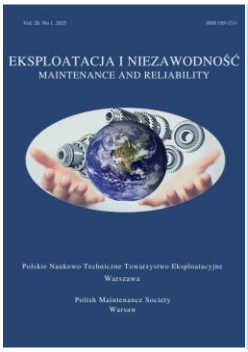

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Risk of adverse events in the transportation of oversize cargoes

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Highlights

- Identification of sources of risk in oversized road transport.
- Risk assessment model for adverse events in road transport of oversize loads.
- Construction of a matrix for estimating the probability of an adverse event.
- Risk assessment procedure.
- Practical example of risk assessment.

Abstract

The issue of risk assessment in road freight transport is currently a significant research gap, which is why the authors decided to conduct research in this field. The article presents a risk assessment model for the occurrence of undesirable events in the transport of oversized cargo. A critical review of the literature on the latest research on risk analysis and methods and tools for assessing the risk of road transport is presented. Based on the identification of the occurrence of various undesirable events, the authors proposed a general approach to the risk assessment model using a risk matrix. Elements of the transport network structure and parameterization of cargo and means of transport were identified and a record was provided. Significant limitations were indicated and a formal record of the probability of occurrence of undesirable situations was proposed. An important element of the article is the presentation of the procedure for calculating the probability of the effects of undesirable events and a practical example for real data for road transport of oversized cargo.

Keywords
risk assessment, transport process, oversize transport, hazardous event

1. Introduction

Road transportation is a key component of global logistics, enabling goods to be transported quickly and efficiently over short and long distances. Despite the numerous benefits of this mode of transportation, it also carries the risk of hazardous events. These incidents can have serious consequences, both for human safety and for infrastructure and the environment. The risk of hazardous events in road freight transportation is a complex issue that requires consideration of many factors. These factors include both technical and organizational aspects, as well as external conditions such as road condition, weather conditions or human-related hazards. In particular, the transportation of oversize cargo, hazardous materials and high-value goods requires special precautions and careful planning.

The aforementioned adverse event in road transportation can be defined as an incident that leads to property damage, damage to infrastructure, injury or death of people, as well as negative effects on the environment. This can include road accidents in general, vehicle crashes and rollovers, emergency releases of

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hazardous substances that can contaminate the environment and endanger public health, fires resulting from collisions or mechanical failures, loss of cargo during transportation, leading to financial losses and traffic obstructions, and road blockages resulting from accidents or inadequate route planning. Managing the risk of such incidents requires the use of appropriate safety measures, such as driver training, regular technical inspections of vehicles, the use of modern monitoring systems, and compliance with laws and regulations to minimize the possibility of adverse incidents and their consequences.

An area of road transportation facing an excessive level of risk is the transportation of oversized cargo. This faction of transportation is a key, albeit highly complex, component of the logistics and transportation industry. The characteristics of such cargoes, exceeding standard dimensions or weights, require not only specialized equipment, but also detailed planning and the application of complex safety procedures. The various challenges involved in organizing such transports involve an increased risk of hazardous events, which can lead to serious economic, environmental and social consequences. The transportation of oversized cargo carries a number of risks that arise from its unusual dimensions, weight and specific transportation requirements. The main risks associated with the transportation of such cargo may include threats to road safety, damage to road infrastructure, technical failures, cargo damage or adverse environmental impacts.

The issue of risk assessment in road transportation of oversize cargo is compiled alongside risk analysis and risk pricing as one of the stages of risk management in the entire road system. The generality of dealing with the occurrence of adverse events in the process of transporting oversize cargo by road often results in an inadequate and insufficient response to the upset of the acceptable level of risk by those involved in the process. A common practice is to respond to the consequences of road incidents rather than to prevent their occurrence. The groups of actors involved in ensuring safety in the transport of oversize cargo by road include: road carriers, shippers and consignees of cargo, infrastructure managers, the Road Transport Inspectorate, authorities responsible for the pilotage of vehicles performing transport, authorities responsible for supervision and regulation.

Risk assessment in the road transportation system can be seen as an approach aimed at identifying risks in nodes and transportation routes, including risks arising from operational processes and the actions of others in the system tasked with carrying out road freight transportation.

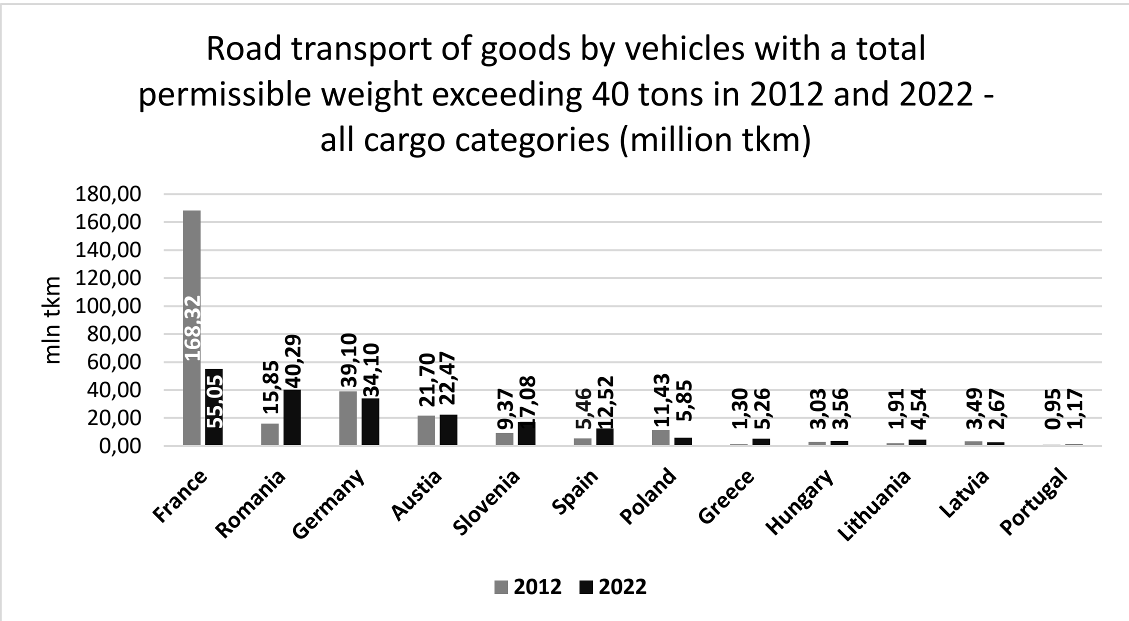

Fig. 1. Road transport of cargo by vehicles weighing more than 40 tons in countries with a permissible total weight of 40 tons. Source: own elaboration based on 14.

The summary (Fig.1) shows road freight transportation by vehicles weighing more than 40 tons, in countries with a permissible total weight of 40 tons. It can be deduced that a large part of these transports are oversize cargo and container transports where the weight can be up to 44 tons. The leading country in the European market in the carriage of cargo by vehicles exceeding the permitted total weight is France. The volume of carriage is more than 55 million ton-kilometer (million tkm). In second place is Romania with a volume of more than 40 million tkm. Third place, in turn, is occupied by Germany, where carriage is 34 million tkm. Poland, carrying less than 6 million tkm of cargo exceeding the permissible total weight of a standard vehicle, ranks seventh in this ranking. It is worth noting that in most countries except France, Germany, Poland and Latvia there is an increase in the share of carriage of this type of cargo. The remaining EU countries are not included in the list, as the permissible total weight in these countries exceeds the ceiling of 40 tons.

The article is divided into 5 parts. In addition to the introduction and summary, a literature review of selected areas of risk assessment is presented in road transport in the broadest sense, with a focus on oversize cargo. The third section is devoted to the specifics of the transportation of oversize cargo by road transport. The subject matter discussed in the article is closely related to the process of implementation of road transport of oversize cargo. Its scope was defined, the critical points of this type of transport were characterized, and factors influencing the increase in risk were identified. The conditions related to accidents, incorrect determinations of the course of the route, improper selection of the vehicle carrying out the transport, the incorrectness of carrying out loading work and the possibility of human error were presented. The fourth presents the basic assumptions of the model for assessing the risk of adverse events in road transport of oversize cargo. Assumptions for the model covering the entire scope of the organization of carriage were characterized. The risk assessment of adverse events was carried out using a five-stage risk matrix. In the last part of the article, a risk assessment for the carriage of a sample oversize cargo was carried out as a case study.

2. Literature review

2.1. The concept of risk in road freight transport

There are many definitions in the literature related to risk in its broadest sense and side terms. However, there is no single official definition. Risk is an incompletely clear concept with many different dimensions, explanations and meanings strictly depending on the area of research 2, 17. To quote a general definition of risk in road transport, it can be the relationship between the frequency and the number of people suffering from a certain level of damage occurring in a certain population as a result of the realization of certain risks 9. In turn, the authors 25 define risk as the product of the probability of the occurrence of an event causing a hazard (a road accident involving a truck carrying cargo is considered a hazard) and the resulting losses. We should distinguish between two basic types of risk occurring in transportation in the broad sense. These can be individual risks and social risks 28. Individual risk, the authors point out, is the probability that a person will be involved in a critical situation (such as a traffic accident) if he or she is in the area of the danger involved. Social risk, on the other hand, refers to the greater number of people involved in the aforementioned accident or traffic collision and the frequency of such accidents. By position 36 road safety analysis is directly related to the survival of people on the roads, while in road safety risk assessment the risk is related to the number of fatalities and is defined as road safety score. In the field of road safety, risk is defined as the road safety score depending on the level of exposure. According to items 13 the term "risk management" can be used to describe the identification, analysis and control of risks that may threaten the assets or earning potential of a company. Risk management can be considered an integral part of the supply chain in order to avoid negative impacts on supply chain performance. Supply chain risk 35 is defined as a “threat” that may affect an organization’s ability to meet the needs of current and future customers. Authors of the work 3 define risk management as the preparation, assessment and sometimes enforcement of appropriate strategies for more effective ways to control, manage and mitigate every day and exceptional risks in the supply chain. Risk analysis 22 in relation to a road accident takes into account the probability of a collision or a road accident and its consequences, with the event ranging from a minor collision to a serious road accident, which may include the loss of human life.

An important area of research is the analysis and management of risk during road transportation of dangerous cargo. A vehicle transporting dangerous cargo poses a “moving” risk due to the movement of dangerous cargo through areas with different levels of exposure, which translates directly into a variable risk value at each point along the route 26. In 32 the authors discussed the environmental risks that occur during the transportation of dangerous goods using system analysis methods. In addition, they proposed a risk assessment model based on the number of road accidents and the degree of their impact on the environment and environmental factors. Publications 44 conducted a literature survey on risk analysis systems for hazardous materials transportation. The authors developed an improved approach to mapping the risks of transporting hazardous substances in Flanders based on historical accident data. The paper 10 developed a methodology focused on identifying key variables to propose a set of operational and strategic indicators to integrate road safety in the transport chain of dangerous cargo transported by road in Colombia. The methodology assesses the extent to which road safety has been integrated into the operational and strategic planning of transport chain stakeholders. In contrast, the paper 5 conducted a quantitative risk analysis of vehicles carrying dangerous goods on routes containing road tunnels. The percentage of trucks carrying dangerous goods, peak hourly traffic volumes and ventilation system failures were estimated to assess their impact on risk levels. The results were compared with those of a study based on a route running entirely in the open air through a densely populated area. The study showed an increased level of risk in the case of an increase in traffic, the number of trucks and failure of the emergency ventilation system. It was found that the risk for transporting hazardous cargo through road tunnels is higher in the event of a fire, while transporting such goods through a densely populated area generates a higher risk in the event of an explosion or release of hazardous substances. An important factor in the risk analysis of road transport of oversized cargo is the analysis of traffic safety. The authors of 39 conducted a characterization and assessment of the road safety level in Poland using a multiple regression model. In 4, a review and a brief discussion of prescriptive risk assessment methods for the transport of dangerous goods through road tunnels in Greece were presented. Finally, an integrated framework for the optimal selection of safety measures based on risk reduction and economic and social considerations was proposed. The subject of risk analysis in the transport of dangerous goods through road tunnels is also discussed in: 6, 7.

The dynamic development of the economy, particularly the construction of new infrastructure and industrial enterprises, is creating an increased demand for road freight transportation. This also affects the increase in demand for the transportation of oversized cargo, an area that generates a high level of risk compared to other areas of road transport 40. An extremely important factor affecting the quality of the transport of oversize cargo is the safety and protection of the environment surrounding the transport in progress and of the people both bystanders and those involved in the transport. Risk management and assessment is one of the key issues when planning the safe transportation of this type of cargo 19. It is usually the case that the mentioned transport is an international transport, and both planning and decision-making should be based on an analysis of the problem at both the national and international levels. Only then is it possible to make the most rational decision 27. The issue of risk management in the movement of oversized cargo was discussed in 33. The authors focused on identifying the threats occurring during the transport of oversized cargo on the route from Estonia to Finland, presenting the legal acts in force in the countries where the transport took place. In addition, the issue of formalities related to obtaining permits for the transport of such cargo in Finland was raised. The unifying point of the publication is the risk analysis based on the identified threats. In paper 29 the choice of methodology for the oversized cargo transport system was discussed, carrying out the transportation of the selected cargo using only road means of transport. The research was conducted in the territory of Lithuania. The authors of the article 11 global method of overcoming viaducts and bridges by vehicles carrying heavy and oversized loads from the perspective of a European Union member state – Slovakia. The research aims to systematize legal regulations in the EU member states in order to prevent permanent damage to viaducts and bridges. Item 30 identifies key factors that should be taken into account when planning oversize transport services, i.e. the specificity of transport, conditions, technology, means of transport used, techniques and methods. The fuzzy set theory was used for the conducted research. In the publication 23 the issue of oversize cargo transport was discussed, using the example of military vehicle transport. The work identified threats resulting from this type of transport and presented the concept of a risk assessment model.

2.2. Risk assessment methods for road freight transport

Due to the dimension of the risks that can cause a collision or an accident on the road during the carriage of oversized cargo, the subject of risk is increasingly becoming the subject of analysis by many authors. 18, 42. Issues related to risk assessment methods are covered in both national and international publications. In turn, in general, it is usually assigned to one of three groups: qualitative methods, quantitative methods or quantitative-qualitative methods. For example, in the work of 41, the use of a non-failure tree and Monte Carlo simulation in enabled qualitative and quantitative assessment of reliability by identifying weak links in a transportation system. On the other hand, 46 presents the relationship between the potential risk of a subsystem and the cost of reliability through the use of a comprehensive allocation method based on fuzzy logic. An approach related to the application of the Hazard and operability studies (HAZOP) method to assess process risk is presented in 31. Through the use of this method, it was possible to identify potential risks and losses that may occur during the implementation of transport tasks.

It should be emphasized that the choice of the method of risk assessment can be determined by the specifics of the branch of transport, which is used to bracarry cargo or passengers. In the framework of rolling stock demand planning by a rail carrier, the article 12 used a Monte Carlo simulation method. The authors assigned risk assessment methods recommended to railroad companies for use as follows:

- Checklists – organizations starting to execute the process in the transport market,
- Failure Mode and Effect Analysis (FMEA), Hazard and Operability Study (HAZOP), COSO II - an organization with extensive experience in the process (e.g., Polish carriers with a minimum of 2 years of experience),
- FTA (from Fault Tree Analysis) - an organization with extensive experience in the process, with a large amount of data on incidents - major freight and passenger carriers, major infrastructure managers.

In a broader context, the FMEA method has been used to select risk mitigation strategies in the road freight transportation industry. The authors' findings 21 indicate to managers that the selection of risk mitigation strategies should be based on the severity of the risks and a limited budget. In addition, it was found that taking into account the subjective opinions of experts and cost-benefit justifications, a convincing result can be obtained by estimating risks in the FMEA approach. In turn, a clear and problem-oriented categorization of FTA methods is made in 34 The article aims to support those using FTA methods for risk analysis in planning processes. On the other hand, the authors 24, using the FTA method, performed a risk analysis in road transport of oversize cargoes.

Meanwhile, the issue of safety assurance in air traffic management systems is discussed in detail in the publication 8. The authors identified potential risks and assigned them to one of three tolerance areas. A methodology based on the use of Markov chains in assessing the security risk of the maritime transport system is included in the article 45. The authors studied the ongoing changes in the state of the system and identified the point at which a low-probability incident transforms into a high-risk event.

In addition to aspects related to the modal view of transportation, one should not forget about international standards that describe and indicate methods for risk assessment. One of the standards used in the area of risk management is ISO 31000:2018 15. The document provides guidelines and principles that can be implemented in enterprises, and assigns to the various stages of risk management the methods and techniques recommended for implementation. The standard presents dedicated methods for stages such as risk identification, risk assessment, risk analysis, risk evaluation, and recording and reporting. In view of the above, it should be emphasized that the selection of a risk assessment method depends primarily on the object under study and the purpose of the analyses to be carried out.

The second standard with significant impact on the topic of risk assessment is the IEC 31010:2019 (ISO/IEC) standard 16. This is an international standard that supports risk management by describing techniques for identifying, analyzing and assessing risks. It complements ISO 31000 and provides practical tools for various industries and applications. The cited standard presents about 40 risk assessment methods, such as FMEA, Fault Tree Analysis (FTA), Monte Carlo Analysis or SWOT, with guidelines for their selection depending on the organization's context and specific risks. It supports the decision-making process, increasing risk awareness, safety and efficiency of operations. The 2019 update introduced new techniques, reflecting changes in the business and technology environment. IEC 31010:2019 is a key tool in risk management, enabling effective identification and minimization of risks.

The authors 37 proposed an approach to the problem of risk occurring in the broader freight transportation system. The publication includes the development of an approach to risk analysis using intuitionistic integration of fuzzy sets and number theory. Fuzzy sets were used to examine the belongingness of an element or lack thereof. Number theory, on the other hand, increases the objectivity of assessments by combining the assessments of multiple experts. The proposed risk assessment model that provides predictability, visibility and measurability in transportation operations was created to help managers develop sustainable freight transportation systems. The created analysis alerts freight managers to potential high-priority sustainability risks and helps formulate a proactive strategy and optimal allocation of mitigation resources to minimize disruption to sustainable transportation systems. The paper 38 developed a fuzzy multi-criteria decision-making model for traffic risk assessment. The authors performed a study based on a fragment of a 7.4 km long road network, consisting of a total of 38 sections. The study was developed based on fuzzy alternative measurement and ranking according to the fuzzy MARCOS trade-off method. In order to determine the weights of the criteria used to assess the road network sections, the PIvot Pairwise RElative Criteria Importance Assessment was used – in short, the fuzzy PIPRECIA method 43. A fuzzy linguistic scale expressed quantitatively in the form of triangular fuzzy numbers (TFN) was also developed 1.

3. Identification of sources of risk in oversized road transport

Oversized loads as defined above are defined as those exceeding the permissible dimensions of the vehicle: i.e. length 16.5 m, width 2.55 m, height 4 m) or exceeding the permissible total weight of 40 tonnes, while maintaining the permissible axle loads of the vehicle.

Road transportation of oversized cargo carries certain risks and the consequences of their occurrence. The mentioned risks can be interpreted as an element of decision-making. A correct decision-making process must be preceded by a relatively optimal and correctly selected risk assessment process. Subsection 2.2 provides an overview of the methods used for assessing possible events in transportation. Various risk assessment methods are used in this process. Evaluation of their suitability in a specific case remains open.

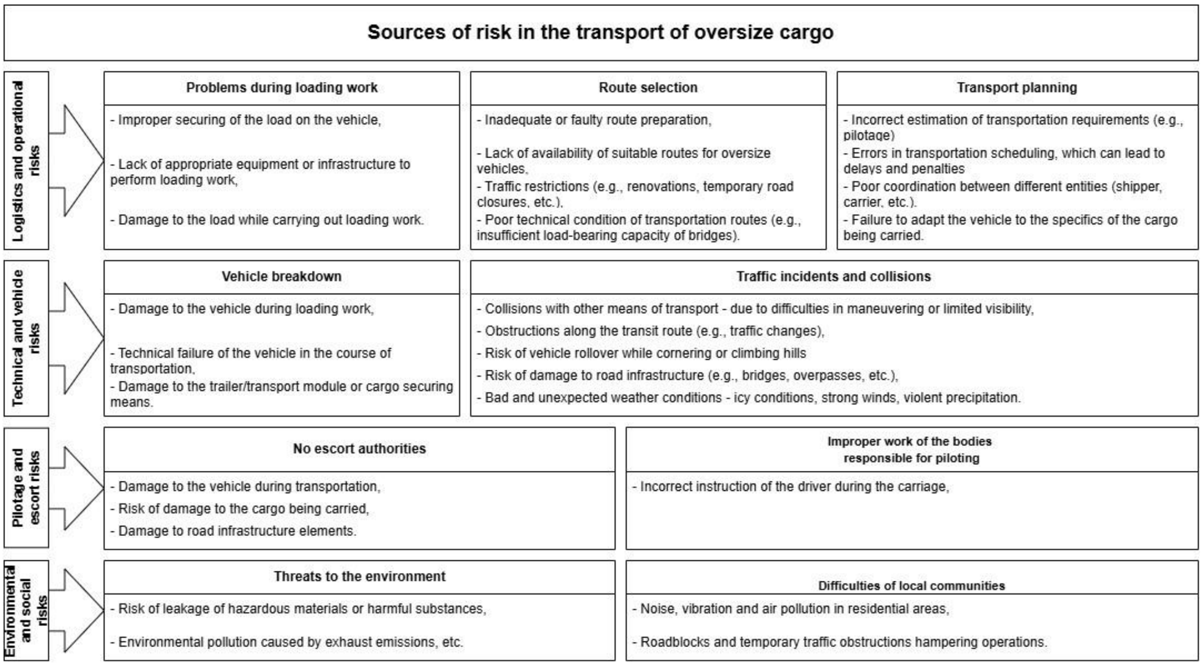

Fig. 2. List of events that are a source of risk in oversize transport.

Source: own elaboration.

An important part of risk analysis and assessment is the identification of adverse events. In oversize transportation, adverse events can be technical, organizational, social, environmental, among others. Figure 2 shows an example of a summary of identified events that are a source of risk during oversize transport. The summary includes the main and most frequent events affecting the level of risk. The identification and risk analysis performed in the article was based on research conducted at a leading transportation company specializing in the transportation of oversize cargo in Poland and Europe.

4. Risk assessment model for adverse events in road transport of oversize loads

4.1. Assumptions for the model

In the case of risk assessment in the implementation of road transportation of oversize cargo, it is important to determine the probability of occurrence of undesirable events along the entire route of transportation and the consequences of the occurrence of these events. It was assumed that the key parameters determining the probability of occurrence of adverse events in oversize cargo transportation are logistics and operational risks, technical and vehicle-related risks, environmental risks, and pilotage and escort risks.

The scale of undesirable situations along the route of the oversize vehicle will reflect the extent of damage and will be determined by the value of the effect at a given point of carriage, such as: accident or road collision, cargo damage, environmental hazard, traffic obstruction. The developed risk assessment model refers to the situation in which the exact parameters of the cargo, the type of cargo operations, as well as the place of shipment and the destination are known. The key aspect is the analysis of the route of the oversize vehicle, characterized by a certain probability of adverse events and the consequences of their occurrence.

The following assumptions were made in the creation of a risk model for the occurrence of adverse events in the road transport of oversize loads:

- oversize road transport is carried out in international traffic,
- the implementation of the freight task involves the transportation of a preset cargo from the shipper to the consignee,
- the freight process consists of the following elements: loading, carriage, unloading,
- points of shipment and destination are connected by road sections,
- adverse events occurring during the transportation process are random events that cannot be predicted at the stage of transportation planning,
- the direct causes of adverse events occur both in the processes of loading, unloading, as well as in the transportation itself,
- the consequences of undesirable events are those occurring at the points where loading operations are performed, along the route of transportation and at the points of destination,
- the distribution of the probability of occurrence of undesirable events will be recorded using a five-stage risk matrix scale.

4.2. Model parameters

The risk assessment model presented in the article was developed on the basis of risk management based on the definition of a risk matrix. Taking into account the above considerations, the risk assessment model (***MORDPP***) is defined as an ordered five:

$$\boldsymbol{MORDPP} = \langle \boldsymbol{GTP}, \boldsymbol{CL}, \boldsymbol{CTN}, \boldsymbol{CTC}\ \boldsymbol{OSD} \rangle \tag{1}$$

where:

– **structure of *GTP* road network** showing links between cargo sending and receiving points,
– **characteristics of *CL* loads** resulting from technical parameters of the cargo,
– **technical characteristics of *CTN* low loader trailer,**
– **technical characteristics of the *CTC* fifth-wheel tractor,**
– **characteristics of *OSD* road network sections.**

Taking into account the above, the input data for the oversize cargo transportation risk assessment model regarding the structure and characteristics of the transportation network, transportation task, technical parameters of vehicles and cargo are summarized in Table 1.

Tab. 1. Input dataset for risk assessment model.

Parameter	Interpretation - commentary
$\boldsymbol{GTP} = \langle \boldsymbol{MZ}, \boldsymbol{OD} \rangle$	Road network structure graph
mz	Cargo handling point numbers, $mz \in \boldsymbol{MZ} \wedge mz \neq mz'$
(mz, mz')	Road section, while $mz, mz' \in \boldsymbol{MZ}$
nd, nd'	Road numbers, $nd, nd' \in \boldsymbol{ND}$
$((mz, mz'), nd) \equiv nod$	Road section assigned to the road number on which it is located
nod, nod'	The road section numbers, while $nod, nod' \in \boldsymbol{NOD}$
pmd(mz)	Max. length of the set, for a given cargo handling point of no. *mz*
pmw(mz)	Max. height of the vehicle, for a given cargo handling point of no. *mz*
pms(mz)	Max. vehicle width, for a given cargo handling point of no. *mz*
CL – charge parameter vector	$\boldsymbol{CL} = [mł(łp), dł(łp), sł(łp), wł(łp)]$
łp	Oversized cargo number: ***ŁP*** = *{1,...,łp,...,ŁP}*
mł(łp)	The weight of the oversize cargo of no. *łp*
dł(łp)	The length of the oversize load of no. *łp*
sł(łp)	The width of the oversize load of no. *łp*
wł(łp)	The height of the oversize load of no. *łp*
CTC – fifth-wheel tractor parameter vector	$\boldsymbol{CTC} = [dmc(cs), lo(cs), mw(cs), mc(cs), mo(cs)]$
cs	Number of the fifth-wheel tractor: ***CS*** = *{1,...,cs,...,CS}*
dmc(cs)	The permissible total weight of the fifth-wheel tractor with no. *cs*
lo(cs)	Number of axles of the fifth-wheel tractor with no. *cs*
mw(cs)	Net weight of the fifth-wheel tractor unit no. *cs*
mc(cs)	The power of the fifth-wheel tractor with no. *cs*
mo(cs)	The torque of the fifth-wheel tractor with no. *cs*
CTN – semi-trailer parameter vector	$\boldsymbol{CTN} = [mw(nan), dmc(nan), mł(nan), lo(nan), md(nan)]$
nan	Low-loader semi-trailer number: ***NAN*** = *{1,...,nan,...,NAN}*
mw(nan)	Net weight of the low-loader semi-trailer no. *nan*
dmc(nan)	The permissible total weight of the low-loader semi-trailer with no. *nan*
mł(nan)	The maximum payload capacity of the low-loader semi-trailer with no. *nan*
lo(nan)	The number of axles of the low-loader semi-trailer with no. *nan*
md(nan)	The maximum length of a semi-trailer with no. *nan*
OSD – characteristics of road network sections vector	$\boldsymbol{OSD} = \begin{bmatrix} od(nod), vmax(nod), mdp(nod) \\ mwp(nod), msp(nod), mmp(nod), mno(nod) \end{bmatrix}$
od(nod)	The length of the section of the road network with no. *nod*
vmax(nod)	The max. permissible speed on the section of the road network with no. *nod*
mdp(nod)	The max. vehicle length on a section of the road network with a no. *nod*
mwp(nod)	The max. height of a vehicle on a section of the road network with a no. *nod*
msp(nod)	The max. width of a vehicle on a section of the road network with a no. *nod*
mmp(nod)	The max. weight of a vehicle on a section of the road network with a no. *nod*
mno(nod)	The max. axle load of a vehicle on a section of the road network with a no. *nod*

Source: own elaboration.

4.3. Construction of a matrix for estimating the probability of an adverse event

There are many examples of road traffic incidents that can result in an adverse event. For each type of adverse event, the cause of its occurrence must be identified. In dependency 2, the mentioned causes are denoted by the subscript p, in turn, the vector of factors influencing the type of a given hazard is shown below:

$$\text{WW} = [(\text{ww}, 1), (\text{ww}, 2), \dots (\text{ww}, \text{p}), \dots (\text{ww}, \text{P})], p \in \text{P} \quad (2)$$

where:

- pair (*ww, p*) denotes the p-th cause affecting the occurrence of the ww-th category of adverse event,

Accordingly, the vector of factors for the area of occurrence on road transportation routes was written as follows:

$$R(osd) = [((osd, (ww, 1)), ((osd, (ww, 2)), \ldots, ((osd, (ww, p)), \ldots, ((osd, (ww, P))] \quad (3)$$

where:

- data set ((*osd*), (*ww, p*)) means the p-th cause affecting the occurrence of the ww-th category of adverse event on the osd-th road section.

In order to assess the risk of adverse events according to the risk matrix (on a five-point scale), it is necessary to define the probability distribution for the separate levels of occurrence of an adverse event. Accordingly, it was assumed that the random variable Y of occurrence of the above-mentioned category of adverse event will be the level of occurrence of the incident, i.e. Y = 1, 2, 3, 4, 5. Its distribution will be as follows for the direct causes of the incident on the road network sections:

Y	1	2	3	4	5
P(Y)	P(DLNZ(*i, osd*)) – P(GLNZ(*i, osd*))	P(DLNS(*i, osd*)) – P(GLNS(*i, osd*))	P(DLSR(*i, osd*)) – P(GLSR(*i, osd*))	P(DLW(*i, osd*)) – P(GLW(*i, osd*))	P(DLBW(*i, osd*)) – P(GLBW(*i, osd*))

where:

- P(DLNZ (*i,osd*)) means the lower limit of the probability interval of an adverse event for the causes of direct incidents on a given road section for a negligible level.

- P(GLNZ (*i, osd*)) means the upper limit of the probability interval of an adverse event for the causes of direct incidents on a given road section for a negligible level.

The limits of the ranges (lower/upper limit) of the probability of an adverse event for a given level of event occurrence (Table 2) will be determined based on data consulted with the transport company.

For each type of adverse event identified, the sk-te consequences of the occurrence of this type of event (ZN) are indicated. In order to systematize further considerations, the effects of undesirable events are denoted by the *sk*-index , assuming that the set of *ZNs* will be a set in the form of:

$$ZN = \{sk: sk = ul, uid, up, o, bd, k, op\} \quad (4)$$

ul – cargo damage,

uid – damage to road infrastructure,

up – damage to the vehicle combination used to transport cargo,

o – delays in cargo delivery,

bd – no possibility of further transportation,

k – occurrence of a traffic collision,

op – injured persons (damage to health).

Based on the above, the impact vectors of the occurrence of a given type of hazard can be written as follows:

$$ZN(ww) = [(ww, ul), (ww, uid), (ww, up), (ww, o), (ww, bd), (ww, k), (ww, op)] \quad (5)$$

Tab. 2. Limits of the ranges of probability of occurrence of an adverse event for the five-stage risk matrix.

No.	Level	The level of occurrence of an adverse event(value of random variable)	Probability of occurrence of an adverse event (upper limit - lower limit)
1.	Slight	1	0,000 – GLNZ(*i, osd*)
2.	Low	2	DLNS(*i, osd*) – GLNS(*i, osd*)
3.	Medium	3	DLSR(*i, osd*) – GLSR(*i, osd*)
4.	High	4	DLW(*i, osd*)) – GLW(*i, osd*)
5.	Very high	5	≥ GLBW(*i, osd*)

Source: own elaboration.

5. Risk assessment procedure

5.1. Risk assessment algorithm for oversized road transport

Important elements in the road transport of oversize cargo is to identify the parameters of the transport order, which may include such elements as the type of cargo, technical parameters of the cargo or the place where the cargo work is performed (loading, unloading). The next step is to plan the main parameters of the carriage. We are talking in particular about determining the route of carriage, estimating costs and time, selecting the means of transport, planning cargo work and organizing the necessary transport documentation. Only after estimating the parameters of carriage can the main part of risk assessment take place by identifying the sources of risk, selecting the method of determining the risk and taking measures to reduce the risk. The following Figure 3 shows the algorithm of procedure and risk assessment during the organization of oversize carriage.

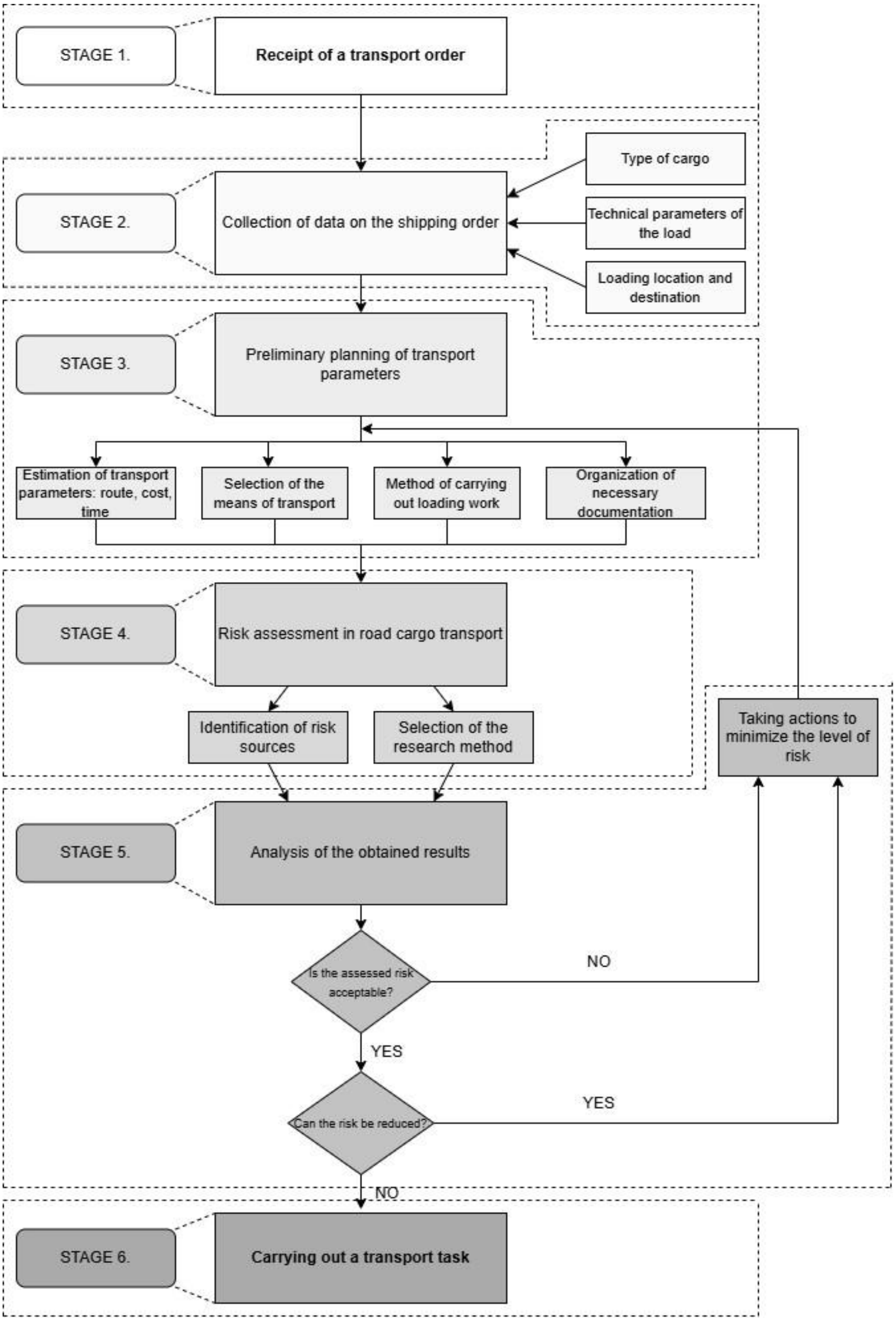

Fig. 3. Algorithm of procedure and risk assessment during the organization of oversize transport.

Source: own elaboration

The proposed risk assessment method is very flexible, and its specific form can be adjusted depending on the needs and scope of the risk analysis performed. The specific solution follows directly from the needs of the risk manager. Taking into account the various risks in oversize transportation, it is possible, among the available methods of analysis, to use a combined method based on the "Risk Matrix" method, the assumptions of which were developed in the paper 20. Due to the nature of the data acquired in cooperation with a transportation company that has been operating in the over-the-road trucking industry for more than 30 years, it was decided that the most appropriate method to use would be the risk matrix method. This is because this method is based on two parameters, i.e. probability and effect. The consequences of adverse events for a given cause may carry the same effect, but the strength of its impact may vary. The risk matrix method makes it possible to determine the scale of adverse events. It is such a universal tool that it can be successfully applied among entities operating in the road freight market, such as infrastructure managers, road carriers and freight forwarders. In addition, it can also be used by entities collecting data on adverse events. The proposed method defines event risk A as *R(A)*:

$$\mathrm{R(A)} = \mathrm{S(A)} \times \mathrm{P(A)} \tag{6}$$

where:

R(A) – risk of an event occurring A

P(A) – probability of an event A

S(A) – consequences of the incident A

The risk assessment method based on the product of probability (P) and consequences (S) is one of the most widely used in risk management. It makes it possible to easily classify risks based on an assessment of two key factors: the possibility of a particular risk occurring and the impact or magnitude of its consequences. For each specific and situation-specific risk, we multiply P by S, resulting in (R(A), which allows us to prioritize risks with higher R(A) values that require more attention and countermeasures.

The first step of the analysis is to provide a scoring of the impact and probability of occurrence of event A. Table 3 shows the probability of occurrence and severity of risk assessment function for the evaluated events.

Tab. 3. Set of parameters for assessing the risk of vehicle components.

Criterion value	Impact force - effects	Probability of occurrence
1	Lack of effects	Zero or almost zero
2	The consequences are not dangerous	Extremely rare, almost non-existent
3	The effects are troublesome	Very rare (once every 3 years)
4	Very dangerous consequences	Occurring (once a year)
5	Catastrophic effects	Frequent (2 times a year)

Source: own elaboration based on 20.

6. Practical example of risk assessment

6.1. Assumptions – parameters of cargo and means of transport

For the purposes of performing the analyses, an example type of load and its parameters were assumed. The load being the subject is a hop harvester, the height of which can reach a ceiling of 4 meters. The load assumed for the tests was a hop harvester with a height of 3.8 m. The remaining technical parameters are listed in Table 4.

Tab. 4 Technical data of an example oversized cargo.

No.	Parameter	Designation	Value
1.	Length of oversize cargo	*dł(łp)*	7,50 m
2.	Height of oversize cargo	*wł(łp)*	3,40 m
3.	Width of oversize cargo	*sł(łp)*	2,70 m
4.	Total weight of oversize cargo	*mł(łp)*	9 000 kg

Source: own elaboration.

The choice of transport mode is closely related to the parameters of the cargo to be transported and the requirements specified in the permit. In the case of a hop harvester, the height of the loading area of the low-loader semi-trailer is crucial. The selected harvester has a height of up to 3.40 meters, and all basic permit categories (from I to VI) allow a maximum vehicle height of no more than 4.30 meters. Due to the restrictions imposed by the height of the load and the requirements of the permit, the low-loader semi-trailer must have a loading area placed below 0.9 m. Table 5 shows the technical parameters of the semi-trailer used to transport the selected cargo. Table 6, on the other hand, shows the technical parameters of the truck tractor cooperating with the semi-trailer.

Tab. 5. Technical parameters of the semi-trailer used to carry out the transport.

No.	Parameter	Designation	Value
1.	Brand of semi-trailer	-	Faymonville
2.	Number of semi-trailer axles	*lo(nan)*	2 pcs
3.	Net weight of the low-bed semi-trailer	*mw(nan)*	12 500 kg
4.	Maximum semi-trailer load capacity	*mł(nan)*	25 500 kg
5.	Permissible gross semi-trailer weight	*dmc(nan)*	38 000 kg
6.	Maximum semi-trailer length	*md(nan)*	16,50 m

Source: own elaboration.

Tab. 6. Technical parameters of the truck tractor used to carry out transportation.

No.	Parametr	Designation	Value
1.	Brand of fifth-wheel tractor	-	Volvo
2.	Permissible gross vehicle weight (tractor + semi-trailer)	*dmc(cs)*	100 000 kg
3.	Number of axles of the tractor unit	*lo(cs)*	3 pcs
4.	Fifth-wheel tractor unit weight	*mw(cs)*	9290 kg
5.	Fifth-Wheel tractor unit power	*mc(cs)*	368/500 kW/HP
6.	Torque of the fifth-wheel tractor unit	*mo(cs)*	2550 Nm

Source: own elaboration.

6.2. Determining the route of transportation

Determining the route for an abnormal vehicle is a key aspect of transportation planning. The route is specified in detail in the permit, which defines the dimensions and permissible weight of the load to be transported. Table 7. shows the parameters of the route of the trip as assumed in subsection 4.2.

Tab. 7. Technical parameters of the truck tractor used to carry out transportation.

No.	Parameter	Designation	Value
1.	Length of road network section	*od(nod)*	1165 km
2.	Maximum permissible speed for heavy vehicles on the road section	*vmax(nod)*	90 km/h
3.	Maximum vehicle length on the road network section*	*mdp(nod)*	30 m
4.	Maximum vehicle height on the road network section*	*mwp(nod)*	4,30 m
5.	Maximum vehicle width on the road network section*	*msp(nod)*	4 m
6.	Maximum vehicle weight on the road network section*	*mmp(nod)*	60 000 kg
7.	Maximum vehicle axle load on the road network section	*mno(nod)*	10 000 kg

Source: own elaboration.

*Parameter established in accordance with the permit for the passage of a category IV non-normative vehicle on public roads.

The analyzed haulage route runs between the loading site located in the Lublin province in Poland and the unloading site in Mainburg, located in Bavaria in the southern part of Germany. The route that the vehicles traveled after loading the harvesters was as follows: the initial phase of the drive from the loading site was on county roads. From Pulawy through Garwolin, Kolbiel along the S17 expressway to Warsaw. Then headed along the southern bypass of Warsaw (road S2) until the exit to the A2 highway at the Konotopa interchange. It continued on the A1 highway, the S8 expressway. Then the A4 highway crossed the border crossing in Zgorzelec and continued on highways 72 and 93 on German territory. The final part of the carriage was along the Land Road 301. The exact course of this route is illustrated in Figure 4.

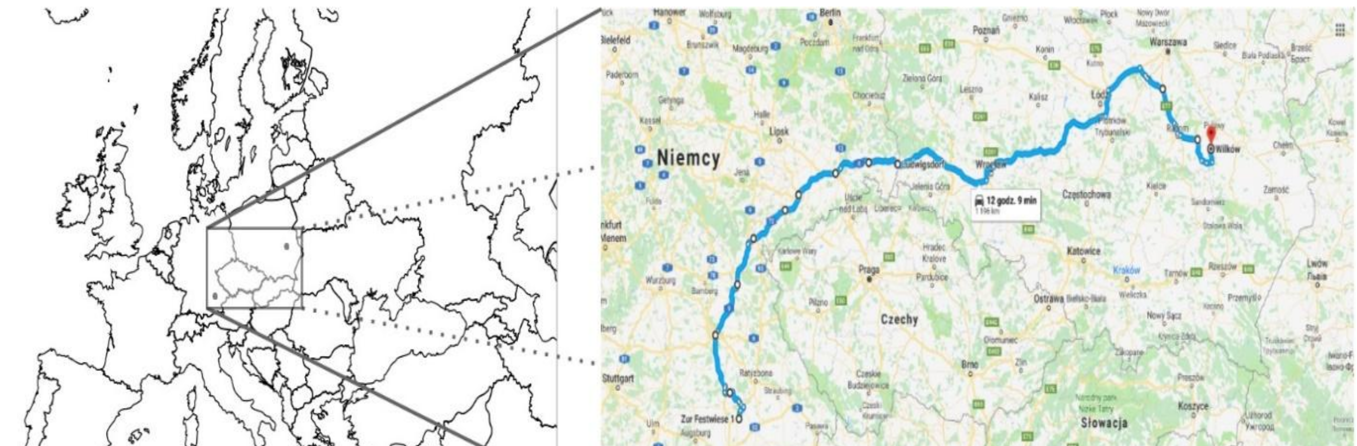

Fig. 4. The route of an oversized vehicle.

Source: own elaboration.

The next step is to formulate a risk matrix. Tab. 8 contains a risk matrix qualifying an event in oversize transport as significant.

All events for which the level of risk is unacceptable must be included in risk management. These are events for which prior preventive action must be taken.

Tab. 8. Risk matrix – assessment of incidents in oversize transport.

Impact \ Risk level	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Source: own elaboration based on 20.

The above-defined method of risk assessment using a risk matrix makes it possible to make a detailed analysis of the risks in the case of a defined transport and to systematically and objectively identify the risks and actions to be taken to minimize them. Twenty-four identified sources of risk in the transportation of oversize cargo were analyzed. The study was based on a five-level risk matrix. A summary of the levels of risk and the effects of each source of risk in the transportation of oversize cargo is summarized in the table. 9.

Tab. 9. Risk analysis of individual identified events.

No.	Sources of risk in the transportation of oversize cargoes	Designation	Risk level elements		
			Risk probability level P	Impact S	**Risk level P x S**
1.	Inadequate securing of cargo on the vehicle	A1	4	5	20
2.	Lack of appropriate equipment to perform cargo work	A2	2	3	6
3.	Damage to the cargo while performing loading work	A3	3	3	9
4.	Inadequate or faulty route preparation	B1	3	3	9
5.	Lack of availability of suitable routes	B2	3	3	9
6.	Traffic restrictions	B3	3	3	9
7.	Incorrect estimation of transportation requirements	B4	2	2	4
8.	Errors in transportation scheduling	C1	2	2	4
9.	Poor coordination between different entities	C2	2	2	4
10.	Technical failure of the vehicle during transport	D1	4	3	12
11.	Damage to the semi-trailer or cargo securing means	D2	3	4	12
12.	Collisions with other vehicles	E1	4	5	20
13.	Obstructions on the road	E2	4	2	8
14.	Bad and unexpected weather conditions	E3	4	3	12

No.	Sources of risk in the transportation of oversize cargoes	Designation	Risk level elements		
			Risk probability level P	Impact S	**Risk level P x S**
15.	Risk of vehicle rollover	E4	2	5	10
16.	Environmental pollution by exhaust emissions	F1	5	2	10
17.	Risk of leakage of hazardous materials	F2	3	4	12
18.	Noise, vibration in populated areas	G1	3	2	6
19.	Roadblocks and temporary obstructions	G2	3	2	6
20.	Risk of damage to road infrastructure	G3	3	3	9
21.	Incorrect instruction of the driver during the course of transportation	H1	2	4	8
22.	Damage to the vehicle during carriage	I1	3	2	6
23.	Damage to cargo during the performance of transportation	I2	3	3	9
24.	Risk of damage to road infrastructure	I3	3	2	6

Source: own elaboration.

As part of the analysis carried out, risks were estimated that need to be mitigated and to which special attention must be paid in oversize transportation. Knowledge of unacceptable risks allows you to take measures to minimize the level of risk. Each of the cases (1, 10-12, 14, 17) should be considered separately, since their area requires different methods of risk mitigation. For example, item No. 10 - technical failure of a vehicle during transport - in terms of risk mitigation requires additional specialized inspection of the vehicle in question, especially for sensitive components during transport of oversized cargo. The following Figure 5 shows the risk assessment map for the analyzed transportation.

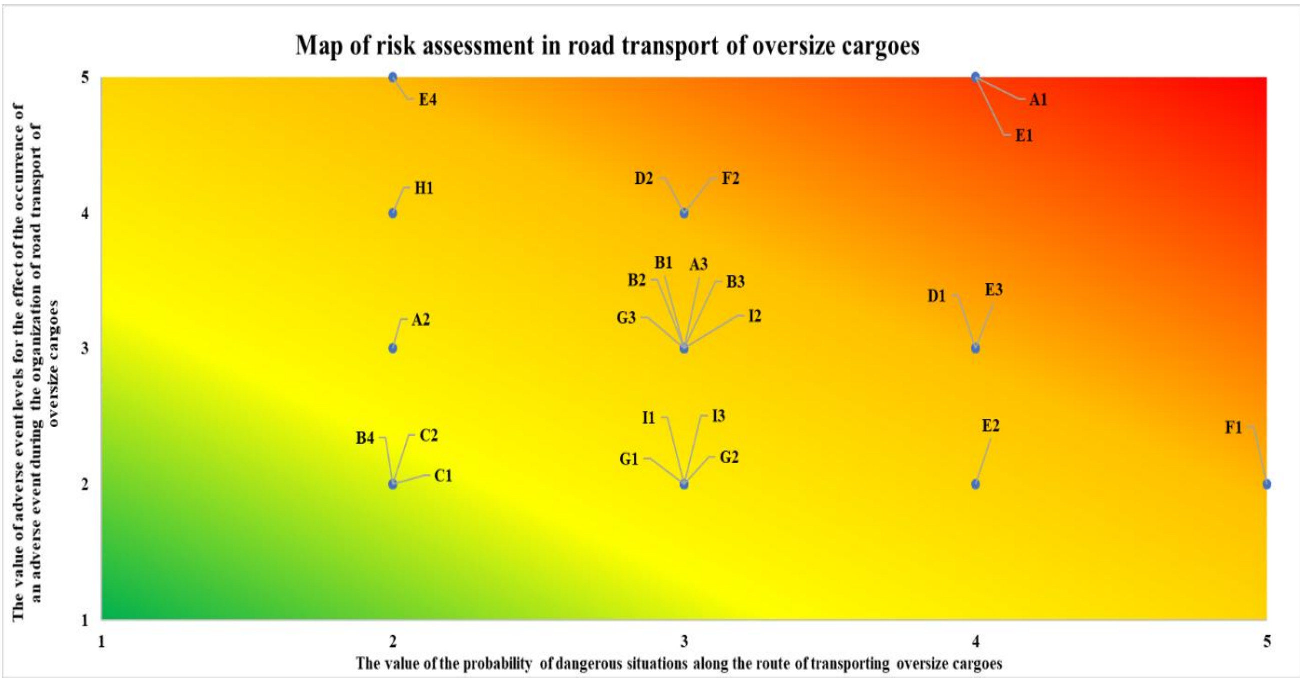

Fig. 5. Map of risk assessment in road transport of oversize loads

Source: own elaboration.

According to the above analysis, the sources of risk with the highest probability of occurrence are: Improper securing of cargo on the vehicle, technical failure of the vehicle during transport, collisions with other vehicles, obstructions on the road, bad and unexpected weather conditions, environmental pollution by exhaust emissions. On the other hand, the sources of risk with the greatest effect of an adverse event are: improper securing of cargo on the vehicle, damage to the semi-trailer or means of securing cargo, collisions with other vehicles, risk of overturning the vehicle, risk of leakage of hazardous materials, erroneous instruction of the driver during transportation.

The final results clearly indicate that improper securing of cargo on the vehicle and collisions with other vehicles have the highest level of risk. The aggregate results are shown in Table 10.

Tab. 10. Risk assessment of the realization of road transport of oversized loads.

No.	Level	Risk range (upper limit - lower limit)	Sources of risk
1.	Slight	0,0 – 1,0	–
2.	Low	2,0 – 4,0	B4, C1, C2
3.	Medium	5,0 – 11,0	A2, A3, B1, B2, B3, E2, E4, F1, G1, G2, G3, H1, I1, I2, I3
4.	High	12,0 – 19,0	D1, D2, E3, F2
5.	Very high	20,0 – 25,0	A1, E1

Source: own elaboration.

7. Summary and conclusions

The research carried out in the article indicates that the issue of risk is very important not only in many areas of transportation but also in the analysis of the operation of any enterprise. Particularly important is the search for methods of risk assessment in the transportation of dangerous cargo or oversized cargo. The authors pointed out that due to the peculiarities of transporting oversized cargo, risk assessment and the identification of methods for its evaluation is particularly difficult due to the various factors that need to be taken into account in the planning and organization of transport and the implementation of the transport itself. In the article, on the basis of statistical data, the volumes of carriage of oversize cargo in the twelve EU countries dominating in this area of road transport are estimated and compared.

An important element of the article is the presented concept of a model for assessing the risk of adverse events in road transport of oversize cargo. The risk estimation procedure presented by the authors, together with a model based on a five-stage risk matrix, can be a convenient tool for risk assessment in oversize cargo transportation. The developed procedure takes into account all relevant elements in the analyzed transports, i.e. from the moment of planning, through the organization and implementation of transports.

The application of the proposed approach is presented on the example of real data a regarding the carriage of an oversize cargo, which is a hop harvester. The analysis was made for an international route from Poland to Germany.

A five-level scale was adopted for the study, where the lowest level means zero or almost zero probability of no consequences of an adverse event. On the other hand, the highest level means very frequent occurrence of the analyzed event and catastrophic consequences of its occurrence. Twenty-seven events that are sources of risk in the transportation of oversize cargo were adopted for the study, which were divided behind four main categories: logistical and operational risks, technical and vehicle-related risks, environmental and social risks, pilotage and escort risks. The identification of events affecting the occurrence of risks, the probability of their occurrence and the consequences of the occurrence of the analyzed event were developed in cooperation with a transport company that has been operating in the field of road transportation of oversized cargo internationally for more than 30 years.

The analysis of the results shows that events such as technical failure of the vehicle during transport, the occurrence of road obstructions, bad and unexpected weather conditions, and environmental pollution have the highest probability of occurrence. The highest impact coefficient of occurrence has such situations as improper securing of cargo on the vehicle, damage to the semi-trailer/module or cargo securing means, road collisions, leakage of hazardous substances, risk of vehicle rollover, and improper instruction of the driver by escort services. According to the survey, the highest level of risk is characterized by events such as improper cargo securing, technical failure of the vehicle, damage to the semi-trailer/module or cargo securing means, collisions with other vehicles, bad and unexpected weather conditions, and leakage of hazardous materials.

The innovation of the research conducted in the publication lies in the broader spectrum of the research conducted. The authors took into account the basic aspects of carrying out the process of transporting oversized cargo, which is an issue addressed in the available literature. The new approach, however, is a broader analysis of the entire transportation process, which includes such elements as, for example, the risks of carrying out cargo work, risks associated with the failure of the means of transport, pilotage problems or changing weather conditions. On the basis of the developed approach to the risk assessment of the realization of road oversize transport using the risk matrix, it is possible to study the phenomena occurring and the causes of undesirable events arising from various factors and the consequences of these events. In addition, the conducted research provides a basis for further analysis.

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