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Comparative analysis of the impact of road infrastructure development on road safety – a case study

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Abstract

The constant development of transport systems and the extensive activities related to the safety of its users necessitate the development of methods for assessing the impact of road infrastructure expansion/modernization on road safety. The objective of this paper is to elaborate the concept of such an assessment, which will form part of the author's activities aimed at creating a methodology for a comprehensive analysis of the operational reliability of transport systems. The concept of assessing the impact of road infrastructure development on road safety presented in this paper refers to the GAMAB and Road Safety Impact Assessment methods from the subject literature. Our method is based on a comparative analysis of the condition of road infrastructure before and following its expansion/modernization, based on commonly available data, which constitutes the main advantage of the concept presented in this paper. Furthermore, the coefficients for occurrence of adverse road events were determined, and then conclusions drawn on this basis. The acquired results constitute an argument for the correctness of the presented concept.

Introduction

Road infrastructure is characterized by its constant development. What is characteristic of it, is that, this development generally follows an evolutionary path. It is only in exceptional circumstances that the infrastructure is built completely from scratch. In most cases, the existing systems are expanded with new sections. It is also common practice to modernize existing roads in order to adapt their characteristics to the changing transport requirements. In some cases, the scope of activities covers only the resurfacing, while in other cases it is necessary to upgrade the road to a higher class, e.g. to an expressway/motorway. Every change of this type should accomplish several tasks. They include:

- adapting the road so it does meet transport needs, taking into account development trends;
- increasing road safety;
- implementing the policy of sustainable development.

Bearing in mind the constant developing transport network, including the road infrastructure, there appears to be a need to elaborate methods for researching the impact of modernization of road infrastructure on road safety.

In the first part of this publication we will justify the need for elaborating a new method, and then proceed to discuss exemplary approaches to road infrastructure safety assessment. The second part of this article is devoted to presenting the original concept of assessing the impact of road infrastructure development on road safety, referring to the GAMAB and Road Safety Impact Assessment methods from the subject literature. The subsequent part of this publication includes verifying the method using the example of selected infrastructure sections. The ultimate part is devoted to discussing acquired results, summary and indication of future research.

Literature review

The subject literature includes numerous works on the modernization of road infrastructure. Some of them focus on the decision-making process determining the justification for road investments (Pasichnyk et al., 2018; Dowd, Franz & Wasek, 2020), and in other cases, infrastructure modernization is linked with road safety (Barci & Czech, 2010; Peltola, Rajamäki & Luoma, 2013; Graczyk & Polasik, 2016; Deac & Tarnu, 2019). Articles on methods of risk assessment in transport systems also form a significant part of research-oriented works. They contain valuable elaborations of the methods presented later in this paper, e.g. the ALARP method (Selvik, Elvik & Abrahamsen, 2020) or the Road Safety Impact Assessment method (Eenink et al., 2005; Basile & Persia, 2012; Kustra, Jamroz & Budzynski, 2016).

When it comes to works on road safety, the emphasis is, on the one hand, on the human factor (Brożyna, 2017; Shinar, 2017; Mygal & Protasenko, 2018), i.e. mainly drivers and other road users. On the other hand, there is research conducted, focusing on the technical factor, i.e. the transport infrastructure (Jaworski, Kuszewski & Ustrzycki, 2016; Wachnicka et al., 2016).

Despite numerous scientific works related to analysis of the impact of expansion or modernization of road infrastructure on road safety, there are no methods enabling the quickest possible assessment based on publicly available data. The approach presented below constitutes one of the stages of current work on a methodology for comprehensive analysis of the operational reliability of transport systems.

Exemplary approaches to assessing the safety of road infrastructure

In recent years, the approach to the broadly understood concept of road safety, defined as a series of activities aimed at reducing adverse events occurring in the transport system, has grown in importance. There are actions undertaken at different planes. Many countries have introduced programs aimed at regulating the acceptable risk levels on their roads. These countries include, the United Kingdom with its ALARP method, France with the GAMAB method and Germany with the MEM method. The analysis of the aforementioned methods is presented in Table 1.

Another important aspect related to the assessment of road infrastructure safety is the tools applied

Table 1. Analysis of transport risk assessment methods in selected countries (based on (Szymanek, 2008))

ALARP method	
Description:	
This method is divided into three sections. These are unacceptable risk, acceptable risk and commonly accepted risk. The main message of this method is that the level of risk should be as low as possible, while taking into account rational premises, such as the amount of required expenditure. This method is related to the frequency of threats and their effects. It covers both group and individual types of risk.	
Advantages:	*Disadvantages:*
This method has an autonomous nature – no benchmark is required.	The complexity of the analysis.
GAMAB method	
Description:	
The GAMAB method is a type of comparative analysis of two systems – the existing and the new (or significantly modernized) one. The main conclusion of this method is that the newly built system must demonstrate a lower risk level than the existing one. In addition, this method presents two variants, the first assuming that the level of safety will increase and the second one in which the risk is expected to remain at the current level.	
Advantages:	*Disadvantages:*
It allows (in the worst case) the possibility of keeping the risk at the current level.	This method requires a benchmark for its application – i.e. the previously functioning system.
MEM method	
Description:	
The MEM method defines a certain point of reference (e.g. natural mortality recorded in the 5–15 age group). This concept assumes that the individual tolerable risk of death in the analyzed system should be less than the elected reference point.	
Advantages:	*Disadvantages:*
The level of risk is determined by a top-down procedure, and there is no need to make time-consuming analysis.	In some cases, a top-down determination of the level of risk is unacceptable.

to manage the risk level as well as identify and designate dangerous places in the transport system. These tools are presented and discussed in the work by Sørensen & Elvik (2007). They include:

- RSIA (Road Safety Impact Assessment) – a method for strategic comparative analysis of the impact of a new or significantly modified road against the existing one. It is applied at the initial stage of infrastructure design.
- RSA (Road Safety Audits) – a method of detailed examination of the safety level of the existing road infrastructure in order to identify dangerous zones.
- RSI (Road Safety Inspection) – method of systematic, periodic road inspections, performed in order to ensure its safety during operation.
- NSM (Network Safety Management) – a method for managing the existing road network or part of it for the purpose of identifying, locating and ranking high-risk zones (e.g. sharp turns, motorway entrances, etc.).
- BSM (Black Spot Safety Management) – a method for managing the existing part of the road network by implementing preventive measures at a localized point or short road section characterized by large number of accidents.

The analysis of the methods of identifying dangerous locations within the transport system is presented in Table 2.

The concept of assessing the impact of road infrastructure development on road traffic safety presented further in this paper refers to the presented methods: GAMAB and RSIA.

Methodology – the concept of assessing the impact of road infrastructure development on road safety

The methodology adopted in this paper consists of several stages. The first step is to collect the required data to create the databases. The second step is to analyze the infrastructure before and following its modernization. The third stage is the calculation stage within which the road incident coefficients are determined. The fourth step is devoted to comparative analysis followed by the final evaluation. It is assumed that this research will provide the results required to conduct further work on the operational reliability of transport systems.

The concept of assessing the impact of road infrastructure development on road traffic safety is a component of the author's work on developing a methodology for the comprehensive analysis of the operational reliability of transport systems. It is assumed that in order for the presented concept to have a utilitarian value, it is necessary to develop it in such a way that the databases forming their sources

Table 2. Analysis of methods for identifying dangerous locations in the transport system (based on (Sørensen & Elvik, 2007))

Black spot method	
Description:	
This method involves indicating the exact locations (or short sections) of the road, where the number of road incidents differs significantly from the analogous parts of the transport system.	
Advantages:	*Disadvantages:*
This method identifies the exact locations, where the accumulation of adverse events occurs.	It is not possible to apply this method at the stage of designing the transport system. In addition, it requires access to databases, e.g. on road accidents.
Black sections method	
Description:	
This method is analogous to the black spot method. The difference is that instead of spots, it indicates entire sections of roads with an increased number of adverse events.	
Advantages:	*Disadvantages:*
It enables the identification of infrastructure sections with a higher probability of adverse events. Depending on the adopted concept, it is possible to apply gradations of these sections, depending on the adopted risk acceptance levels.	It is not possible to apply this method at the stage of designing the transport system. In addition, it requires access to databases, e.g. on road accidents.
Risk zones method	
Description:	
This method involves selecting area fragments of transport infrastructure, where a possibility of observing an increased number of adverse events in relation to other infrastructure elements occurs.	
Advantages:	*Disadvantages:*
The greatest advantage of the risk zones method is that there is no need to analyze data on adverse events.	This method requires field research.

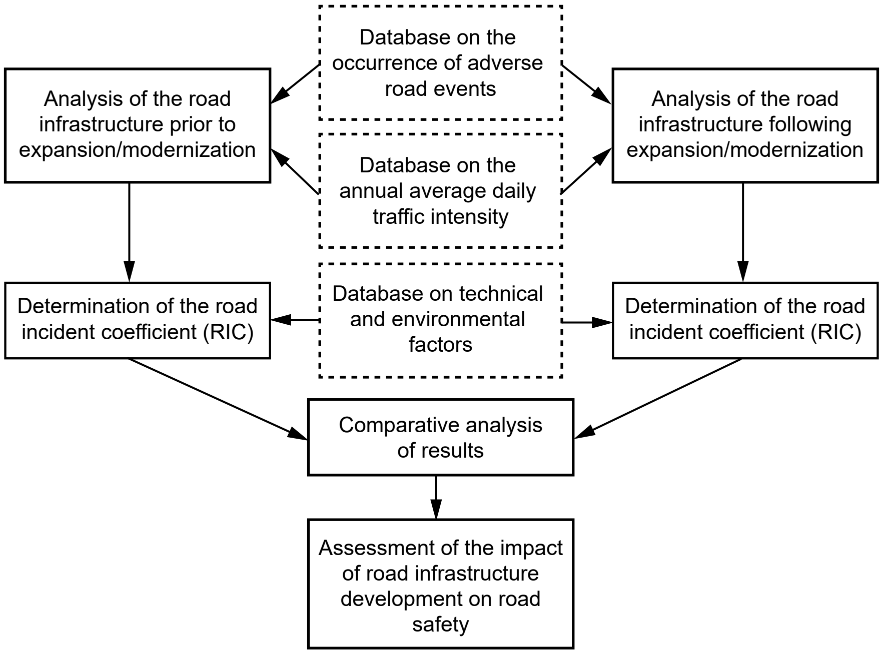

Figure 1. The diagram for assessing the impact of road infrastructure development on road safety

are as commonly accessible as possible. Hence, the rate of occurrence of adverse road events is determined based on data on road accidents (as defined by the Polish Road Safety Observatory – POBR) and road traffic intensity from the materials of the General Directorate for National Roads and Motorways (GDDKiA). The diagram of the concept is presented in Figure 1.

In order to assess the impact of modernization of the road infrastructure (or newly built sections) on the road safety of the previously used road, a simplified road incident coefficient (RIC) can be used. This coefficient is described by the following formula:

$$\mathrm{RIC} = \frac{\mathrm{NRI}}{\frac{\sum_{i=1}^{n} \mathrm{AI}_i}{n} \cdot 365 \cdot L \cdot 10^{-6} \cdot \frac{\sum_{i=1}^{m} C_i}{m}} \quad (1)$$

where:

NRI – the number of road incidents that occurred in the respective year on the analyzed section,

AI – annual average daily traffic intensity at the measurement point i,

L – segment length,

C – calibration coefficient.

The C coefficient in the proposed formula is defined as technical factors (e.g. unfavorable road curvature or lack of passive safety elements at the analyzed section) and environmental impact (e.g. weather conditions that occurred during the adverse events forming part of the calculations).

It should be noted that while the data on the average annual daily traffic intensity presented by GDDKiA are characterized by adequate accuracy, obtaining reliable data on adverse events presents a significant issue. As already noted in the World Health Organization report (WHO, 2015), there are very large discrepancies in the data on people who died in road accidents depending on the reporting institutions. These inaccuracies are presented in Table 3.

Table 3. The level of discrepancy in the data on the number of deaths due to road accidents (based on (WHO, 2015))

Country	According to police reports	According to medical institutions	Discrepancy (%)
Belgium	724	1014	40.1
Chile	1623	2116	30.4
Italy	3385	4192	23.8
Japan	4373	5971	36.5
Korea	5092	6374	25.2
Egypt	6700	11 000	64.2

The data presented in Table 3 demonstrates that there is an issue with reporting identical events all over the world, which allows us to state that it is universal in nature and its solution requires a systemic approach.

The underlying reason for these discrepancies may be differences in the terminology applied. What is problematic, is the very definition of the concept of a road accident. Moreover, after analyzing the available reports and statistical studies on road accidents, we noticed that there are at least six institutions in Poland that collect data on accidents.

These arguments cited allow us to state that the analysis of adverse road events is subject to high uncertainty. The activity of organizations combining data from various sources, such as POBR, give us the chance to lower the information noise connected therewith.

Verification of the concept on the example of a selected section of road infrastructure

The proof of the concept presented in this work will be limited to determining the RIC for selected road sections. Moreover, we adopted the simplification stating that the calibration factor *C* is equal to 1. The data for verifying the concept is presented in Table 4, where the section before the infrastructure expansion is the road serving as the main link between the cities of Szczecin and Gorzów Wielkopolski until the new road (the S3 expressway) is commissioned, defined in the table as the section after infrastructure expansion.

The selection of sections for comparative analysis was related to the expansion of the road infrastructure and the related transfer of road traffic to the new section (the S3 expressway). In 2010, the section *before the expansion* was the main road connecting Szczecin with Gorzów Wielkopolski, as evidenced by the average annual daily traffic intensity ranging from 9245 to 12 801. In the following years, the S3 expressway was commissioned, largely taking over the role of the previous section. Moreover, the development of transport increased the average annual daily traffic intensity in the range of 13 333–16 528.

The use of data from 2010 and 2015 is related to the General Traffic Measurements performed in these years. It should be noted that one measuring point was omitted (from the 2010 survey) due to the significant discrepancy of the result compared to the others. This discrepancy could be as a result of the point being located at an intersection.

The rates of occurrence of adverse events in the discussed sections were determined on the basis of the acquired data and using the formula presented in this paper. In the variant before expansion, in 2010, it amounted to:

$$RIC_{2010} = 0.075,$$

while in the variant following the expansion of the road infrastructure in 2015:

$$RIC_{2015} = 0.014.$$

These results, together with the reference to the average annual daily traffic intensity, are presented in the form of a graph in Figure 2.

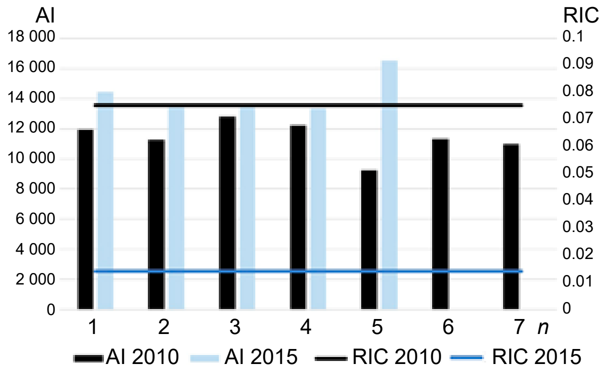

Figure 2. Graphical interpretation of the comparison of the average annual daily traffic intensity with the calculated RIC coefficients for 2010 and 2015

The resulting RIC_{2010} and RIC_{2015} are significantly different. An even greater disproportion is observed when comparing the coefficients with the values of the average annual daily traffic intensity recorded at measuring points on the analyzed sections of road infrastructure. We observe that in the first case, for

Table 4. Data for proof of concept (based on (GDDKiA, 2010; 2015; POBR, 2020))

The section before infrastructure development	The section following infrastructure development
Location, and route: The beginning of the section – Szczecin, Kijewo junction Via – Kołbacz, Pyrzyce, Lipiany End of the section – Gorzów Wielkopolski, the junction of the provincial road No. 130 and the S3 expressway	Location, and route: The beginning of the section – Szczecin, Klucz junction Via – S3 expressway End of the section – Gorzów Wielkopolski, the junction of the provincial road No. 130 and the S3 expressway
Length of section L: 82.9 km	Length of section L: 81.7 km
The annual average daily traffic intensity at the measuring point (in 2010): $AI_1 = 11\,937$ $AI_2 = 11\,254$ $AI_3 = 12\,801$ $AI_4 = 12\,236$ $AI_5 = 9245$ $AI_6 = 11\,346$ $AI_7 = 10\,997$	The annual average daily traffic intensity at the measuring point (in 2015): $AI_1 = 14\,439$ $AI_2 = 13\,422$ $AI_3 = 13\,603$ $AI_4 = 13\,333$ $AI_5 = 16\,528$
Number of road incidents on the analyzed section in 2010: 26	Number of road incidents on the analyzed section in 2015: 6
C coefficient: 1	*C* coefficient: 1

the section prior to expansion of infrastructure, the relation between the traffic intensity and the RIC coefficient is unfavorable, while in the latter case the situation is completely reversed. Even with the increase in traffic intensity, the RIC coefficient drops significantly. We should look at the characteristics of compared sections, when looking for the reasons for such a significant discrepancy. The 2010 section consists of single-carriageway roads with two lanes (in opposite directions), while the 2015 section is entirely an expressway class road – with two lanes separated by a green belt.

Conclusions

The ability to assess the impact of road infrastructure development on road safety is very important. It allows us to determine the correctness of the implemented modernizations, and then, by using the analogy method, to feed the decision-making process during planning of subsequent works aimed at the development of the transport system.

The advantage of the concept presented in this paper is the possibility of performing an analysis based on commonly available data on adverse road events and traffic intensity. Moreover, the introduction of the calibration factor to the formula enables further expansion of the databases feeding the formula, which has the positive consequence of obtaining even more precise results. The simplifying assumptions made in the proof affect the final result.

For the provincial-class road – single-carriageway with two lanes, the calculated coefficient was 0.075, while for the expressway-class road it was only 0.014. It is worth noting that the significant discrepancies between these results, which, bearing in mind the comparison of roads of different classes, constitutes an argument for the correctness of the assessment.

Further research will be aimed at a more detailed evaluation such as taking into account the analysis of road incidents on the verified sections, incorporating additional criteria in the calibration coefficient, or inclusion of the so-called human factor.

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