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# OPERATIONAL PROBLEMS OF 2+1 BYPASS ROAD SECTIONS

**Marian Tracz[1], Mariusz Kieć[2]**
[1,2]Cracow University of Technology, Faculty of Civil Engineering Cracow, Poland
[1]e-mail: mtracz@pk.edu.pl
[2]e-mail: mkiec@pk.edu.pl

***Abstract:*** *The paper presents several problems of designing trunk-road bypasses of towns, which can be very helpful in improving their traffic performance. Such roads perform supplementary functions to the operation of network of motorways and express-roads constructed in Poland over the last decade. These problems include: selection of the cross section, selection and design of intersections and interchanges on bypasses, safety and traffic operation problems. The authors highlight the advantages of bypasses and point out some errors, which can be seen in the operation stage, basing on research and observation of 8 bypasses. In the paper traffic operation and road safety analyses for Zyrardow bypass are presented. The final part of the paper gives conclusions and recommendations for 2+1 bypass use and design.*

***Key words:*** *bypass, two lane road, 2+1 cross-section, speed, overtaking, traffic performance, operating, travel speed.*

## 1. Introduction

Building of trunk road bypasses of towns is again becoming a very effective way of improving the performance of road networks, supplementary to building a network of motorways and express-roads. Sections of heavily loaded national or regional roads running through towns are often even more loaded, what creates traffic bottlenecks, resulting in frequent stops and delays and lower travel speed. Very important is also the operational uncertainty of routes and environmental impacts, i.e. traffic noise and air pollution (Deakin and Plaut, 2006; Elias and Shiftan, 2010; Koornstra et al. 2002).

Bypasses help to improve traffic performance and increase travel speed by reducing local bottlenecks and offer some possibilities for overtaking very slow moving vehicles by cars. They also, to some extent, decrease car drivers' frustration (The Highways Agency, 2008; Smart, 2010). However, the question remains to the degree of this improvement, without an unambiguous answer.

There are several problems in planning and design of bypasses related to an overtaking demand. Therefore 2+1 cross-section of bypasses are used in order to improve traffic performance. However as foreign research projects indicate that capacity of 2+1 road can be even lower than capacity of two lane roads (Bergh et al., 2016). Important factor affecting traffic performance of 2+1 roads could be too high share of heavy vehicles.

Other design issues are related to the selection of cross-section elements, types of intersections or interchanges at the end of a bypass, signing and marking as well as traffic safety problems.

The paper is based on the research project *The decision support tools in the design and reconstruction of bypasses and roads passing through small towns*, financed by The National Centre for Research and Development (R10 10-0067-10), which covered the analysis of 33 bypasses built on the national roads in Poland over the last decade. Eight of bypasses have 2+1 cross-sections and generally do not create traffic performance and safety problems mainly because of low traffic volumes. Therefore analyses presented in this paper are focused on operation of one special case of the long 2+1 bypass of town Zyrardow with the total length of 15 km which consists of alternately overtaking lanes, where traffic volumes reach more than 16,000 veh/24h, at very high average 40% share of heavy vehicles. Such traffic volumes on this particular bypass have been a source of problems with its operation and traffic safety. Other analysed bypasses have not caused such problems. The authors decided to present in depth results of these analyses, as they identified several problems which should be taken in design 2+1 bypasses and necessity of certain limitations of their use.

## 2. Purposes of road bypasses construction. Why 2+1 cross sections?

By building bypasses road administration carries out their task of eliminating road bottlenecks and increasing the capacity and traffic performance on trunk roads. It also meets the demands of towns' communities to reduce the intrusive impacts of through traffic, i.e. noise and air pollution as well as accident hazard caused by through traffic. However, what drivers expect from new road bypasses is not only avoiding delays on sections through such towns and an improvement of traffic performance along routes, by transferring traffic flows from the town streets to the bypass. They also expect some possibilities for overtaking. The importance of these objectives depends also on traffic volumes and their composition. In general, road administration intends to achieve all these goals.

With regard to the goal of increasing overtaking capabilities, a question arises as to the overtaking efficiency of bypasses. The capacity manuals do not give a direct clear answer to this question, but the expectations of road administration and designers are great. No doubt the traffic performance of a bypass depends on a number of factors including the length of a bypass, the number and lengths of segments and subsections with an overtaking lane (+1), the speed of vehicles on the basic lane used by slow moving vehicles and on the behavior patterns of drivers.

Designs of bypasses are mostly based on conventional guidelines for trunk roads, however, the analysis of bypasses' operation (Tracz M. et al., 2013) has shown that these sections of roads, with 2+1 cross sections in particular, require special guidelines. Such conclusion emerges from various designs of 2+1 cross sections on newly designed route sections in Poland shown in fig. 1.

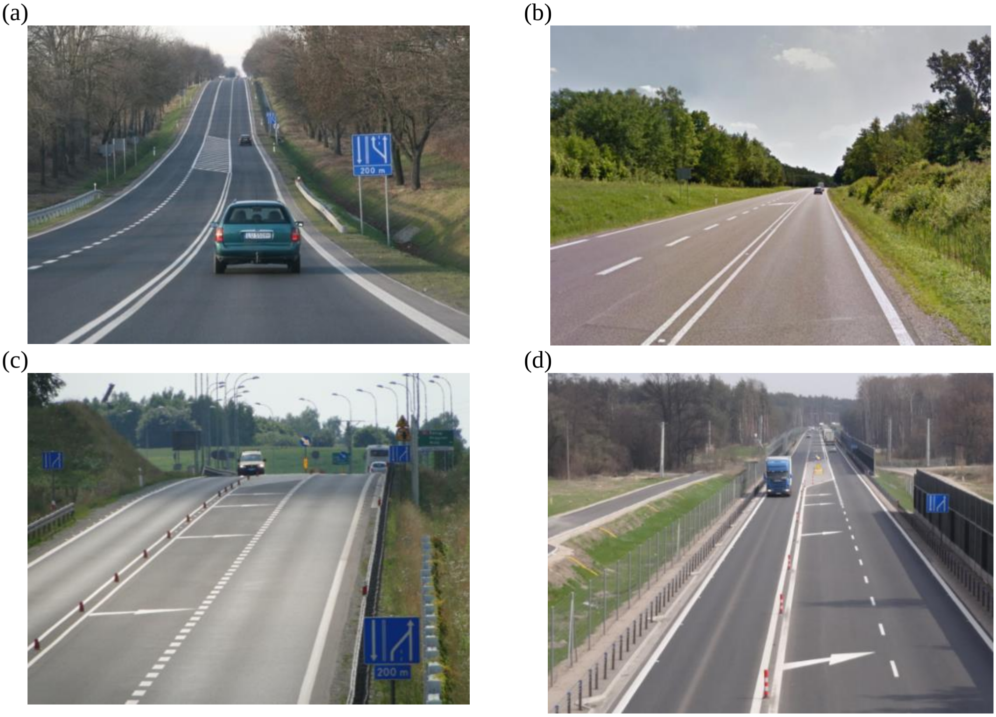


Fig. 1. Various types of medians in 2+1 cross-sections used in Poland (a) double continuous line, (b) double continuous line with retro-reflecting elements (www.maps.google.pl), (c) double continuous line with separating elements, (d) double continuous line with guideposts

In a few Polish references (Szagała, 2005; Sandecki and Szagała, 2007) on the operation of overtaking lane the the following criteria supporting the decision on implementing the 2+1 cross section are pointed out:

- traffic volume and its composition (regarding speed)
- demand for overtaking of slow moving vehicles,
- expected traffic performance (Level of Service – LOS)
- expected traffic safety,
- type of terrain (preferably rolling)

## 3. Intersections and interchanges on bypasses

On the basis of review of several projects of bypasses constructed in Poland from since 2005 one can conclude that on bypasses at first three or four legs channelized intersections were built. More recently instead of these channelized intersections are designed by:

- small one or semi-two lane roundabouts, and turbo roundabouts,
- trumpet or diamond interchanges instead of at-grade intersections.

The choice between the use of at-grade designs and an interchange to a large extent depends on the purposes of building a bypass described earlier, particularly on how important the overtaking is for a given route. The environmental criteria should also be taken into account, especially when designing the bypass vertical alignment (Tracz M. et al., 2014).

Besides of capacity requirements, the choice between intersections or interchanges has an impact on selection of driving speed on the bypass and on preceding road sections. At-grade intersections force drivers to reduce speed, or even to stop, in this way shortening part of the bypass on which 2+1 system could be applied.

Particular care should be exercised when selecting very popular roundabouts, as on their approaches can form long queues of vehicles. It is important to take into account traffic variations and changes in the road network as well as to perform a capacity analysis of such roundabouts in “entry by entry” manner. Large, over 20% share of heavy vehicles can additionally reduce the capacity of a roundabout calculated with use to known capacity manuals. Designing right turn bypasses on such roundabouts for large right turning traffic streams is very favorable. In selecting turbo-roundabouts at the end of a bypass special attention should be paid to the presence of pedestrians, and even more so the cyclists, which should not use circulatory carriageway of a turbo roundabout. The authors found that what is favorable as regards flow design is often the non-symmetrical scheme, for example with a roundabout on one and channelized intersection on other side of a bypass.

The implementation of interchanges not only eliminates stopping on the bypass but also elongates the road section that can be used for 2+1 system. Its end can be extended outside the basic part of the bypass. In such case signing of parallel overtaking lanes and merging or diverging lanes may be a problem.

## 4. Traffic operation of Zyrardow bypass

### 4.1. General assumption

In depth analysis has been done for a bypass around the town of Zyrardow (40,000 inhabitants) with 2+1 cross sections, which was open for operation in 2012. It was selected for the observation of operation of 8 bypasses with 2+1 cross-sections. However low traffic volumes (up to 7,000 AADT) have not allowed for development of practical conclusions. Therefore analyses were focused on one very special bypass of Zyrardow town, because of high traffic volumes including exceptionally high share of heavy vehicles, its length and problems with operation overtaking segments and intersections at end of the bypass. These problems in operating of the bypasses including: impacts of widths of cross-section elements, accidents and their location, failures of vehicles and related traffic performance. There were several accidents on this bypass compared with other 2+1 bypass roads in operation in Poland since 2011. The bypass was built on the part of national route, which has the function of a bypass of Warsaw for trucks. The effect is traffic reaching 16 000 vehicle/24h with nearly 50% (40% on average) of heavy vehicles. There is no automatic speed control on the bypass.

### 4.2. Site measurements and data

On the 15km long bypass there are eleven segments with overtaking lanes of 6 and 5 layouts for one direction. There are three access points, i.e.: two roundabouts (with diameters of 45 m) at both ends of the bypass and a diamond interchange in the middle of the bypass. Apart from these, there are no other access points. The bypass horizontal alignment has a small curvature. There are small grades in the ±2% range. Large part of the bypass runs on an embankment. On the entire length of the road the cross section has 2+1 lanes. The geometrical parameters have been shown in fig. 2.

In cross-section the shoulder consists of a hard strip and gutters in front of the cable barriers (together 1m width). Gravel shoulder is located behind the cable barrier. There is no recovery area, which causes significant operations problems in case of emergency (accident, collision, stopping) with access of emergency vehicles to accident place. Traffic lanes in opposite directions and traffic flows are separated by a median with double continuous lines on which guideposts (1m height) were fixed. At the end of transition between cross sections (2+1 into 1+2 – conflicting changeover) the traffic signs with separators fixed in the pavement were located. These measures should force drivers to change lane.

### 4.3. Traffic operation measurements

For evaluation of the traffic operation on the bypass traffic measurements were conducted covering local and travel speed, headways, types of vehicles travelling on the road. For the measurements the following instrumentation were used: pneumatic detectors, video camera with automatic number plate recognition system, and GPS to floating car technique. The metering equipment were placed on the traffic lane directly upstream and downstream the overtaking lane in measurements carried on single 2+1 section and also between the roundabout entries for the analysis of the entire segment of the bypass. The aim of the measurements was evaluation of traffic parameters changes for a single 2+1 segment (at the beginning of the bypass) and for the section which for the analyzed direction was composed of five segments with an additional overtaking lanes. In total, data were recorded for 15,100 vehicles during two measurement days. The investigation also covered speed measurements using data from GPS. To improve data quality at expected high speeds the device with frequency of 10Hz was used.

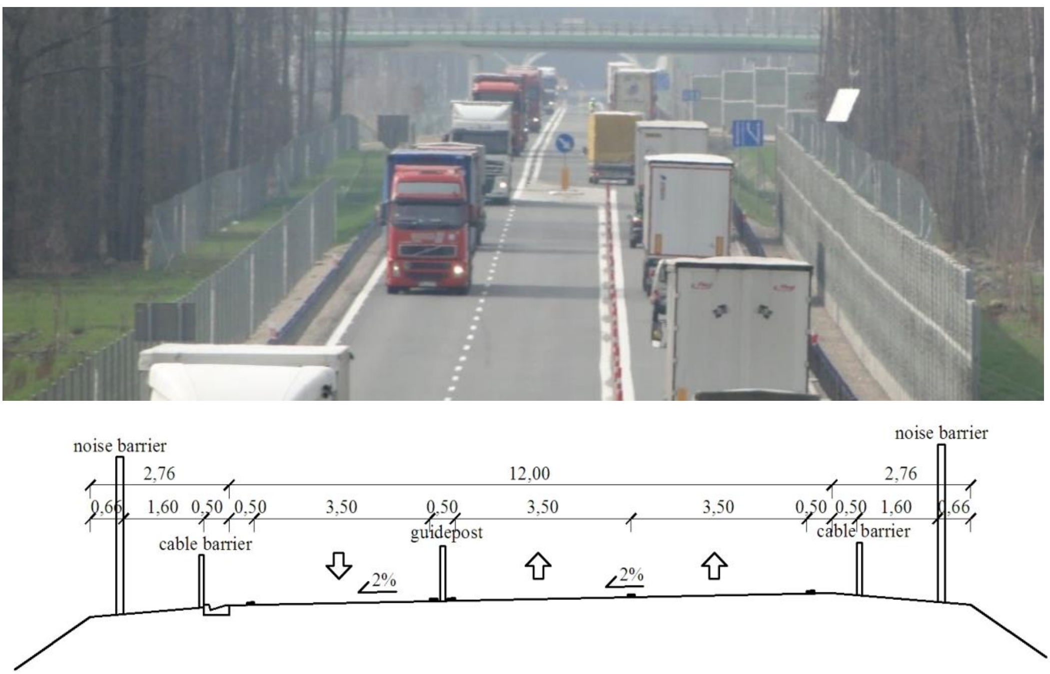


Fig. 2. 2+1 cross section of the Zyrardow bypass

**4.4. Traffic operation on the single segments**

The results allowed an assessment of general traffic parameters on a single segment with an overtaking lane. On the basis of data from pneumatic detectors located upstream and downstream of the overtaking segment 1,350 m in length the effect of platooning and changes of speed were determined in a point where the additional lane was terminated. The results from the measurement sites, the first and the last are shown in table 1.

Table 1. Results of traffic measurements for a single segment of 2+1 system

| | Site 1 - upstream | Site 2 - downstream |
|---|---|---|
| Length of segment [m] | 1350 | |
| Average traffic volume [veh/h] | 483 (total number 2415) | |
| Percentage of heavy vehicles *HV%* [%] | 48 | |
| Average speed of traffic flow $S_A$ [km/h] | 68.4 | 84.1 |
| Speed percentiles 85th $S_{85}$ [km/h] | 76.9 | 97.4 |
| Speed standard deviation *SD* [km/h] | 10.4 | 16.7 |
| Speed variability coefficient $SD/S_A$ [-] | 15.2 | 19.8 |

The mean traffic volume in the measurement cross sections in the period of five hours of the measurements was 483 veh/h with percentage of heavy vehicles about 48%.

The comparison of speed 85th percentiles in measurement sites 1 and 2 shows an increase of traffic flow speed equal 20.5 km/h within 2+1 single segment. The increase of speed is also observed in case of mean speed of platoon traffic (headways between vehicles to 3s) and free flow traffic (headways between vehicles above 6s). The comparison of mean speeds in free flow and in platoons at the beginning and at the end of the segment shows 19-29% speed increase in free flow. It indicates improvement of traffic performance. High dispersion of the speed of cars in comparison to speed of heavy vehicles and large differences between these two sets of vehicles should be underlined (fig. 3).

Besides of overtaking the 2+1 cross section gives the opportunity of driving faster, which is confirmed by the increase of the average free flow speed. It also refers to increase of the mean speed in platoon traffic, where the leading vehicle forming the platoon also increases its speed due to more favorable traffic performance, which in turn increases the mean speed of the whole platoon.

The mean share of overtaking vehicles in mean traffic flow of 483 veh/h was 29%. Journey on the segment with an additional overtaking lane results in a slight increase of the share of platoon traffic by about 2.9%. This slight change of platoon traffic share is accompanied by about 17 % reduction in the number of platoons, with a simultaneous increase of the average size of platoon from 2.72 to 2.89 vehicles, which corresponds to 6% change. Despite of the long overtaking lanes on the Zyrardow bypass, the reduction of platoon size is insignificant, due to a great extent to a large share of heavy vehicles, reaching 50%, as well as to a relatively low share of platoon traffic.

There were observed considerable variations in the high share of heavy vehicles (35-70%) depending on the time interval (length of 15 minutes).what significantly affects overtaking characteristics. Mean speeds of heavy vehicles are lower than those of cars by about 20 km/h, which can be explained by the speed limit and the mechanical potential of vehicles.

**4.5. Traffic operation of the entire bypass**

Investigations of travel speed on the whole length of the bypass were performed with use of video cameras. Recorded travel speed met the expectations resulting from the speed of vehicles of 87,3 km/h in free flow upstream the bypass. The tendency of mean travel speed changes which depends on traffic volumes is similar to the dependence for two lane two way roads determined according to HCM 2010 (Fig 4). Mean values of traffic parameters on the bypass have been presented in table 2.

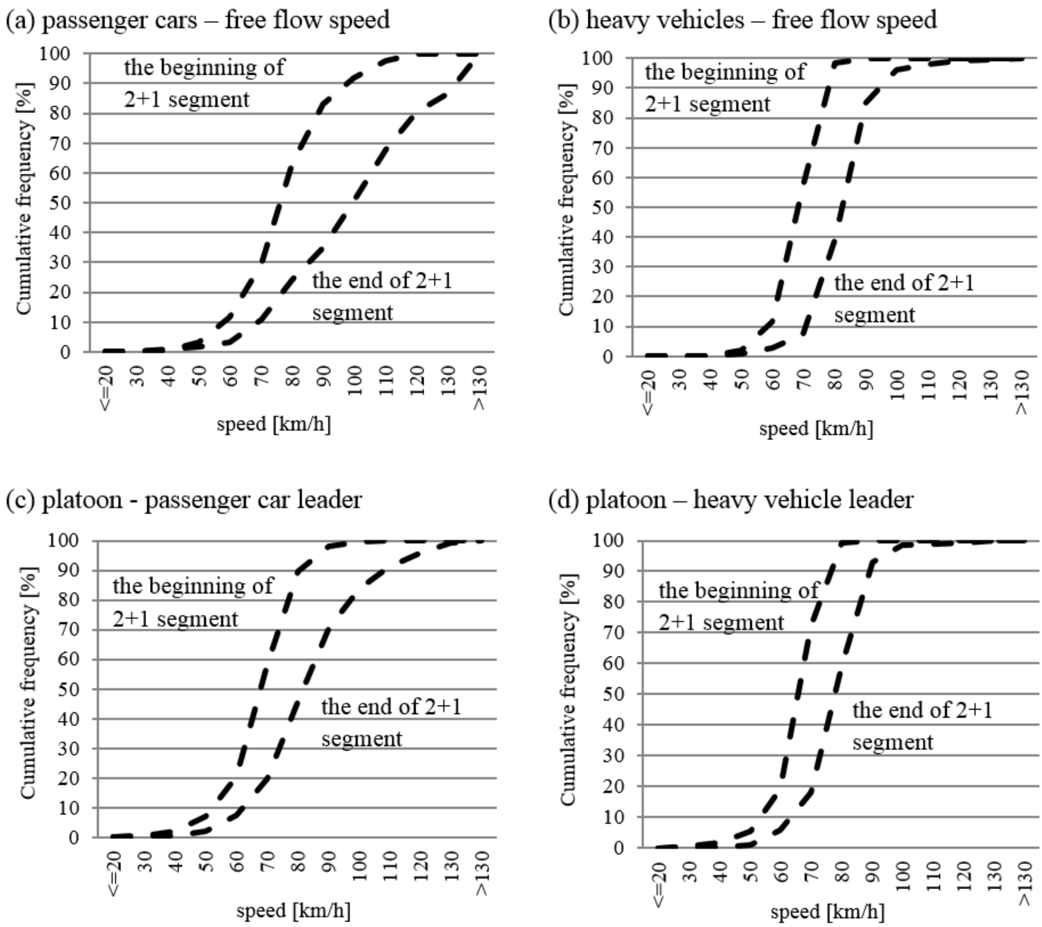


Fig. 3. Speed distribution of vehicles in free flow and platoon at the beginning and at the end of 2+1 segment

Table 2. Mean values of traffic parameters on the bypass

| | Bypass |
|---|---|
| Length of section [km] | 12.2 |
| Average traffic volume [veh/h] | 559 |
| Percentage of heavy vehicles *HV%* [%] | 46.1 |
| Average travel speed of traffic flow $ST_A$[km/h] | 71.2 |
| Travel speed percentiles 85th $S_{85}$ [km/h] | 79 |
| Minimum travel speed [km/h] | 45.7 |
| Maximum travel speed [km/h] | 105.1 |
| Travel speed standard deviation *STD* [km/h] | 8.0 |
| Speed variability coefficient $STD/ST_A$ [-] | 11.2 |
| Share of overtaking vehicles [%] | 41.4 |

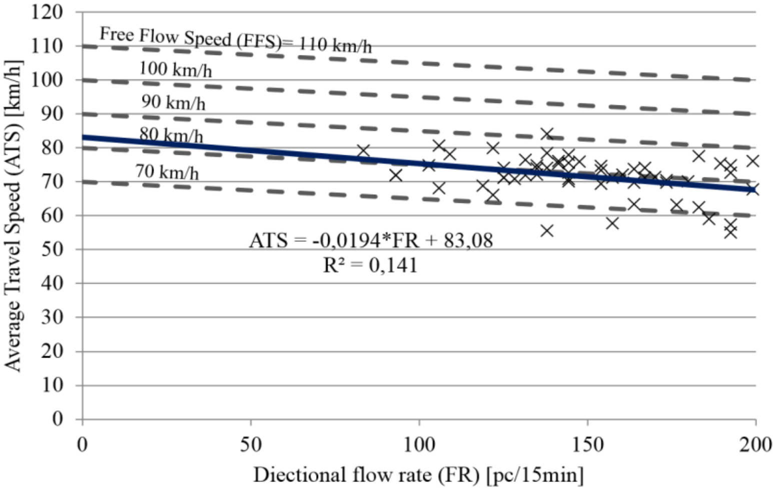


Fig. 4. Relationships between average travel speed and traffic volume on Zyrardow bypass

The percentage share of vehicles overtaking *(SHO)*, (changes of vehicle position in traffic flow, evaluated based on recognition of number plate) on the whole bypass length was 41.4 %, which in comparison with this share on the first segment of 29% may indicate a drop in demand for overtaking when subsequent 2+1 segments appear. This is also indicated by the mean number of overtakings performed by a single vehicle, which on the length of the bypass is ca. 4.25 (for average traffic volume 559 veh/h), and for the first single 2+1 segment – is equal 1.48 (for average traffic volume 483 veh/h) overtakings. Fig. 5 presents distribution of overtaking numbers on entire bypass.

$$SHO = \frac{NVC}{TV} \cdot 100[\%] \qquad (1)$$

where:
*SHO* – the percentage share of overtaking,
*NVC* – number of vehicles, which change position in traffic flow,
*TV* – traffic volume (veh/h/dir).

The analysis also included the local speeds and accelerations on bypass, which may affect traffic safety. The measurements tests were performed using the floating car method. Fig. 6 illustrates changes of speed and acceleration on the bypass length and on 2+1 segments with an overtaking lane taken as average value from 10 floating car tests. The considerable differences of speed on traffic lanes and areas of conflicting changeover, equal to 20 to 30 km/h at the end of the overtaking lanes, point out the need to pay special attention to termination of these lanes by designers. They also indicate significant dispersion of speeds on the length of the analyzed segments of the bypass.

Analyses of traffic operation does not included evaluation of capacity of 2+1 segments Such capacity can be lower than expected in comparison to two lane roads (1700 veh/h/lane) (HCM 2010), i.e. (1400-1500 veh/h/lane). Implementation of 2+1 cross sections may cause deterioration of traffic performance in a certain range of traffic volumes. Such situation can take place at high traffic volumes i.e. exceeding 1400 veh/h/lane (Bergh et al., 2016; Kirby et al., 2014).

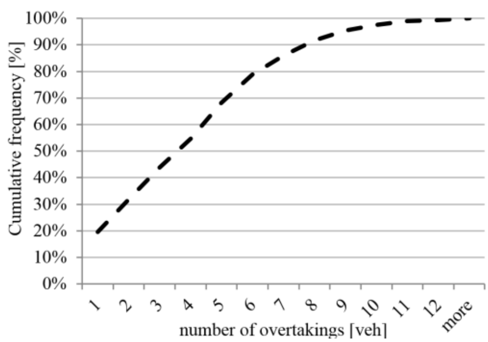


Fig. 5. Distribution of overtaking number for entire bypass

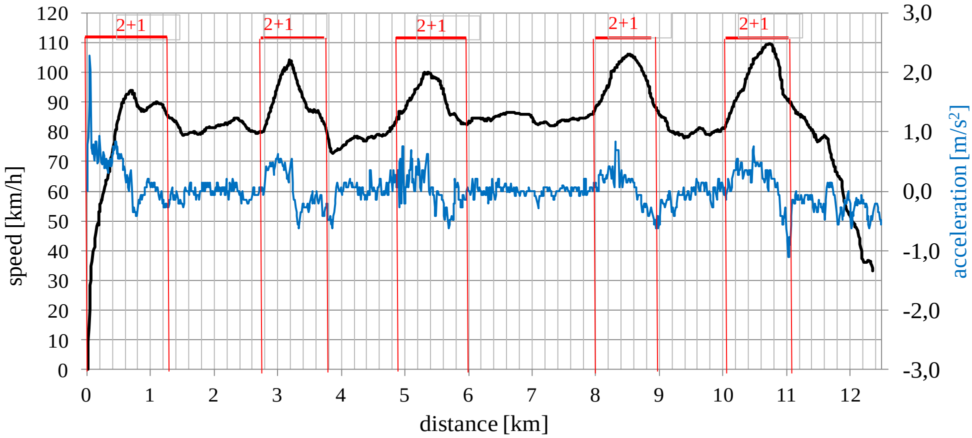


Fig. 6. Mean speeds and accelerations on the bypass

Analyses of traffic operation does not included evaluation of capacity of 2+1 segments Such capacity can be lower than expected in comparison to two lane roads (1700 veh/h/lane) (HCM 2010), i.e. (1400-1500 veh/h/lane). Implementation of 2+1 cross sections may cause deterioration of traffic performance in a certain range of traffic volumes. Such situation can take place at high traffic volumes i.e. exceeding 1400 veh/h/lane (Bergh et al., 2016; Kirby et al., 2014).

### 4.6. Road safety problems

From the research references listed in (Kirby et al., 2014) it follows that use of 2+1 cross section results in the reduction of the number of accident casualties up to 40% compared with 1x2 lanes cross section (mean reduction is ca. 30%). Also in Poland on other bypasses the analysis of traffic safety indicates its improvement after 2+1 cross sections construction on bypass roads, on which no traffic accidents are practically recorded.

The short period of operation of the analysed 2+1 bypasses has not made it possible to perform reliable road safety analyses of large part of newly built bypasses. Most of them have low traffic volumes and large capacity reserves. It results in small number of recorded accidents. On the basis of the observed accidents it can be stated that only few occur in places where there are intersections on the bypass and those that do occur are sideswipe or run off types.

The Zyrardow bypass, where head-on collisions take place, is an exception. Over the period of one year after it started operation there were five accidents reported (four head-on and one rear end). This is why there was an analysis done for the Zyrardow bypass on the basis of the data from the police accidents reports (Property Damage Only (PDO)). From these it follows that PDO events take place on sections with an overtaking lane most often in the area of merging before the conflicting changeover. It is due to the lack of physical separation of traffic directions in such places that head-on collisions do occur. Another type of accidents is sideswipe at merge areas where vehicles merge into the right lane from the overtaking lane. Sideswipe events also occur when the overtaking driver is too close to the vehicle being overtaken or when the driver starting the overtaking maneuver is not aware that the overtaking lane is already occupied and hits the side of the car on this lane. No head on collisions which are caused by overtaking on the lane for the opposite direction traffic were reported on the length of overtaking lane.

In the period of a one year since the bypass started operation 38 accidents have been reported including seven crashes and thirty-one PDOs. As a result of crashes twelve persons were injured, two were killed. Table 3 presents the basic characteristics of the aforementioned traffic events. The majority of these are sideswipe (on straight sections, at the end of overtaking lane), the main cause of which was speed inappropriate for traffic performances and violation of speed limits.

A certain traffic accident hazard is also indicated by a large number of damaged guideposts in the median. This damage may result from too narrow carriageway. It may be due to too narrow cross section (lack of a wide area free of obstacles), a large percentage of heavy vehicles and ineffective markings and signing of the overtaking lane termination area.

Table 3. Characteristics of road accidents recorded on Zyrardow bypass

| Location | |
|---|---|
| Straight section | 70.6 % |
| Major/minor priority intersection. | 14.7 % |
| Roundabout | 8.8 % |
| Horizontal curve | 5.9 % |
| **Type of accident** | |
| Sideswipe | 44.1 % |
| Rear end | 26.5 % |
| Head-on | 11.8 % |
| Collision with barrier | 11.8 % |
| Others | 11.8 % |
| **Circumstance (according to police)** | |
| Following too closely | 26.5 % |
| Improper lane change | 23.5 % |
| Unsafe speed | 20.6 % |
| Failure to yield right of way | 17.6 % |
| Improper overtaking | 5.9 % |
| Others | 11.8 % |

The results presented above show only importance of the problem and can not be used for generalization of the impact of using of 2+1 cross-section on road safety. Simplified analyses of road safety result from too small sample size and too short period of observation which caused certain caution in formulating reliable conclusions

## 5. Conclusions

Analysis of Polish and foreign guidelines shows that current guidelines of bypass design generally do not include any special rules for the use of 2+1 cross sections. The existing guidelines relate separately to bypasses or to use of 2+1 cross-sections on ordinary roads. The Polish guidelines for 2+1 roads include the specificity of bypass roads design and traffic on these roads only to a small extent. Limitations of use of 2+1 sections and problems in operation of such road sections in practice have not been analyzed. In comparison to two lane roads, the 2+1 cross sections can slightly increase travel speed and reduce risky overtaking maneuvers.

Empirical measurements devoted to very special case of the long bypass (with roundabouts at its ends), carrying large traffic volumes with very high share of heavy vehicles – moving with high speeds, gave several valuable conclusions and observations, which should be taken into account in design guidelines and practice.

- Too large volumes of heavy vehicles and their movement in platoons with high speed impede the merging maneuvers of overtaking vehicles just before the changeover. Therefore a major traffic control problem is the reduction of operating speed of trucks on the basic lane in order to provide the opportunity to overtake without excessive increase of speed. This problem needs further research.
- A certain traffic accident hazard is also indicated by a large number of damaged guideposts in the median. This damage may result from too narrow carriageway. It may be due to too narrow cross section (lack of a wide recovery area free of obstacles), a large percentage of heavy vehicles and ineffective markings and signing of the overtaking lane termination area.
- To meet the requirements of drive-ability in emergency cases in one direction with a single lane it is necessary to adopt appropriate total width of lane, hard strip, and shoulder so as to enable bypass a stopped vehicle. The total width of such elements available for traffic or stopping should not be smaller than 4.5 – 5.0 m. Additionally, in the middle of the section with a single lane it is recommended to locate an emergency lay-by for stopping.
- The intersections at both ends of the bypass should not seriously interrupt traffic flow performance and operation of the 2+1 system on a bypass, which could be caused by the formation of long platoons of vehicles. It is recommended that they operate at some capacity reserve. The analysis of the capacity of roundabouts, if these are intended at the bypass ends, should be done with particular care regarding queuing. At a roundabout located at one end of the bypass long upstream queues of vehicles reached overtaking lane. To meet the road

and flow capacity requirements, channelized intersections should be designed with a clear preference for straight on traffic. To some degree these requirement can meet turbo-roundabout or an interchange, which can extend the 2+1 system.

- The number of overtaking lanes can differ in traffic directions depending on overtaking demands.
- Tendency to eliminating vulnerable road users from the cross section of the bypass and in practice restricting their presence only to intersections is right, as is the case of using full access control on segments between intersections. In Poland such policy strongly depends on common use of noise barriers on several segments of bypasses located close to traffic lanes. It creates impression of the lack of room and affects comfort of driving.
- Studies of publications from other countries concerning 2+1 cross sections include interesting results of capacity of traffic safety analyses.
- The selection of 2+1 cross section must be preceded by an in-depth analysis of the predicted traffic including its volume and composition. 2+1 roads should be intended for traffic volumes in the range about 10,000 veh/day to 25,000 veh/dayh, while the share of heavy vehicles in other investigation should not exceed 20% (Irzik, 2010; Kirby et al., 2014).
- Use of barriers in the lane separating traffic directions reduces the accident rate and the severity of accidents on sections between changeovers. The barriers are more effective than horizontal marking itself. However, they require a wider separating lane, adapted to the barriers' operating width, as well as a greater width of the whole cross section due to the possibility of traffic accidents or vehicle failures on the sections with a single traffic lane. In that case the required width is close to the dimensions of the 2x2 lanes cross section. This width can be slightly smaller in the case of cable barriers. Location of majority of accidents close to changeovers on the investigated Zyrardow by-pass suggests that 1.0-1.5 m marked median in other colour (red or green as in the UK and Germany) can be also good design.
- The manner of separating traffic directions in 2+1 cross sections should also depend on the predicted operating speed and traffic volume. For the operating speed lower than 100 km/h the travel directions can be separated by a double continuous line 0,5m in width, or a coloured lane of 1.0m width surrounded by a double continuous line. for traffic volume higher than 10,000 veh./day. This design is commonly used in Western European countries (The Highways Agency, 2008; Irzik, 2010).

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