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Using the Methodology of Network Thinking to Solve a Problem Situation on the Example of Road Transport

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Abstract:

Purpose: *The aim of this article is to define the undesirable factors that occur in the road transport process and to identify their negative impact on the project under way, so that corrective action can be taken as early as possible.*
Design/Methodology/Approach: *A literature study was carried out to identify key risk factors and their impact on road transport in Poland. For this purpose, a list of road accidents between 2010 and 2020, which resulted in injuries or significant environmental damage, is presented.*
Findings: *The first part presents a literature review on road transport and network thinking methodology. The second part describes the research methodology and presents the research results representing the issues discussed. The resulting analysis diagnoses undesirable factors and identifies their impact on road transport.*
Practical Implications: *developing guidelines and demonstrating the need for conscious management of undesirable factors in road transport. In addition, the paper demonstrates the possibilities offered by modelling a problem situation using network thinking methodology for solving complex problems, including for fostering creativity and creativity on the example of road transport in Poland.*
Originality/value: *Isolate the factors influencing road transport using network thinking methodology.*

Keywords: *Road infrastructure, road transport, network thinking methodology.*

JEL classification: *L91, L92, R42.*

Paper Type: *Research study.*

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1. Introduction

The directions of development of the world economy have fundamentally influenced changes in transport, which has become an indispensable element of modern social and economic processes. The proper functioning of transport requires a well-functioning transport system, which is a set of integrated elements, processes and dependencies, transforming the stream of material goods and passengers (demand for transport services) into a stream of outputs from such a perceived system. The essence of road transport boils down to the transportation (movement) of goods or passengers (persons) using means of transport (motor vehicles) based on the available transport infrastructure.

A particular feature of road transport is that it is the most reliable and spatially accessible in relation to other modes of transport. Compared to rail and water transport, road transport costs are higher, but compared to air transport they are significantly lower. Taking into account the criterion in the form of transport time and securing goods, road transport is second only to air transport, and in terms of capacity to rail transport (Koźlak, 2018).

Defining problem situations in the area under study is a complex process, requiring a multi-faceted view of the issue under analysis. In the case of road transport, undesirable factors affecting the phenomenon under study must be taken into account. The primary source used to write this article was the available literature on the subject in the field of road transport and network thinking methodology. Inference was based on the results of logical analysis verified empirically using statistical methods.

The realisation of the objective focused on a research procedure encompassing the theoretical plane, which included an analysis of the hitherto existing theoretical achievements in the field of the road transport process, and the empirical plane, focused on conducting research, which included the identification and evaluation of key factors influencing the realisation of road transport in Poland.

In addition, the paper presents the possibilities offered by modelling a problem situation using the network thinking methodology for solving complex problems, including for fostering creativity and creativity on the example of road transport in Poland.

According to strategic assumptions, road transport should be characterised by a very high level of safety. The article analyses road transport in Poland, which still does not have an effective network of modern road connections. Nevertheless, Poland's accession to the European Union and the possibility of obtaining significant investment funds gave a real chance to boost road investments on an unprecedented scale. Despite many measures taken to improve the situation on the road haulage market, road transport still faces numerous problems.

The poor technical condition of the existing infrastructure, the uneven distribution of the road network and competition from road transport are just some of the challenges facing Polish road transport.

2. Literature Review

The proposed research is closely linked to two research areas: road transport and network thinking methodologies. The authors briefly review the key literature in each of these areas in the next section.

2.1 Characteristics of Road Transport

Transport is a key element of logistics services. They involve planning, executing and controlling the efficient and economically effective flow of raw materials, materials, finished goods and relevant information from the point of origin to the point of consumption, in order to satisfy customer requirements (Czapiewska, 2020).

The development directions of the global economy have fundamentally influenced changes in transport, which has become an indispensable element of modern social and economic processes (Markusik, 2009). Road transport is the primary branch of transport without which it is not possible for goods to reach their destination. The essence of road transport boils down to carrying (moving) goods or passengers (persons) using means of transport (motor vehicles) based on the available transport infrastructure (Gaca, 2017).

Road transport is a significant part of the transport system of Poland and the European Union as a whole. Road transport is the branch of transport that currently dominates freight transport in Poland and the entire European Union (Rokicki, 2014). Its share of freight work (excluding maritime and air transport) has remained fairly stable at around 72 per cent in the EU-28 for years (Koźlak, 2018). Road transport is characterised by the following features:

- very high availability of basic means of transport (as evidenced by the large number of lorries on the road),
- the possibility of having a fleet of lorries at any location (as opposed to other means of transport),
- the large choice of different types of transport means,
- the possibility of transporting goods over short and medium distances,
- high speed of transport combined with delivery to the customer,
- timeliness and punctuality of services (becoming increasingly important in the world of transport).

Transport needs have been and continue to be variable in space and time, as they depend on the level of socio-economic development, especially the level of social

awareness, science, knowledge and technology, and the hierarchy of recognised human values (Grzywacz and Burnewicz, 1989). The sources of transport needs are mainly derived from socio-economic phenomena and are diffuse and heterogeneous in nature (Szajt, 2013). Needs change with the development of living standards, the functioning of national economies (Nowicka-Skowron, Dobrovský and Kaczynska, 2019).

In Poland, an important development challenge is still to increase the dynamics of improving the indicators of the density of the transport infrastructure network characterised by high quality standards in relation to the growth of GDP and the volume of performed transport. Since Poland's accession to the European Union, there has been a definite increase in the length of motorways and expressways in Poland - in 2003, there were 405 and 226 km, respectively.

However, in 2016, Poland's road network consisted of more than 19,000 km of national roads, including 1,631.7 km of motorways and 1,531.7 km of expressways (GDDKiA, 2017).

The creation of a transport network faces numerous constraints in practice. These include the usual barriers to the creation of infrastructure (i.e. existing land-use, environmental barriers or insufficient capital). The variability of the quality and density structure of the transport network is an element that seriously disrupts the realisation of transport needs (Skorupka *et al*., 2018). The consequences of not adapting the technical and operational parameters of the pavement to the growing transport needs can be very severe.

A number of empirical studies suggest that government spending on public infrastructure, including transport, has the potential to increase productivity or reduce production costs and thereby increase economic growth (Tong, Yu and Roberts, 2014). It is expected that EU transport activity will continue to grow in the coming decades, with road transport maintaining its dominant role (European Commission, 2016).

Specifically, growth in road passenger transport is estimated at 16% during 2010-2030 and at 30% for 2010-2050. Road freight transport is projected to increase by 33% by 2030 and 55% by 2050.

The development of road transport is closely correlated with the development of transport infrastructure (Luskova, 2017). In this area, it is necessary to maintain a good level with regard to the technical condition of roads, which often involves reconstruction or major reconstruction, followed by high standards in the maintenance of linear infrastructure elements. Important for the development of road transport is the creation of conditions for improving the state of traffic safety on all categories of roads in Poland.

Table 1. *Density of railroad lines in provinces of Poland in 2020*

Voivodeship	Surface area [km^2]	Length of expressways and motorways [km]	Expressways and motorways per 1000 km2	Density of expressways and motorways	Voivodeship	Surface area [km^2]	Length of expressways and motorways [km]	Expressways and motorways per 1000 km2	Density of expressways and motorways [km/100 km^2]
Dolnośląskie	19947	425,0	21,28	46,93	Podkarpackie	17846	183,0	10,23	109,00
Kujawsko-Pomorskie	17972	273,0	15,19	65,83	Podlaskie	20187	110,0	5,43	163,38
Lubelskie	25122	146,0	5,81	172,07	Pomorskie	18310	169,0	9,23	148,65
Lubuskie	13988	258,0	18,44	54,22	Śląskie	12333	364,0	29,51	38,43
Łódzkie	18219	449,0	24,66	40,58	Świętokrzyskie	11711	106,0	9,01	171,88
Małopolskie	15183	190,0	12,51	79,91	Warmińsko-Mazurskie	24173	241,0	9,98	63,00
Mazowieckie	35558	466,0	13,11	76,30	Wielkopolskie	29826	478,0	16,03	74,39
Opolskie	9412	88,0	9,36	106,95	Zachodniopomorskie	22892	316,0	13,79	29,78

Density expressways and motorways in Poland = (Length of expressways and motorways in km / Surface area of Poland in km^2) x 100%

Density of expressways and motorways in Poland = (19422 km / 425,0 km^2) * 100 = 46,93 km / 100 km^2

Source: *Own study based on data from the Regional Data Bank.*

One of the factors determining the effectiveness of road transport organisation is the network of roads and motorways and the quality of their surface. The data on the number of registered vehicles and the density of the road network in Poland in the years 1990-2010 are presented in Table 1. Moreover, the parameters of the transport infrastructure such as its state of maintenance and technical level of construction, its distribution, saturation in geographical areas influence the possibility of transport, transport time, cost or quality. When planning transport, special consideration should be given to the condition of the road surface on which transport is to take place.

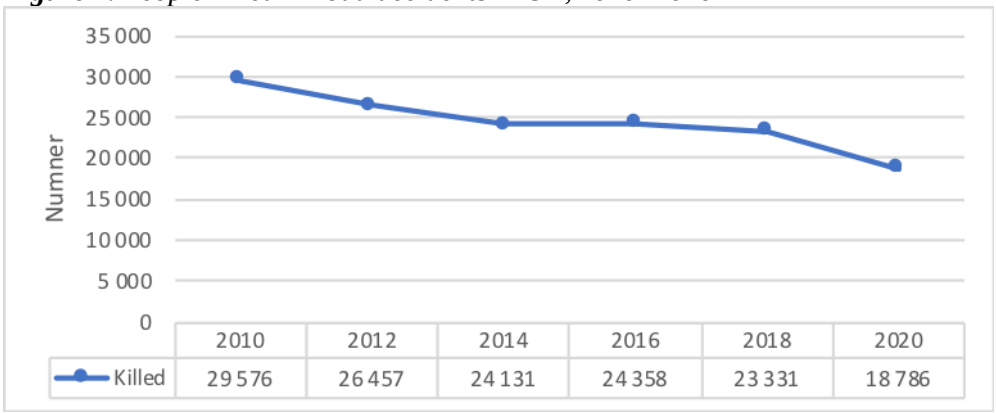
2.2 Adverse Events in Road Transport

Road accidents are the most unwanted thing that can happen to a road user, although they happen quite often (Mingwei *et al.*, 2021). The most unfortunate thing on the road is that we do not learn from our mistakes (Fu *et al.*, 2022). Most road users are

quite aware of the general rules and safety measures when using the roads, but it is only the laxity of some road users that causes accidents and crashes (Orleans, Dela Cruz *et al.,* 2021). The main cause of accidents and crashes is human error. We discuss some of the typical human behaviours that result in accidents. these can include speeding, drunk driving, avoiding safety equipment such as seatbelts and helmets, or overtaking in an inappropriate manner. Various national and international studies have shown that these are the most common behaviours of road drivers that lead to accidents.

In 2019, the number of persons killed in road traffic accidents decreased by 2.5% compared to 2018. The total number of people who died in road accidents in the EU was 22 756, of which 44% were passenger car occupants, 20% pedestrians, 16% on motorcycles, 9% on bicycles and 11% in other categories (including light and heavy goods vehicles, buses and coaches, mopeds and other vehicles). There has been a downward trend over the last 10 years in the number of road traffic victims in the EU. Compared with 2009, the number of road fatalities has fallen by more than 10 000 persons (-31%), from almost 33 000 to less than 23 000 in 2019 (Euroststst, 2021).

Figure 1. *People killed in road accidents in UE, 2010 -2020*



Source: *CARE database (the Community database on road accidents resulting in death or injury); Ireland, Malta and Sweden: 2020 data from the regional data collection).*

Figure 1 shows the available accident data by European Union country (available in the CARE database) from the year 2020 . Two years ago, Germany (264 000 499), Italy (118 000 298) and France (45 000 117) had the highest number of accidents per 12 months. However, when considering the highest rate of fatalities per 100 accidents, Poland came out on top (10.6), overtaking Denmark (6.5) in this respect (Kaminski, 2022).

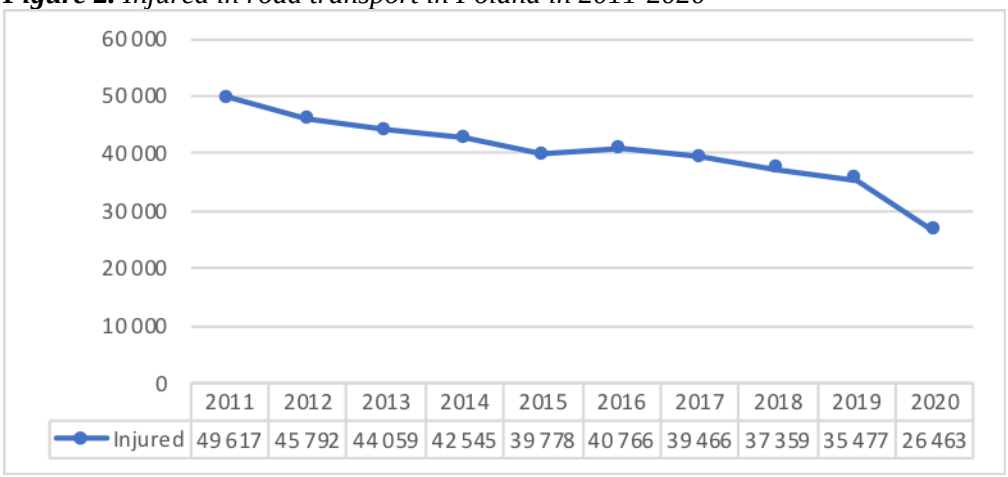
In Poland in 2021, the highest number of accidents occurred in June (11.4% of the total), July (11.0%) and October (10.3%), with the latter having the highest number of fatalities (10.4%). The first two months are associated with high traffic volumes

caused by holiday trips (in June there were 226 fatalities in 2,610 accidents, a month later there were 227 victims in 2,508 accidents), while the tragic figures for October are associated with worsening weather conditions, which translated into 2,351 accidents with 234 fatalities. As might be expected, the highest number of road incidents and the highest number of casualties were recorded on days with good weather conditions - these put drivers' vigilance to sleep and prompt many drivers to drive faster, with high speeds reducing the margin for error and exacerbating the impact of crashes.

Interestingly, in 2021, the majority of accidents - 68.6% - occurred in the built-up area, but it was outside the built-up area that most people died (accounting for 61.2%). The least safe sections are the straight stretches of road. On straight stretches, according to the police, the main cause of accidents was failure to adapt speed to traffic conditions, and at junctions, failure to give priority.

It is worth mentioning that as many as 80% of all accidents, with 85.8% of the total number of fatalities, occurred on single carriageway two-way roads. The fewest accidents occurred on motorways (1.6%) and expressways (1.8%). In addition, 2021, like the year before, the A4 motorway was the least safe of all motorways. (Kaminski, 2022).

Figure 2. *Injured in road transport in Poland in 2011-2020*



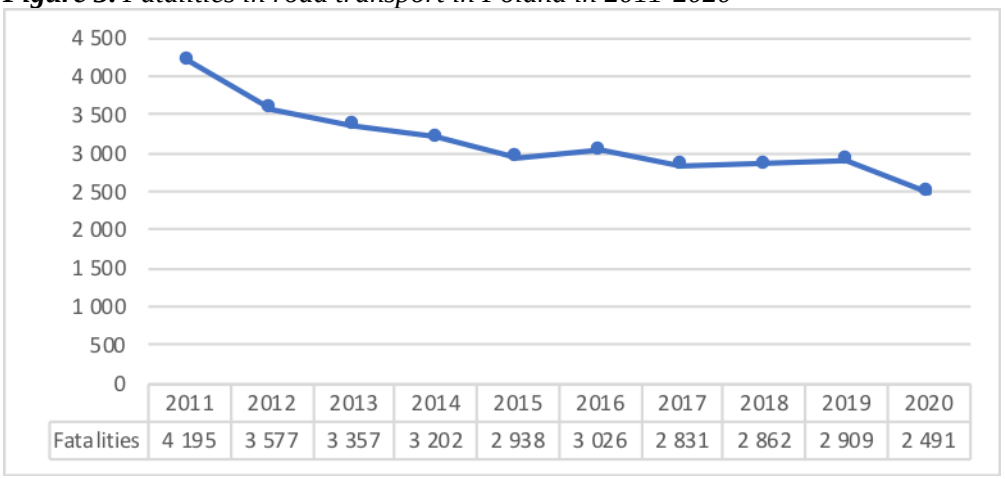
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Injured	49 617	45 792	44 059	42 545	39 778	40 766	39 466	37 359	35 477	26 463

Source: *Own study based on data from the Regional Data Bank.*

In 2020, 26,463 people were injured in accidents (Figure 2) Compared to 2018, when 37,359 people were injured, the number of injured people decreased by 10,896 (29.2%), while compared to 2019, when 35,477 people were injured, the number of injured people decreased by 9,014 (-25.4%). Both in 2020 and in previous years, the highest increase in accidents occurred between 13.00 and 19.00, a very busy period; approximately 44% of accidents occurred during these hours.

The lowest number of accidents was recorded between 00.00 and 05.00; this was also the time when the fewest people were injured and lost their lives. The occurrence of road accidents is also influenced by weather conditions and lighting, with the latter depending on the time of day and season. As in 2018, most accidents occurred in good weather conditions. In good weather conditions, drivers feel more comfortable driving and develop higher speeds, with more tragic consequences if an accident occurs (Symon, 2022).

Figure 3. *Fatalities in road transport in Poland in 2011-2020*



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Fatalities	4 195	3 577	3 357	3 202	2 938	3 026	2 831	2 862	2 909	2 491

Source: *Own study based on data from the Regional Data Bank.*

In the last decade (Figure 3), the highest number of fatalities was recorded in 2011. From that year onwards, a decrease in road accidents and their victims was observed until 2016, when there was an increase in the number of accidents and their victims (3,026). In 2017, there was a significant decrease compared to the previous year. In 2018 and 2019, the number of accidents and injured people decreased, with an increase in the number of people killed. There were decreases in 2020 and 2021.

3. Materials and Methods

The aim of the article is to define undesirable factors in road transport and to show that the lack of sufficient identification of risks in the various phases affects the implementation of this mode of transport. A literature study is conducted to identify key factors and their impact on road transport in Poland.

The realisation of the objective focused on a research procedure encompassing the theoretical plane, which included an analysis of the existing theoretical work on road transport, and the empirical plane, focused on conducting research, which included the identification and assessment of key factors affecting the realisation of road transport in Poland using the network thinking methodology.

For this purpose, a list of road accidents in Poland and selected EU countries for the period 2010-2020 is presented.

4. Research Methodology

There are, however, several methods for modelling relationships using networks - one of them being network thinking methodology. Its premise is to provide complete information on the undesirable factors and the most significant (foreground) impacts in relation to their position in the network. Such an analysis is extremely important, as in some circumstances it may turn out that factors of seemingly minor importance can be the source of the consequence of a whole series of disorderly events, resulting in a much higher intensity of negative phenomena (Bekisz *et al.*, 2022).

The network thinking methodology consists of six interrelated phases that are not sequential, making it possible to return to a previously completed phase or to go through it several times. These phases include: setting goals and modelling the problem situation, analysing the impacts, capturing and interpreting the possibilities for changing the situation, clarifying the possibilities for steering, planning strategies and actions, and putting the problem solution into practice.

The use of network methodology also makes it possible to recognise changes in factors so that corrective action can be taken as early as possible (Grzelczak and Werner, 2011). Any number of additional factors can also be included in the problem situation model and analysed not in isolation, but in conjunction with other factors. Such a picture of the situation makes it possible to reflect the underlying linkages, their intensity, feedbacks and delays in the system (Vester, 2008). The network approach is based on the assumption that the structure of relationships can influence the behaviour of network participants. Networks are composed of social actors, called nodes, who are linked by relationships (Klincewicz, 2016).

An interesting alternative to the labour-intensive mathematical models currently in use are the so-called qualitative models. In these models, assumptions about the development of the problem situation are reflected. Visualising the situation with a qualitative model allows the possibility of influencing the situation to be considered. For example, the impact of demographic change and globalisation on the development of individual regions in the world can be depicted using a qualitative model.

Using a computer programme, the interactions between the individual factors included in the model are mapped. In each case, the influence of one factor on the other is approximated. A distinction is made between weak, medium and strong interactions. The intensity of interactions between factors can also be expressed as a percentage (Piekarczyk, 2016).

Sources of undesirable factors are usually numerous and mainly result from variability in nature, lack of information, as well as the uniqueness and uniqueness of the analysed process. Therefore, identifying undesirable factors requires determining the nature of the process in the context of which these sources are analysed (Kulinska, 2011). The literature distinguishes the following sources of undesirable factors:

- external - which include factors of the political, economic, legal, demographic and environmental situation, as well as available technologies and the requirements of state and government institutions,
- internal - related to the organisation's strategy, its potential, size, human and capital resources, technological resources,specific to the implementation of a specific undertaking, e.g. seasonality (Bizon - Górecka, 2010).

The network thinking methodology is based on group work (Piekarczyk and Zimniewicz, 2010), therefore experts were invited to carry out the analysis: from a company characterised by a high degree of scastomisation and representatives of science. In the initial stage of the research, factors potentially influencing proactive risk management in road transport were identified.

The main advantage of network thinking methodology is the modelling of relationships between variables (Czarniewski, 2015). It enables inferences to be made on the basis of known causes, as well as the search for causes of events (effects). Thanks to a holistic view, it is possible to predict and generate strategic scenarios that allow us to circumvent the risk of making wrong decisions (Jablonski, 2014). Systems thinking results in the construction of a management system in a company (Mitchell, 2006).

The management system, together with business processes and strategy, forms a certain mutual, coherent whole, resulting in an effective management platform determining the development and growth of the enterprise. In order to solve the analysed problem, it is necessary to consider the nature of the problem beforehand and verify whether a probabilistic network is the right modelling methodology for the given situation.The use of network thinking methodology is quite time-consuming, as it requires skills and constant close contact with experts in the field.

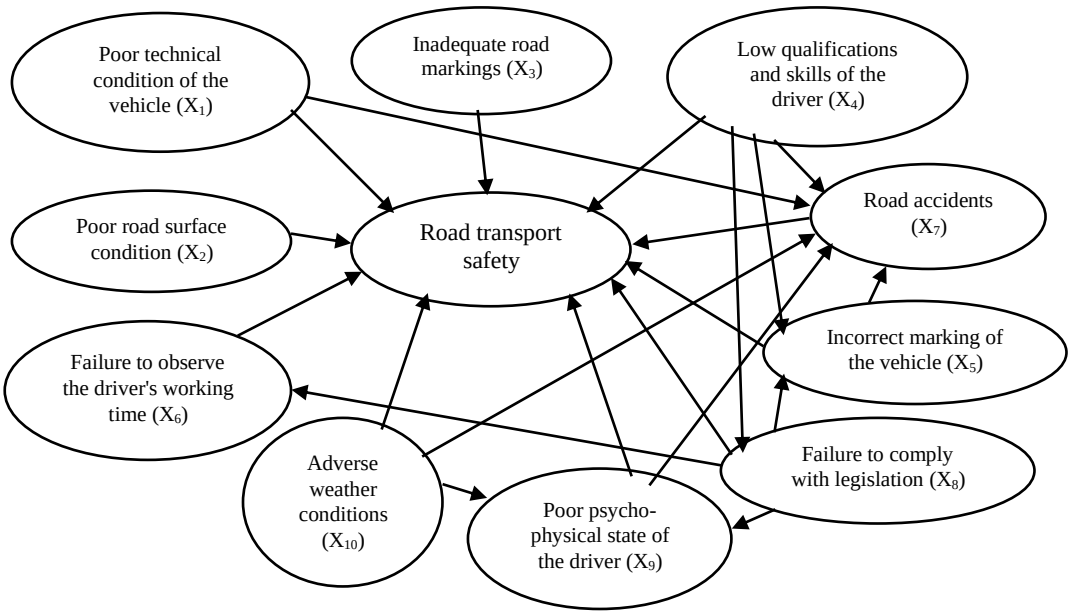
The two key problems in the model-building process are the identification of variables and the relevant relationships between them. The main advantage of the intensity map is the holistic approach (Kubiak, 2022) to road transport management, making it possible not only to identify undesirable factors (groups of factors), but also to estimate the level of risk of their occurrence.

Once the first phase has been implemented, i.e. the aim of the study has been established and the problem situation has been defined, a network should be created between the factors influencing the defined problem and an analysis of their

interactions should be carried out (Figure 4). It is also very important to select the factor at the centre of the network to be built in relation to this factor. Due to the problematic nature of this article, it was decided that this factor would be road transport accident/safety.

After discussion in the expert group, it was agreed that the following elements of the network would be related to it: poor vehicle condition, poor road surface condition, inadequate road markings, low driver qualifications and skills, inadequate vehicle markings, non-compliance with driver working hours, accidents on the road, non-compliance with legislation.

Figure 4. *Network of relationships affecting safety in road transport*



Source: *Own study.*

The analysis of the interactions between the factors listed in Figure 1 should include their type and intensity. As far as type is concerned, it corresponds to the directions of the arrows indicating unidirectional and bidirectional interactions. The intensity, on the other hand, is shown in Table 1, the so-called intensity matrix.

Understanding and examining the interactions in the network is the starting point of the analysis of the intensity of the influences on each other. The influence matrix was used for this analysis. It estimates the intensity of influence on a four-point scale: O - no influence, 1- weak influence, 2 - strong influence, 3 - very strong influence (Zimniewicz, 2003).

- Active factors influence other elements very strongly, but are not themselves influenced,
- Passive factors have little influence on other elements, but are themselves strongly influenced,
- Critical factors strongly influence other elements, but are themselves strongly influenced,
- Lazy factors weakly influence other elements, but are also only weakly influenced themselves (Stasiuk-Piekarska, Hadaś, Wyrwicka and Piekarski, 2017).

Relationships between individual variables (locally) and objects (globally) were established through expert consultation and in-house knowledge. Importantly, the data necessary for the quantitative network analysis (a priori probability, TPW) were instead obtained through expert consultation.

Table 2. *Intensity of interaction of undesirable factors in road transport*

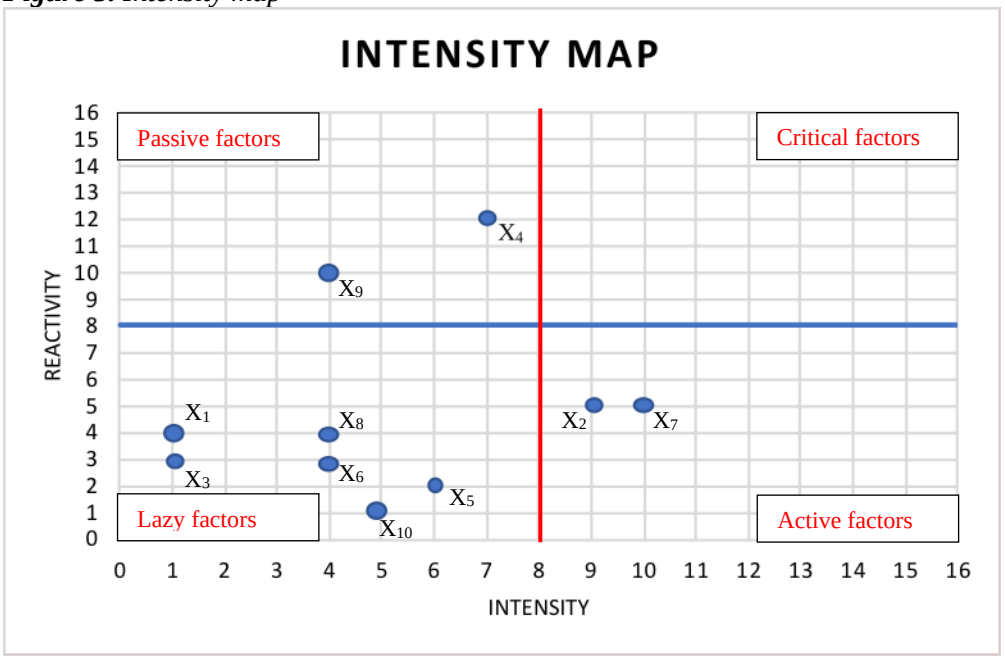
Factor	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	$\sum$
Poor technical condition of the vehicle	X	1	0	0	0	0	3	0	0	0	4
Poor road surface condition	0	X	0	1	0	0	3	1	0	0	5
Inadequate road markings	0	1	X	2	0	0	0	0	0	0	3
Low qualifications and skills of the driver	0	1	0	X	2	2	3	2	2	0	12
Incorrect marking of the vehicle	1	0	0	1	X	0	0	0	0	1	2
Failure to observe the driver's working time	0	0	0	0	1	X	0	0	1	1	3
Road accidents	0	3	0	1	1	0	X	0	0	0	5
Failure to comply with legislation	0	1	0	0	0	1	0	X	1	1	4
Poor psycho-physical state of the driver (stress, nervousness)	0	1	1	1	2	1	1	1	X	2	10
Adverse weather conditions	0	1	0	0	0	0	0	0	0	X	1
Total P	1	9	1	6	6	4	10	4	4	5	X

Source: *Own study.*

The influence matrix presented in Table 2 is the starting point for developing an intensity map, which unambiguously allows the factors listed in it to be assigned to one of the four groups described. At the same time, it makes it possible to identify which factors play a key role in terms of adverse events in road transport. When creating an intensity map, it is extremely important to draw a dividing line between the factors.

In this analysis, the dividing lines are assumed to run where the maximum values of A and P are divided by 2. The resulting values are A = 8 and P = 8. The intensity map is shown in Figure 5. The necessary calculations were made and the following intensity map calculations were obtained. As can be seen from the quality map, the analysed factors qualify as lazy, active and passive. None of the factors was identified as critical.

Figure 5. *Intensity map*



Source: Own analysis.

The factors presented are shown on an intensity map, which is a tool used to identify the nature of individual factors. Based on the intensity map presented in Fig. 5, key factors can be identified (active – influencing these factors will result in high effectiveness of an action, as these are the elements that significantly affect other elements, but are themselves subject to very little impact). These factors include:

- Poor road surface condition (X_2),
- Road accidents (X_7).

From the point of view of the aforementioned improvement, an action proposal should be developed in accordance with the network thinking methodology (Borowiec, 2016). Due to the nature of the factors found in the action model, it is worth dividing them into internal and external factors. From the point of view of road transport, the two controllable factors are closely related.

5. Results and Discussion

Transport is the cornerstone of the national economy and mobility is extremely important not only for the domestic market, but also for the quality of life of citizens (Rodrigue Comtois and Slack, 2017). Transport is one of the most important factors that determine a country's economic development.

The road transport process is associated with a complex of problems related to the reduction of human and economic losses. Road transport managers are awaiting guidance on optimal yet integrated management. It is, therefore, a matter of great importance of undesirable factors that can flow down to road transport management in a key way (Szymanek, 2014).

Among the factors that have a decisive impact on road safety (man-road-vehicle as a causal factor of accidents), man definitely comes first. It was the behaviour of individual groups of road users that generally influenced the occurrence of road accidents. Other factors were far less important.

The correct diagnosis of undesirable factors allows the smooth and uninterrupted execution of road transport. All tasks and undertakings carried out are fraught with uncertainty as to their correct execution. Every activity, from the planning stage onwards, carries risks, which can be caused by several internal as well as external factors at the same time.

Therefore, it is important to monitor possible adverse factors in order to avoid the occurrence of adverse events. All measures aimed at minimising undesirable factors, including mitigating the effects of these risks, can be defined as proactive measures, as they are taken in advance of the occurrence of an undesirable event. For some types of factors, it seems necessary to implement a combination of different measures, as only then will it be possible to reduce their negative consequences to an acceptable level.

The use of network methodology makes it possible to recognise changes in factors so that corrective action can be taken as early as possible. Any number of additional factors can also be included in the problem situation model and analysed not in isolation, but in conjunction with other factors (Honegger, 2008).

In a complex road transport system, it is essential to: identify the interactions occurring between elements that: affect safety. In the search for the factors that have the greatest influence on adverse events in road transport, the authors have examined many aspects of the relationships between the different parts of the relationship network.

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