Characteristics of the Locations of Increased Road Traffic Incidents in Urban Road Networks in Poland

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Abstract. The results of studies carried out for years by researchers around the world point to man as the most important and – at the same time – the weakest link in traffic processes, and therefore road traffic incidents are caused by hardly anything other than human error. A majority of such errors leading to traffic incidents are made for specific reasons, such as a faulty road environment. The spatial distribution of road traffic incidents is not random – it follows a specific pattern with most incidents concentrating at the ‘weakest’ points of a road network with identifiable shortcomings, making it more difficult for the road users to assess the circumstances and take appropriate action. Points like these are referred to as ‘hazardous locations’. The purpose of this article is to define and describe such locations where specific types of road incidents concentrate at urban road network intersections and intermediate sections between them in Poland. The analysis utilised a modern IT system, WZDR (Road and Traffic Management Support IT System), currently implemented in a few cities in Poland. The most important analytical part of the study contains a detailed description of the relationship between the characteristics representing an increased hazard to road traffic participants in the hazardous locations and incorrect behaviour of the users caused by the considered faults of road infrastructure. This analysis enables identification of typical faults of selected elements of a road network from the point of view of road traffic safety. It provides a basis for improvement of the current principles of design applied both to intersections and to elements of road infrastructure located between intersections.

1. Introduction
Road traffic is a process which is triggered by specific decisions and behaviour of its participants, whereas such decisions and behaviour are influenced by external factors (mainly psychological and physical characteristics and motivations of the participants) and internal factors (properties of the road, its environment and the mode of transport). As mankind cannot function in any conditions in a perfect way, there is no way the road traffic process can reach ultimate reliability today. Road traffic incidents are therefore an inevitable consequence of the occurrence of the process. The results of studies [1,2,3,4,5] carried out by researchers around the world for years indicate that man is the most important and also the weakest link in the traffic process, and road traffic incidents happen nearly always through the fault of man. A majority of errors leading to traffic incidents are made by traffic participants for specific reasons, which include an inadequate physical ability to respond, a deliberate harmful action and a faulty road environment [1,6,7]. This thesis is confirmed, for example, by maps of road traffic incidents, showing that the spatial distribution of the incidents is not at all random, but follows a specific pattern with most incidents concentrating at the ‘weakest’ points of a road network with identifiable shortcomings, making it more difficult for road users to assess the circumstances and respond properly,
referred to as hazardous locations, or ‘black spots’. They tend to have an above-average level of risk of a specific traffic incident. Analyses of traffic incidents in Poland carried out at the University of Science and Technology in Bydgoszcz using modern IT tools demonstrate beyond any doubt that road infrastructure with the traffic and the surroundings (i.e. the road environment) has a major influence on road safety [1,6,7]. A search for the connection between the number of road traffic incidents and the characteristics of the road and traffic has yielded unexpected results implying that such characteristics may contribute to an incident at as much as 75% of cases. Of course, the majority of traffic incidents are still caused by human error, but the error may often result from shortcomings or imperfections of road infrastructure, as the above-mentioned results indicate.

Considering far-reaching consequences of traffic incidents, nobody seems to question the need to eliminate them nowadays. However, it must be remembered that such incidents are very difficult to examine in terms of causes and effects. This is mainly due to a large number of factors involved, including those applying to the road environment. Nevertheless, a correct assessment of the causes of road traffic incidents from the point of view of the road requires establishment of the areas of concentration of the incidents and identification of the relationships between the areas and the faults of the road environment which contribute to specific errors on the part of traffic participants.

This study aims to provide a detailed characteristics of the locations in which road traffic incidents concentrate in urban road networks in Poland. In order to reach the goal, the Road and Traffic Management Support IT System (WZDR) was used, developed in 1993 and significantly upgraded since by the University of Science and Technology in Bydgoszcz [8,9]. The WZDR system is currently one of the most advanced IT systems in Poland used to manage roads and road traffic. It comprises a number of themed subsystems operating together, the most extensive of which in terms of analytical functions is the ‘Road Traffic Safety’ subsystem. The subsystem includes a graphical and descriptive database of traffic incidents, including historical data, and an analytical module. It also uses data from other subsystems, providing detailed descriptions of roads, their environment and traffic, as well as their general performance parameters.

2. Structure of the locations of increased road traffic incidents

When analysing the results of road traffic safety studies a clear and growing trend in the occurrence of specific types of incidents in urban road networks can be seen. This supports the thesis that most road traffic incidents happen not at random places but in areas which are hard for the road users to assess correctly, which is vital for them to behave safely in a traffic process. Shortcomings of such locations, therefore, are the cause – if only indirect – of a majority of traffic incidents happening there.

Table 1 presents averaged results of analysis of the locations in which specific types of road traffic incidents concentrate in a few selected cities (different in terms of size, population, traffic systems etc.). The locations of such increased numbers of traffic incidents follow different distribution patterns in the cities concerned, which is mainly due to different road networks. However, the observed trends in all the cities were evidently dissimilar to those found on non-urban roads. This is mainly due to a substantial involvement of the so-called ‘unprotected road users’ (pedestrians and cyclists) in urban road incidents.

Most traffic incidents on Polish roads happen at intersections; 60.4% of the incidents are road accidents, 50.1% are collisions, 55.6% involve pedestrians, 62.4% cyclists and 47.3% children.

Exits from intersections are the road network elements where a majority of traffic incidents concentrate in the analysed cities. On average, 26.6% of all incidents occur at such exits. It is also where most traffic incidents involve pedestrians (29.9%), cyclists (28.2%) and a lot of accidents with children going to or from school (about 21%).
Table 1. Structure of the concentration of traffic incidents in road networks of Polish cities [%] [10]

| Item | Locations of increased traffic incidents | General characteristics | Specific characteristics |
|------|------------------------------------------|-------------------------|-------------------------|
| 1.   | General                                   | Traffic accident (60.4) | Specific Traffic accident (50.1) |
| 2.   | Road network                              | Traffic collision (55.6) | Pedestrian accident (62.4) |
| 3.   | Intermediate sections                     | Cycling accident (47.3)  | Child accident (50.9)    |
| 4.   | Car park, structure                       |                          |                         |
|      | Total                                     | 100.0                   | 100.0                   |

Other road network elements where substantial numbers of traffic incidents are observed include:
- Sections between conflict points (21.8%);
- Intersection approaches (21.4% on average);
- Intersection crossing conflict zones (12.4% on average).

In the analysed cities no road incidents have been recorded in the intersection merging conflict zones and in the U-turn zones.

Traffic incidents involving pedestrians mainly happen at:
- Intersection exits (29.9%);
- Sections between conflict points (27.9%);
- Intersection approaches (21.8%).

On the other hand, the structure of the locations of traffic incidents with children as pedestrian road users is the following:
- Sections between conflict points (31.6%);
- Intersection exits (21.0%);
- Intersection approaches (15.8%).

One of the primary descriptors of road traffic incidents is the incident weight index (WC) [1], which is used to express an average weight of a traffic incident in the analysed area. It is a quotient of the number of equivalent traffic incidents X and the number of traffic incidents in a given area Y.
\[ WC = \frac{X}{Y} \quad [-] \] (1)

where:

- \( Y \) – total number of traffic incidents over time \( T \) in a given area;
- \( X \) – number of equivalent traffic incidents over time \( T \) in the area:

\[ X = \sum_{i=1}^{Y} x_i \quad \text{[incidents]} \] (2)

where:

- \( x_i \) – equivalent factor of a given traffic incident:

\[ x_i = n_{Z,i} \cdot q_Z + n_{H,i} \cdot q_H + n_{R,i} \cdot q_R + n_{P,i} \cdot q_P \] (3)

where:

- \( n_{Z,i}, n_{H,i}, n_{R,i}, n_{P,i} \) – number of: fatalities, badly injured, slightly injured and vehicles involved in the incident;
- \( q_Z, q_H, q_R, q_P \) – weights of individual consequences of the traffic incident: fatality, badly injured person, slightly injured person, damage of the vehicle involved (the weight is defined as a ratio of the mean cost of given individual consequences of the incident to the mean cost of a traffic collision).

Figure 1 shows mean values of the traffic incident weight indices (WC) for individual elements of the road network. An analysis of the data presented in the figure indicates that the most severe incidents happen in the area of pedestrian crossings. The highest WC can be seen in the case of pedestrian crossing points at intersection exits (WC=8.01) and approaches (WC=7.24). A certain regularity is evident as far as the weight of the traffic incidents at urban intersections is concerned, namely – the consequences of traffic incidents happening at intersection exits are much more severe than at approaches. This must be due to greater average vehicle speeds in those areas.

**Figure 1.** Mean values of the traffic incident weight index (WC) for the individual elements of the analysed road network
3. Most dangerous places of the road network

3.1 Most dangerous areas of the intersections

Based on the data obtained for the analysed cities, it can be stated that multilane intersections with a divisional island and flared approaches (traffic signal-controlled or uncontrolled) and extensive channelised traffic intersections with traffic lights, situated on major routes, make up a great majority of ‘black spots’ within the urban road network. This is due to a rather small capacity of the intersections with regard to the traffic volumes handled. A detailed analysis of typical locations where increased number of traffic incidents happen in those types of intersections is shown in Tables 2, 3 and 4.

Table 2. Detailed analysis of typical locations of concentrated traffic incidents at multilane intersections with a divisional island and flared approaches with uncontrolled traffic

| Item | Features causing increased risk to traffic participants | Incorrect traffic behaviours | Locations where specific traffic incidents caused by the problematic feature concentrate |
|------|--------------------------------------------------------|-----------------------------|-----------------------------------------------------------------------------------|
| 1.   | Multilane minor road approaches                        | Failure to yield when entering the intersection due to inadequate visibility caused by obstructing vehicles | Side collisions in possible crossing conflict zones of the intersection and rear-end collisions at approaches, exits and inside the intersection |
| 2.   | Insufficient flow capacity for the existing traffic volumes. | Excessive waiting times make drivers impatient and nervous, leading to dangerous behaviours and taking unnecessary risks. | All possible traffic incidents, especially those listed in 1 above. |
| 3.   | Approach and exit lanes routed tangentially to the divisional island. | Possibility to drive through the intersection at a high speed or suddenly stop in front of the stop line. | Same as above. |
| 4.   | Large size of the intersection.                        | Insufficient transparency of traffic channels causes that drivers make mistakes and induce hazardous situations, mainly by cutting off other drivers. | All possible traffic incidents, especially happening inside the intersection. |
| 5.   | Lots of potential conflict points at the intersection. | Lots of decisions for a driver to make while at the intersection increases the risk of error. | Same as above. |
| 6.   | Incorrectly designed stop lines at intersection approaches. | Failure to yield when entering the intersection due to inadequate visibility caused by obstructing vehicles. | See: 1. |
| 7.   | Corner radius too big.                                | High-speed turning and sudden stopping to give way. | Side collisions within the crossing conflict zone in front of exits, rear-end collisions at right turn lanes, and accidents involving unprotected road users at crossings located at intersection exits. |
| 8.   | Pedestrian crossings too long.                        | Difficulty when choosing the right moment to cross the street makes drivers often fail to yield to pedestrians. | Rear-end collisions in front of pedestrian crossings and accidents involving pedestrians at crossings. |
| 9.   | Long distances between pedestrian crossings.          | Same as above.               | Same as above. |
| 10.  | Long cycle crossings.                                 | High traffic volumes make safe crossing of the street difficult for cyclists, so they often fail to yield to vehicles. | Rear-end collisions in front of cycle crossings and accidents involving cyclists at crossings. |
### Table 3. Detailed analysis of typical locations of concentrated traffic incidents at multilane intersections with a divisional island and flared approaches with controlled traffic

| Item | Features causing increased risk to traffic participants | Incorrect traffic behaviours | Locations where specific traffic incidents caused by the problematic feature concentrate |
|------|---------------------------------------------------------|-----------------------------|---------------------------------------------------------------------------------|
| 1.   | Insufficient flow capacity for the existing traffic volumes. | Frequent entering the intersection at the red traffic light. Also – see: Table 2, Item 2. | See: Table 2, Item 2. |
| 2.   | Multilane minor road approaches. | Reduced visibility of conflicting streams at the approach leads to a collision if the vehicle enters the intersection when the red light comes up. | See: Table 2, Item 1. |
| 3.   | Approach and exit lanes routed tangentially to the divisional island. | Possibility to drive through the intersection at a high speed encourages drivers to enter at the red traffic light or suddenly stop at the approach. | See: Table 2, Item 3. |
| 4.   | Large size of the intersection (large area for possible collisions). | Possibility to drive through the intersection at a high speed (see: Table 3, Item 3). Also, traffic lights often increase the waiting time and reduce the flow capacity (see: Table 3, Item 1). | See: Table 2, Items 2 and 4. |
| 5.   | Lots of potential conflict points at the intersection. | Use of traffic lights on conflicting streams leads to frequent cases of failure to yield. On the other hand, multi-stage traffic signals considerably reduce the flow capacity leading to the consequences listed in 1. | Side collisions of vehicles at conflict points and rear-end collisions in the area of accumulation of vehicles in the conflicting stream. Also, see: Table 2, Item 2. |
| 6.   | Corner radius too big. | Driving onto pedestrian or cycle crossings at a high speed at the intersection approach and exit if the green arrow permits leads to failure to yield to unprotected road users. Sudden stopping to give way. | See: Table 2, Item 7. |
| 7.   | Pedestrian crossings too long | Extended presence of pedestrians within a crossing conflict zone increases the risk of a knockdown. Long crossings also cause unprotected road users to remain there after the red traffic light comes up. | See: Table 2, Item 8. |
| 8.   | Long distances between crossings | Frequent cases of crossing while the red traffic light is on. | Same as above. |
| 9.   | Multilane areas of accumulation of vehicles within the intersection | If the traffic signals allow conflicting streams on left-turn lanes, rows of vehicles waiting in the accumulation zone obstruct the view of the main stream for some drivers. This often leads to the drivers turning left failing to yield. | Side collisions of vehicles where the crossing conflict zone overlaps with the accumulation zone, rear-end collisions within the accumulation zone and accidents involving unprotected road users at intersection exits. |
| 10.  | Long cycle crossings | See: Table 3, Item 7. | See: Table 2, Item 10. |
Table 4. Detailed analysis of typical locations of concentrated traffic incidents at extensive channelized intersections with controlled traffic

| Item | Features causing increased risk to traffic participants | Incorrect traffic behaviours | Locations where specific traffic incidents caused by the problematic feature concentrate |
|------|--------------------------------------------------------|-----------------------------|-----------------------------------------------------------------------------------|
| 1.   | Insufficient flow capacity for the existing traffic volumes | Driving onto the intersection at a high speed, also through the red light, and sudden braking of vehicles if the driver decides not to cross the intersection. | Rear-end collisions at approaches and side collisions within crossing conflict zones. |
| 2.   | High speeds of vehicles approaching the intersection | Failure to yield. Sudden stopping of vehicles in front of the crossing conflict zones. | Side collisions of vehicles in possible conflict zones and rear-end collisions in the accumulation zone of conflicting streams. |
| 3.   | Conflicting streams of vehicles triggered by the traffic signalling programme | Drivers’ failure to yield to cyclists and pedestrians at intersection approaches and exits. Sudden braking of vehicles at pedestrian and cycle crossings. | Vehicle incidents involving cyclists and pedestrians at pedestrian and cycle crossings situated at intersection approaches and exits. |
| 4.   | Conflicting streams involving unprotected road users in the traffic signalling programme | Too long lines of vehicles waiting in through and left-turn lanes impedes or prevents movement. As a result, long waiting induces dangerous behaviour of the drivers, including driving through the red light. | Side collisions of vehicles at the approach and within the crossing conflict zone behind. |
| 5.   | Corner radius too big | See: Table 3, Item 6. | See: Table 2, Item 7. |
| 6.   | Turn lanes too short at the approach | See: Table 3, Item 7. | See: Table 2, Item 8. |
| 7.   | Long pedestrian crossings | See: Table 3, Item 7. | See: Table 2, Item 10. |

3.2 Most dangerous areas between intersections
The data shown in Table 1 indicates that 37.8% of road traffic incidents happen in intermediate sections of the road network, and 78.5% of those involve unprotected road users. The most crucial areas include entries to and exits from structures and pedestrian crossings with a high traffic density between intersections. These two types of locations are analysed in Tables 5 and 6.

Table 5. Detailed analysis of typical locations of concentrated traffic incidents in entry/exit areas of structures with a high traffic density

| Item | Features causing increased risk to traffic participants | Incorrect traffic behaviours | Locations where specific traffic incidents caused by the problematic feature concentrate |
|------|--------------------------------------------------------|-----------------------------|-----------------------------------------------------------------------------------|
| 1.   | Lack of necessary visibility of a walkway/bikeway at a structure | Failure to yield to unprotected road users taking the walkway/bikeway. | Vehicle incidents involving unprotected road users, esp. cyclists. |
| 2.   | Too many entries and exits at structures and car parks | Too much information to be perceived and processed by drivers of vehicles travelling on the major lane may delay or prevent response to a dangerous situation on the road. | Side collisions and rear-end collisions on the major lane. |
Table 5. (cont.) Detailed analysis of typical locations of concentrated traffic incidents in entry/exit areas of structures with a high traffic density

| Item | Features causing increased risk to traffic participants | Incorrect traffic behaviours | Locations where specific traffic incidents caused by the problematic feature concentrate |
|------|---------------------------------------------------------|-----------------------------|-----------------------------------------------|
| 3.   | Bikeways too narrow for the existing traffic volumes    | Problems with overtaking and passing make cyclists cut off one another. | Bike collisions and bike incidents involving pedestrians. |
| 4.   | Insufficient separation between walkways and bikeways  | Possible intrusion of a bike onto a walkway or vice versa. | Bike incidents involving pedestrians. |
| 5.   | Lay-bys located directly along the lane                 | Drivers joining traffic from a lay-by fail to yield, causing the vehicles in the major lane to brake suddenly. | Side and rear-end collisions in the area of the lay-by. |
| 6.   | Bikeways not clearly identifiable                      | Cyclists failing to yield to pedestrians and drivers failing to yield to cyclists. | See: Table 5, Item 1. |
| 7.   | No merging lanes in entry/exit areas of structures     | Failure to yield and sudden braking due to speed differences. | Side collisions in exit areas and rear-end collisions in exit and entry areas of structures. |

Table 6. Detailed analysis of typical locations of concentrated traffic incidents at pedestrian crossings in intermediate sections

| Item | Features causing increased risk to traffic participants | Incorrect traffic behaviours | Locations where specific traffic incidents caused by the problematic feature concentrate |
|------|---------------------------------------------------------|-----------------------------|-----------------------------------------------|
| 1.   | Long pedestrian crossings                              | Failure to yield on the part of unprotected road users and crossing the street at very short distances between vehicles. | Vehicle incidents involving unprotected road users and rear-end collisions in front of pedestrian crossings. |
| 2.   | Insufficient identification of pedestrian crossing by drivers | Failure to yield to unprotected road users and driving at high speeds between intersections. | Same as above. |
| 3.   | Inadequate visibility of pedestrians or cyclists crossing the street for drivers | Failure to yield to unprotected road users in a walkway or bikeway. | Same as above. |
| 4.   | High density of pedestrian traffic                      | Frequent cases of pedestrian intrusion onto the street. | Same as above. |
| 5.   | Locating pedestrian crossings on multilane streets      | Poor visibility of pedestrians crossing the street for drivers caused by vehicles moving along other lanes obstructing the view. This leads to failure to yield to pedestrians. Also see: Table 6, Item 2. | Vehicle incidents involving pedestrians, often at a high speed. |

4. Conclusions
The following conclusions can be drawn from the information analysed above:

1. The greatest concentration of traffic incidents in urban road networks is observed at intersection exits where – on average – 26.6% of all incidents happen. Also, a majority of incidents involving pedestrians (nearly 30%), cyclists (28.2%) and a substantial number of traffic incidents with children (about 21%) occur in the area of intersection exits.

2. Other locations on urban road networks, where large numbers of traffic incidents happen, include the following:
• Areas between traffic conflict points (21.8%);
• Intersection approaches (~21.4%);
• Crossing conflict zones in intersections (~12.4%).

3. Incidents occurring at pedestrian crossings have the greatest incident weight index: WC=8.01 in the case of intersection exits and WC=7.24 at intersection approaches.

4. The most dangerous intersections are multilane intersections with a divisional island and flared approaches with high traffic volumes. An excessive concentration of traffic incidents at this kind of intersections is mainly due to the following shortcomings: multilane approaches of minor streets, tangential arrangement of approaches and exits with respect of the island, large intersection area, numerous conflict points, and too long pedestrian and cycle crossings.

5. Increased traffic incidents are also observed in sections situated between intersections, mostly in the area of entries to and exits from structures with a high traffic density, and in the area of pedestrian crossings, particularly situated on multilane streets. One of the major and most common problems with these elements – contributing to traffic incidents – is lack of necessary visibility.

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