Influence on the Type of Intersection on Road Traffic Safety in Poland

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Abstract. Analysing accidents in Polish towns it can be seen that a great majority of them occur at intersections. Moreover, it can be observed that some types of intersections are particularly dangerous. Hence, a question arises: which types of intersection can be considered to be more dangerous and which ones less dangerous? It needs to be emphasized that engineering projects do not include guidelines of this type. For designers of road infrastructure this kind of knowledge is very important. Therefore, the article aims at determining the degree of risk to a road traffic user, depending on the intersection type. The risk degree was defined as an average number of accidents falling on 1 vehicle and one traffic lane at the intersection inlet. Data on accidents which occurred in selected Polish towns during 3 years was used. In order to provide diversification of the intersections, each group included intersections with lower and higher significance for the city transport network so the traffic intensity was different for different intersections. The mean risk index as well as the dependence between the number of accidents and a variable characterizing the likelihood of collision were determined for each intersection type by means of regression analysis. Multi-lane roundabouts and intersections with a central island and extended inlets without traffic light signalling (both with right of way for one direction and the necessity of yielding way at each inlet) were found to be the most dangerous types of intersections. Intersections with priority to the right were found to be relatively dangerous, particularly those with traffic canalizing islands. Not channelized intersections with multi-phase traffic signalling were found to be potentially the safest ones. The research shows that single traffic lane roundabouts are potentially safe intersections, for which the risk degree is 2.5 times smaller than at multi-lane roundabouts.

1. Introduction

According to the available results of investigations carried out worldwide the road infrastructure featured by traffic and the surrounding environment has a significant impact on road traffic safety (rts) [1,2]. These results indicate that a great majority of accidents in cities occur at intersections [3,4]. Therefore, they need to be properly designed and maintained to provide road users with safety. The authors’ experiences gained while preparing reports on the State of Road Traffic Safety for many towns show that many accidents occur at intersections of some types. They are included in the lists of places which are most dangerous in terms of road traffic safety in a given town. Hence, a question arises: which intersections can be considered to be more safe and which ones less? Such a classification of intersection types is of great practical importance, as it would enable a constructor to choose the safest intersection at the stage of the road investment design.
Potential level of road traffic safety at particular types of intersections can depend on: clearly specified traffic rules, number of potential collision points, allowable speeds, visibility for the intersection users of traffic streams, angles of intersection of colliding traffic streams, method of utilization of particular traffic channels, type of traffic subordination, etc. [5,6,7,8].

Therefore, the article aims at determination of the risk degree a road user is exposed to depending on the intersection type.

Data bases of Information Systems for Road Traffic Management of (WZDR (Provincial Road Administration)) [9], which have been implemented in a few Polish towns, were used. This system is of complementary character. It includes blocks of data bases (both descriptive and graphic including historical data), analytical blocks enabling detailed analyses and are equipped with appropriate applications and a tool block enabling creation of appropriate data sensor graphics. A data basis consists of a detailed description of all elements of a given town road network. It is made up of a series of theme subsystems—see Figure 1.

![Figure 1. General scheme of computer system of WZDR (Provincial Road Administration) [9]](image)

A subsystem for road traffic safety contains, among others: detailed information on road accidents from the last several years including maps of road accidents. It provides a precious data base to be used for detailed analyses of road traffic risk.
2. Risk assessment for particular intersections

Intersections were divided into 4 groups according to their general shape, (geometry), that is: an ordinary intersection (without traffic channeling), channelized intersections, intersections with a central island and with extended inlets and roundabouts. Next, different types of intersections with different solutions of traffic organization were distinguished. Totally, as many as 16 different kinds of intersections, which are presented in table 1, were analysed. Some types of intersections were not taken into account as data bases include too little information about them, e.g. turbine or spiral roundabouts. In cities, where the analyses of intersections were performed, these types of intersections do not occur.

Table 1. Division of the analysed intersections

| Group of intersections                  | Type of intersections                  | Marking |
|----------------------------------------|----------------------------------------|---------|
| Conventional intersections             | with two phase traffic lights           | ZD      |
|                                        | with multi-phase traffic lights         | ZW      |
|                                        | with priority to the right              | ZR      |
|                                        | with priority of way for straight direction | ZP    |
|                                        | with broken right of way                | ZL      |
| Channelled intersections               | with two-phase traffic lights           | SD      |
|                                        | with multi-phase traffic lights         | SW      |
|                                        | with priority to the right              | SR      |
|                                        | with the right of way for one direction | SP      |
|                                        | with broken priority of way             | SL      |
| Intersections with a central island and | with two-phase traffic lights           | WD      |
| with extended inlet                     | with multi-phase traffic lights         | WW      |
|                                        | with traffic organization like roundabouts | WR    |
|                                        | with right of way                       | WP      |
| Roundabouts                             | with one -traffic lane                  | RJ      |
|                                        | with multi - traffic lane               | RW      |

Among the considered groups of intersections, the so called intersections with a central island and with extended inlets need to be explained, as this type of intersections is not well known in other countries, except for Poland. However, in Poland, in the past (the 70-80-s of XX century) they were pretty common and today there are many of them in many different towns. Traffic on such intersections goes according to the rules similar to roundabouts, that is, around the central island. They are characterized by multi-lane inlets, multi-lane roads around the island and routing of inlet and exit roads tangent to the central island (see Figure 2). Intersections which are not equipped with traffic light signalling, are characterized by high capacity. Hence, these intersections are constructed primarily in big cities, where important arteries cross, and they were designed to postpone construction of traffic nodes. While being used, they turned out to have a serious disadvantage, that is, a significant number of accidents. Therefore, today’s directives [10] do not recommend to use them without traffic light signalling.

Risk assessment for a given type of intersection was performed at an intersection of a given type with the use of an index, expressing the number of accidents per one vehicle and one traffic lane at the inlet:
\[ WR_S = \frac{1}{n} \sum_{i=1}^{n} \frac{LZ_i}{Q_{R,i} \times l_i \times T} \quad \left[ \frac{\text{accidents}}{\text{P} \times \text{traffic lane}} \right] \]  

(1)

where:

- \( WR_S \) – mean risk index of accident rate at ‘S’ type intersection [accidents/P × traffic lane];
- \( LZ_i \) – number of road accidents at a given intersection ‘i’ from ‘S’ type group in ‘T’ period [accidents];
- \( l_i \) – total number of traffic lanes on the inlets of a given intersection ‘i’ [traffic lanes];
- \( Q_{R,i} \) – average annual traffic intensity at a given intersection ‘i’ in analysis period ‘T’ [P/year]:

\[ Q_{R,i} = \frac{1}{T} \sum_{j=1}^{T} Q_{H,M,j,i} \cdot \alpha_{d,M} \times \alpha_M \times \alpha_{R,M} \quad \left[ \frac{\text{P}}{\text{year}} \right] \]  

(2)

\( Q_{H,M,j,i} \) – intensity of traffic measured at 3 selected intersections in the morning rush hours and 3-hour of the afternoon rush hours ‘H’ on a weekday, in a given month ‘M’, in a given year ‘j’ at intersection ‘i’ [P/6h];

- \( \alpha_{d,M} \) – coefficient expressing the share in average daily traffic on a week day of 6-hour traffic intensity in rush hours, in a given month ‘M’ [6h/24h];
- \( \alpha_M \) – coefficient expressing the share in monthly average daily traffic intensity on a weekday in a given month ‘M’ [24h/month];
- \( \alpha_{R,M} \) – coefficient expressing the share in annual traffic of monthly traffic intensity in month ‘M’ [month/year];

- \( T \) – period of analysis: 4 years were accepted [years];

- \( n \) – number of analyzed intersections from the group of ‘S’ type.
The analysis was made on the basis of data from 121 intersections. In order to increase diversity of values of considered variables, intersections with different numbers of traffic lanes at the inlet and with different traffic intensity were selected to a set of the analysed intersection type. Thus, in the set there were intersections important for the city road traffic network (with high traffic intensity) and these with lower traffic intensity.

The analyses included data on accidents from the period of 4 years, that is from 2013-2016. This data, like information on the traffic intensity in rush hours $Q_H$ and the number of traffic lanes at the inlets, come from the WZDR system. Whereas, the values of coefficients $\alpha_{D,M}$, $\alpha_M$, $\alpha_{R,M}$ were determined on the basis of a doctoral dissertation [11].

In order to determine values of risk index $WR_S$ for a given type of intersection, „S”, analysis of regression was used to determine, the so called, direction regression coefficient for function:

$$LZ_{i(S)} = WR_{i(S)} \times x_{i(S)} \text{[accidents]} \quad (3)$$

where:

$x_{i(S)}$ – variable of an accident occurrence likelihood at a given intersection ‘i’, from the set of ‘S’ type of intersections.

$$x_{i(S)} = Q_{R,i(S)} \times I_{i(S)} \times T, \quad (4)$$

The function meets the boundary condition:

$$x_{i(S)} = 0 \rightarrow LZ_{i(S)} = 0 \quad (5)$$

Table 2 shows regression diagrams of $LZ(x)$ function for particular types of „S” intersections. Whereas, in table 3, there are obtained values of regression coefficients, and subsequently indexes of risk $WR_S$ and the values of correlation coefficient, for particular functions.

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**Figure 3.** Diagram of the risk index values for particular intersection types
Table 2. Diagrams of regression function $LZ(x)$ for particular types of intersections ‘S’

| Intersec. marking | Diagram of regression function | Intersection marking | Diagram of regression function |
|-------------------|-------------------------------|----------------------|-------------------------------|
| ZD                | ![Diagram ZD](image)           | ZW                   | ![Diagram ZW](image)          |
| ZR                | ![Diagram ZR](image)           | ZP                   | ![Diagram ZP](image)          |
| ZL                | ![Diagram ZL](image)           | SD                   | ![Diagram SD](image)          |
| SW                | ![Diagram SW](image)           | SR                   | ![Diagram SR](image)          |
| SP                | ![Diagram SP](image)           | SL                   | ![Diagram SL](image)          |
| Intersec. marking | Diagram of regression function | Intersection marking | Diagram of regression function |
|-------------------|--------------------------------|----------------------|--------------------------------|
| ZD                | ![ZD Diagram](image)          | ZW                   | ![ZW Diagram](image)          |
| ZR                | ![ZR Diagram](image)          | ZP                   | ![ZP Diagram](image)          |
| WD                | ![WD Diagram](image)          | WW                   | ![WW Diagram](image)          |
| WR                | ![WR Diagram](image)          | WP                   | ![WP Diagram](image)          |
| RJ                | ![RJ Diagram](image)          | RW                   | ![RW Diagram](image)          |
Table 3. Obtained values of the risk index for particular types of intersections

| Type of intersection | Number of analysed intersections | Value of WR index [accidents/vehicle×traffic lane×10⁻⁸] | Value of correlation coefficient ‘R’ |
|----------------------|----------------------------------|--------------------------------------------------------|---------------------------------------|
| ZD                   | 8                                | 1.01                                                   | 0.71                                  |
| ZW                   | 10                               | 0.46                                                   | 0.87                                  |
| ZR                   | 8                                | 1.49                                                   | 0.71                                  |
| ZP                   | 10                               | 1.00                                                   | 0.93                                  |
| ZL                   | 10                               | 1.28                                                   | 0.92                                  |
| SD                   | 3                                | 0.84                                                   | 0.96                                  |
| SW                   | 10                               | 0.74                                                   | 0.91                                  |
| SR                   | 10                               | 2.01                                                   | 0.76                                  |
| SP                   | 10                               | 1.41                                                   | 0.89                                  |
| SL                   | 6                                | 1.99                                                   | 0.89                                  |
| WD                   | 3                                | 1.39                                                   | 0.97                                  |
| WW                   | 7                                | 1.36                                                   | 0.76                                  |
| WR                   | 10                               | 2.42                                                   | 0.91                                  |
| WP                   | 9                                | 2.15                                                   | 0.89                                  |
| RJ                   | 3                                | 1.17                                                   | 0.76                                  |
| RW                   | 4                                | 3.10                                                   | 0.77                                  |

3. Analysis of research results

In order to facilitate a comparison of particular intersection types in terms of accident risk, figure 3 has been provided where particular types of intersection are presented according to decreasing value of WR index.

The obtained results show that the most dangerous intersections are multi-lane roundabouts (WR=3.10). The highest risk at this type of intersection is concentrated mostly in the place where the traffic stream of vehicles exiting the inner traffic lane of the envelope, crosses with the stream of those moving around the island on the outside traffic lane [9]. The results of analyses show that they are 2.5 times more dangerous than one traffic lane roundabouts. Another type of intersections where road users are exposed to high risk of accidents are intersections with a central island with extended inlets, without traffic light signalling. For intersections with a central island and traffic rules like roundabouts, (right of way must be yielded at each inlet) the risk rate equals 2.42. However, for intersections with a central island where one of the crossing routes has right of way, this rate is slightly lower and equals 2.15; this being caused by high speed while approaching and crossing the intersection and limited visibility of drivers of colliding traffic streams, for those who stand at the inlet without right of way (visibility is limited by vehicles standing on traffic lanes on the left side of the intersection). Hence, collisions at intersections with a central island and with extended inlets most frequently concentrate in places behind the inlets without right of way.

It should also be observed that the value of risk index is quite high for intersections with priority to the right (for those who exit channelized intersections WR=2.01, for conventional intersections WR=1.49). Drivers moving at intersections of this type are often surprised that it is necessary to give way to vehicles coming from the right. It should be noted that in Poland intersections with priority to the right are often unmarked with vertical signs. Conventional intersections with multi-phase traffic signalling (WR=0.46) and channelized ones, also equipped with two-phase traffic light signalling, have been found to be potentially the most dangerous intersections. Intersections equipped with two-phase signalling are also ones of the most dangerous intersection type, though the risk level is not...
higher than at channelized intersections with multi-phase traffic signalling. It results from the fact that there are more simultaneous colliding traffic streams.

It must be noted that also at intersections with broken priority of way (channelized and not channelized), which in both cases provide the road users with higher safety than intersections with priority to the right though lower than an intersection with right of way.

4. Conclusions
The following conclusions can be formulated on the basis of the carried out analyses:

1. The type of intersection has a significant influence on the safety level of its users.
2. At an intersection equipped with traffic light signalling the risk level is much lower than at intersections without traffic light signalling. Whereas, intersections with multi-phase traffic lights provide more safety.
3. The most dangerous intersections are two-lane roundabouts and intersections with a central island and extended inlets without traffic light signalling. However, the lowest risk level was found for conventional and channelized intersections with a multi-phase traffic light signalling.

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