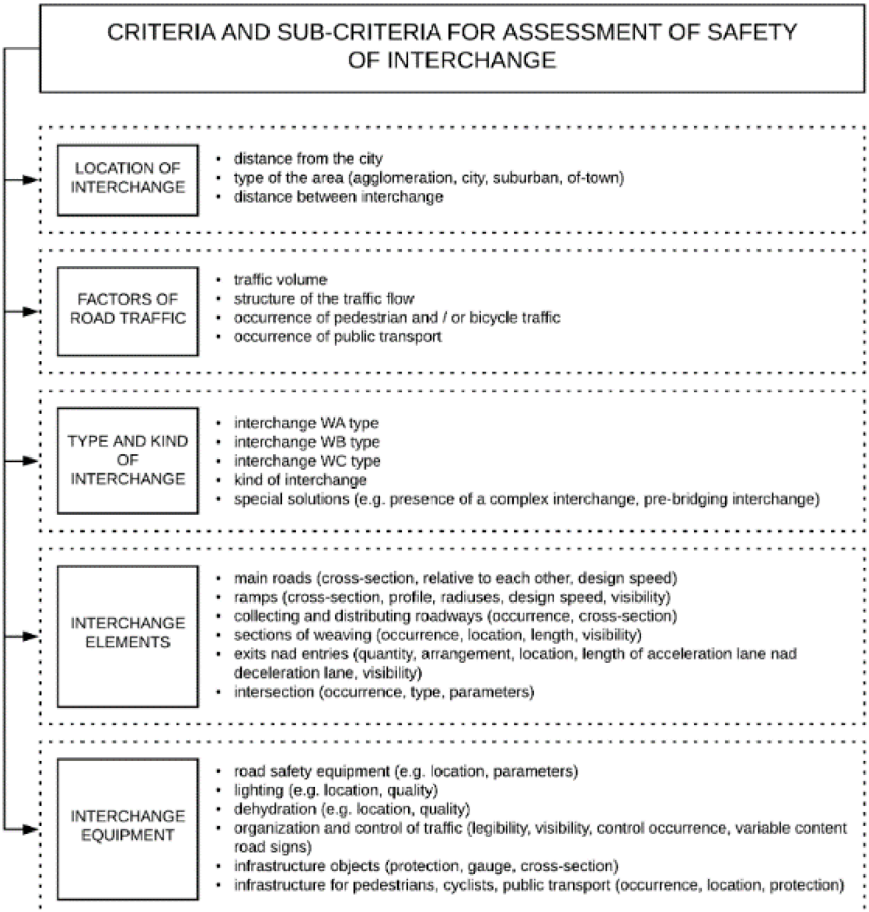


Fig. 7 Set of criteria and sub-criteria for assessing interchanges safety

In studies (Bared et al., 1999 and Sarhan et al., 2008) increased acceleration and deceleration lane lengths leads to reduced number of crashes. But in studies (Garnowski and Manner, 2011), it was indicated that deceleration lane lengths higher 180 meters are associated with increased number of fatal crashes. This also requires additional speed-related analyzes on main lanes in the interchange area.Based on the statistical analysis, a positive impact on road safety was demonstrated in the case of collecting and distributing roads, which is in line with the node design guidelines (AASHT, 2018; Krystek et al. 2008 and FHWA, 2007). The starting point for further more detailed safety analyzes of interchanges in Poland may be the method adopted in studies on the road network in the Czech Republic (Ambros et. Al., 2018). The similar characteristics of the geometric parameters of the interchanges in both countries will make it possible to reliably determine the impact of the parameters of selected elements of interchanges on road safety.

5. Conclusions

Interchanges are the most complex elements of a road infrastructure. For this reason, they require detailed safety analysis of their functioning. As objects particularly sensitive to errors made at all stages of the design process (planning - location, concept -

type, construction project - geometry parameters), they can generate serious hazards to their users. Currently, it becomes necessary to develop a comprehensive interchange evaluation system. This is due to the continuous development of expressways in Poland and the need to rebuild interchanges that do not meet modern safety and functionality standards. Preliminary analysis allowed the identification of the most common hazards in the area of interchanges and determining the impact of selected factors on safety. In the next stages of building the method, it will be necessary to identify accidents and their victims throughout the interchange. In the next stages of research, the authors plan to expand mathematical models and further develop the method of assessing interchanges safety.

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