1. Introduction

The problem of risk assessment in railway transport is presented next to risk analysis and risk evaluation as one of the stages of risk management in the whole railway system. The level of generality in dealing with adverse events in the process of freight transport by rail often results in an inadequate and insufficient response to the upsetting of the acceptable level of risk by those involved in the process. It is common practice to react to the effects of rail incidents rather than prevent them from occurring. The groups of entities involved in ensuring safety in railway transport include rail operators, infrastructure managers, users of sidings, rolling stock manufacturers, manufacturers of devices and railway traffic control systems, designers and entities responsible for maintenance of rolling stock and railway infrastructure facilities.

Risk assessment in the rail transport system can be seen as an approach aimed at identifying risks at junctions and on railway lines, including risks arising from operational processes and the actions of other actors in the system whose task is to provide rail freight transport operations. Risk assessment also consists of risk analysis and evaluation.

Particularly relevant in this context is the risk profile $R$ the so-called risk scenario representing the pattern of the risk distribution probability and its consequences written in the form of the following pairs [53]:

$$\{ (P_1, S_1), (P_2, S_2), \ldots, (P_i, S_i), \ldots, (P_n, S_n) \}$$

where:

- $R$ – risk,
- $P_i$ – probability of risk due to $i$-th factor,
- $S_i$ – effects of risk due to $i$-th factor,
- $i$ – risk factor number, $i = 1, \ldots, n$.

Risks can come from internal sources resulting from the transport system under study and from external sources resulting from causes in its environment. A single risk may consequently generate multiple negative effects with varying degrees of impact. At the same time, one effect of risk implementation may have several causes.

Identification and analysis of adverse events allow for understanding and improving the weaknesses of the organisations operating within the railway system where such situations have been diagnosed. Positive aspects of studying this type of situations include:

- effective accident prevention by learning from mistakes,
- minimising the risks involved through proactive management,
- elimination of repetition of potentially dangerous situations.
The aim of this article is to assess the risk of performance of rail freight transport on the basis of an analysis of identified risk areas based on statistical data on the causes of accidents that occurred on the lines of railway transport in Poland. Identification of risks is a starting point for further research in the area of risk assessment for performance of rail freight transport operations.

The article is divided into four parts. In the first one, a critical analysis of the literature on selected areas of risk assessment in the rail transport system and on tools and methods for risk assessment in other areas is carried out. The second part is the identification of the research area. The authors have presented the process of performance of rail freight transport operations, defining their scope and characteristics, i.e.: punctuality, probability of no further delays, quantitative and qualitative criteria of independent changes, i.e.: detection of dangerous situations and behaviours, raising awareness, both among employees and subcontractors, developing a culture of safety, reducing the organisation’s losses.

In case of risk, the level of which is acceptable to the evaluating entity, periodical risk analyses are performed. On the other hand, when the level of risk is unacceptable, actions necessary to reduce the risk are determined. In the last stage, changes are made to the system to reduce the level of risk (Fig. 1).

Fig. 1. Decision-making process related to risk management

Source: own study.

The risk value formula was based on classical risk theory viewed as a combination of the probability of a negative event occurring and the severity of its consequences. Whereas possible methods of risk assessment together with types of risks divided into categories of their sources – individual, technical, environmental, social, economic were presented in the paper [15]. A rather interesting approach to system performance evaluation and operational process evaluation using fuzzy logic is presented by the author of the paper [28]. The proposed model allows combining inconsistent system and process characteristics, e.g.: punctuality, probability of no further delays, quantitative and qualitative performance of planned processes or reconfiguration level. Many authors point out that the assessment of risk and the effectiveness of system operation in different aspects is a multi-criteria decision making (MCDM) problem [9], [28], [57]. In the paper [48] the MCDM aspect related to risk assessment of railway infrastructure has been pointed out, while the paper [35] presents the risk assessment of infrastructure investment projects on the railway network. The performance of the systems in terms of environmental aspects and minimisation of the number of exhaust gases has been extensively presented in [4].

The paper [13] presents a model of railway accident occurrence and the use of fault tree analysis method. A breakdown of studies of reliability and safety of the railway transport system in four areas is presented, i.e.: transport, in which the infrastructure is analysed with respect to minimising life-cycle costs, the performance of dispatching tasks after the occurrence of disruptions and the cause-effect sequences during the transition of individual elements to an inoperable state, reliability, including: vehicles, individual facilities or subsystems within the infrastructure, process reliability, punctuality.
security, analysing the minimisation of negative effects of system operation and occurring errors,
critical infrastructure – of a general nature that does not take into account certain features of the railway, e.g. the power supply system.

The risk assessment methodology for the railway infrastructure network was investigated in the DESTination RAIL project. Authors of the study [39] presented the process of risk assessment supporting railway network infrastructure managers in risk reduction for selected facilities by applying unified probability of failure connected with different state of infrastructure facilities and consequences of occurrence of such failures. The risk assessment is presented at four levels – facility, section, route and network taking into account the different types of failures and their impact on stakeholders.

At this point, it is also worth pointing to the INFRARISK project (2013-2016) whose subject of research was, among others, risk assessment of the implementation of both railway infrastructure investment projects on the road infrastructure [2], [17]. The objective of the project was to develop a process for assessing infrastructure network risks resulting from natural hazards (e.g. floods, landslides, earthquakes). This process illustrates the functional interdependencies between multiple facilities in the network and indicates the impact and consequences of individual risks. The main tasks of the research project were to initiate, conduct tests under extreme conditions to determine whether there is an acceptable level of risk associated with natural hazards and to prepare an intervention programme aimed at reducing the risk to an acceptable level by decision makers.

Many studies also address the aspect of modelling reliability analysis of railway infrastructure. Infrastructure maintenance and management play a major role in ensuring the reliability and availability of railway transport [38]. Managing infrastructural assets also means managing their exploitation [57] and functional reliability [31]. The article [45] determined the correlations between the type of infrastructure elements used and the number of incidents, as well as the correlation between the type (and age) of infrastructure elements used and the number of failures.

Other areas of research on rail freight transport risk assessment have been touched upon in the works [1], [3], and they concern risk assessment on level crossings and risk assessment of transport of dangerous goods by rail [6], [37], [43]. The organisation of the transport process [27] as well as the use of modern traffic control devices [26], [29], [54] are important. In the case of a risk assessment model for a railway accident at work [34], classification of five main causes of accidents (collision, derailment, fire, accident at level crossing, accidents related to train movement) was made and the process of creation of risk assessment model in railway system was presented and its application on Slovak railways was indicated. The management of risks to the railroad surface is presented in [49]. The safety of train traffic is influenced by many factors [7] such as type of track: classic or jointless [14], the state of stress in the rails [33]. The type of track and the quality of its maintenance also affect the better smoothness of driving and less noise emission [50]. There is also significantly less wear and tear on vehicles and traction energy consumption [55]. In order to increase the degree of level crossing safety, the supporting system should be independent of the currently used traffic control devices, as indicated by the authors of the paper [5]. Therefore, as the authors point out [25], the occurrence of an adverse event should be analysed and used to improve safety procedures.

Important documents in risk analysis and assessment include the international standards related to risk management [21], [22], [23] which relate to the identification, analysis and evaluation of risks. The application of techniques in the risk management process according to ISO 31000 is shown in Figure 2.

Dedicated to any organisation regardless of its type, size and location, standard ISO 31000:2018 presents principles and guidelines for risk management in a systematic and transparent way within any issue and context. Although it cannot be part of a certification, it provides guidelines for internal or external audit programmes. In addition, it points to three main stages of risk management:

- adoption of risk management principles,
- development, introduction and continuous improvement of the framework structure,

### Table 1. Specification of selected research areas related to the risk assessment of rail freight transport operations in relation to bibliographic sources

| No. | Research area                                                                 | Sources of issues |
|-----|------------------------------------------------------------------------------|-------------------|
| 1   | Legislation relevant to safety of railway systems                           | [8], [10], [11], [12], [20], [47] |
| 2   | International standards and internal procedures related to risk management   | [21], [22], [23]  |
| 3   | Risk assessment of rolling stock                                            | [15], [16]        |
| 4   | Risk assessment at level crossings                                          | [1], [3]          |
| 5   | Risk assessment for the transport of dangerous goods by rail                 | [6], [18], [19], [37], [43] |
| 6   | Risk assessment for infrastructure investment projects                       | [35]              |
| 7   | Multi-criteria decision making in the area of reliability and risk assessment| [4], [9], [28], [48] |
| 8   | Causes of railway accidents                                                  | [34], [41], [52]  |
| 9   | Reliability of railway infrastructure                                        | [13], [39], [40], [45] |
| 10  | Research projects related to risk assessment in railway transport            | [2], [17], [39]   |

Source: own study.
3. The research problem and its evaluation

Many factors influence the freight transport process. One of them is the location of raw material sources, as well as the location of intermediate and final markets. Among other factors, there are operational factors, which include: the size of the organisation, distribution channels and geographical dispersion [27].

The rail freight transport process is a set of structured and interrelated activities which involve moving a specific cargo batch (shipment) from a forwarding station to a destination station and delivering it to the recipient (direct or indirect) [26], [27]. From a technological point of view, the rail freight transport process should be understood as those elements of the transport process that involve freight cars – from the start of their loading at the forwarding station to the end of their unloading at the destination station (Fig. 3).

Cars can be moved in a direct transport process (when a certain cargo batch is only moved from a forwarding station to a destination station by one train) and in an indirect transport process (cargo is moved from a forwarding station to a destination station by two or more freight trains).

In rail freight transport, the type of cargo transported will be an important factor that affects the entire process of movement. In 2019, the main commodity groups (according to the simplified standard classification of goods for transport statistics) carried by rail freight transport operators included [51]:

- hard coal, lignite, crude oil and natural gas – 91.1 million tonnes,
- metal ores and other mining and quarrying products – 64.8 million tonnes,
- coke, briquette, refined petroleum products – 27.8 million tonnes,
- chemicals, chemical products, man-made fibres, rubber and plastic products, nuclear fuel 10 million tonnes,
- metals and finished metal products (excluding machinery and equipment) – 9.2 million tonnes.

The total weight of cargo transported by rail freight transport in 2019 at the territory of Poland amounted to 236.4 million tonnes.

The Office for Railway Transport and the European Railway Agency (ERA) commonly use the terms “accident”, “serious accident” and “incident” in their reports and studies. The Railway Transport Act [56] defines the concept of an accident, a serious accident and an incident as follows:

a) accident – unintended sudden event or sequence of such events with the participation of a railway vehicle, causing negative consequences for human health, property or the environment; accidents include in particular: collisions, derailments, incidents on level crossings, incidents with the participation of persons caused by a railway vehicle in motion, fire of a railway vehicle;

b) serious accident – any accident caused by collision, derailment or any other event with an obvious impact on railway safety or the safety management, i.e. resulting in at least one fatality or at least 5 seriously injured persons or causing significant damage to a railway vehicle, the railway infrastructure or the environment, which can be immediately estimated by the accident investigation committee to cost at least EUR 2 million;

c) incident – any event, other than an accident, associated with railway traffic and affecting its safety.

The regulation on serious accidents, accidents and incidents [47] indicates that in order for a serious accident or an accident to be classified in a specific category depending on the established immediate cause, the following should be done:

- select a group according to the severity of the consequences of the event and specify the letter designation corresponding to that group as follows: A – serious accident, B – accident (other than serious);
- select the immediate cause qualification and determine the corresponding numerical category,
- qualify the event by inserting in place of the * a number relating to the category of the immediate cause specified above.

In order to qualify an incident to a specific category depending on the determined immediate cause of its occurrence, it is necessary to make a qualification of the cause and to specify a letter and number category corresponding to this cause (for an incident a letter designation C).

Adverse events in railway transport system coming from infrastructure manager (PKP PLK S.A.) or State Commission for Examination of Railway Accidents include, among others [20]:

![Fig. 3. Basic activities in the rail freight transport process (technological approach)](source: own study)

![Fig. 4. Accidents and incidents on railway lines and railway sidings](source: own study based on [52])
Table 2. Causes of accidents occurring on railway lines in 2019

| No. | Cat (A, B) | Description of the cause                                                                 | Number of causes | Pp   |
|-----|-----------|------------------------------------------------------------------------------------------|------------------|------|
| 1   | 00        | causes other than those listed below or the overlapping of several causes at the same time, creating equivalent causes | 10               | 0.019048 |
| 2   | 03        | dispatching, accepting or driving of a railway vehicle on an incorrectly planned, unsecured route or incorrect operation of traffic control devices | 13               | 0.024762 |
| 3   | 04        | failure of a railway vehicle to stop before a ‘stop’ signal or in a place where it should stop, or starting a railway vehicle without required authorisation | 22               | 0.041905 |
| 4   | 06        | exceeding the maximum permissible speed                                                   | 1                | 0.001905 |
| 5   | 08        | inadvertent starting of a railway vehicle                                               | 3                | 0.005714 |
| 6   | 09        | damage or poor maintenance of the surface, bridge or overpass, including also improper execution of works, e.g. improper unloading of materials, surface, leaving materials and equipment (including road machines) on the track or within the clearance of the railway vehicle, or running the railway vehicle over elements of the structure | 28               | 0.053333 |
| 7   | 10        | damage to or poor technical condition of powered railway vehicle, special-purpose vehicle (including running over an object which is a structural part of powered railway vehicle, special-purpose vehicle) and damage to or malfunction of the on-board part of ERTMS (European Rail Traffic Management System) | 5                | 0.009524 |
| 8   | 11        | damage or poor technical condition of a car (including running over a structural part of the car) | 20               | 0.038095 |
| 9   | 13        | premature termination of the route or release and shifting of the railway point under the railway vehicle | 13               | 0.024762 |
| 10  | 15        | improper loading, unloading, irregularities in securing the cargo or other irregularities in cargo operations | 7                | 0.013333 |
| 11  | 17        | collision of a railway vehicle with a railway vehicle or other obstacle (e.g. brake skid, luggage trolleys, postal cart, etc.) | 23               | 0.04381 |
| 12  | 18        | collision of a railway vehicle with road vehicle (other road construction equipment, agricultural machinery) on a level crossing with grade-crossing gate (cat. A according to the transit metric) | 8                | 0.015238 |
| 13  | 19        | collision of a railway vehicle with road vehicle (other road construction equipment, agricultural machinery) on a level crossing equipped with automatic crossing system with traffic lights and grade-crossing gate (cat. B) | 14               | 0.026667 |
| 14  | 20        | collision of a railway vehicle with road vehicle (other road construction equipment, agricultural machinery) on a level crossing equipped with automatic crossing system with traffic lights and without grade-crossing gate (cat. C) | 27               | 0.051429 |
| 15  | 21        | collision of a railway vehicle with road vehicle (other road construction equipment, agricultural machinery) on a level crossing not equipped with a crossing system (cat. D) | 123              | 0.234286 |
| 16  | 23        | collision of a railway vehicle with road vehicle (other road construction equipment, agricultural machinery) outside level crossings in stations and routes or on the communication and access track to the siding | 7                | 0.013333 |
| 17  | 24        | fire in a train, marshalling train or railway vehicle                                     | 1                | 0.001905 |
| 18  | 30        | malicious, hooligan or reckless misconduct (e.g. throwing stones at a train, stealing cargo from a train or marshalling train in motion, placing an obstacle in the track, devastation of power, communication, signalling or track surface equipment and interfering with such equipment) | 9                | 0.017143 |
| 19  | 31        | collision of a railway vehicle with persons when crossing the tracks at level crossings or guarded crossings | 12               | 0.022857 |
| 20  | 32        | collision of a railway vehicle with persons crossing the track at a level crossings with an automatic crossing system (cat. B, C) | 5                | 0.009524 |
| 21  | 33        | collision of a railway vehicle with persons when crossing the tracks at other level crossings and crossings | 10               | 0.019048 |
| 22  | 34        | collision of a railway vehicle with persons when crossing the tracks at level crossings or crossings at stations or on the routes | 142              | 0.270476 |
| 23  | 35        | events with persons related to the movement of a railway vehicle (jumping, falling from a train, railway vehicle, strong approach or sudden braking of a railway vehicle) | 19               | 0.03619 |
| 24  | 41        | the category has not been established or the cause of the incident is still being determined | 3                | 0.005714 |

Source: own study based on [41], [52].

- notification of an event,
- report of visual inspection of the scene,
- sketch of the scene of the accident or incident,
- report on final findings of the State Commission for Railway Accident Investigation,
- documents concerning the implementation of preventive measures,
- summary of proceedings,
- facts directly related to a serious accident,
- description of test and hearing records.
recorded for the same group of incidents on railway sidings. 1240 incidents were recorded on railway lines while 23 incidents have resulted in them not being included in official statistics. In 2019, activities that revealed the misclassification of some events which may noticeable since 2014. This is due, among other things, to supervision possible if the following factors occur simultaneously:  
  - a conscious or unconscious decision to misuse the system,  
  - continuation of the system misuse,  
  - disrupted train traffic (mainly serious accidents caused by the traffic dispatcher),  
  - human error (driver or traffic dispatcher).

For incidents on railway lines (Fig. 4), an increasing trend has been noticeable since 2014. This is due, among other things, to supervision activities that revealed the misclassification of some events which may have resulted in them not being included in official statistics. In 2019, 1240 incidents were recorded on railway lines while 23 incidents were recorded for the same group on railway sidings.

### Table 3. Causes of accidents occurring on railway sidings in 2019

| No. | Cat (A, B) | Description of the cause                                                                 | Number  |
|-----|-----------|----------------------------------------------------------------------------------------|---------|
| 1   | 00        | causes other than those listed below or the overlapping of several causes at the same time, creating equivalent causes | 3       |
| 2   | 03        | dispatching, accepting or driving of a railway vehicle on an incorrectly planned, unsecured route or incorrect operation of traffic control devices | 17      |
| 3   | 04        | failure of a railway vehicle to stop before a “stop” signal or in a place where it should stop, or starting a railway vehicle without required authorisation | 6       |
| 4   | 07        | carrying out a manoeuvre that creates a risk for the safety of train traffic            | 1       |
| 5   | 08        | inadvertent starting of a railway vehicle                                              | 1       |
| 6   | 09        | damage or poor maintenance of the surface, bridge or overpass, including also improper execution of works, e.g. improper unloading of materials, surface, leaving materials and equipment (including road machines) on the track or within the clearance of the railway vehicle, or running the railway vehicle over elements of the structure | 24      |
| 7   | 10        | damage to or poor technical condition of powered railway vehicle, special-purpose vehicle (including running over an object which is a structural part of powered railway vehicle, special-purpose vehicle) and damage to or malfunction of the on-board part of ERTMS (European RailTraffic Management System) | 1       |
| 8   | 11        | damage or poor technical condition of a car (including running over a structural part of the car) | 6       |
| 9   | 12        | failure or malfunction of signalling equipment                                        | 1       |
| 10  | 13        | running over a railway vehicle or other obstacle (e.g. brake skid, luggage trolleys, postal cart, etc.) | 26      |
| 11  | 15        | premature termination of the route or release and shifting of the railway point under the railway vehicle | 1       |
| 12  | 17        | improper loading, unloading, irregularities in securing the cargo or other irregularities in cargo operations | 10      |
| 13  | 21        | collision of railway vehicle with road vehicle (other road construction equipment, agricultural machinery) on a level crossing not equipped with a crossing system (cat. D) | 12      |
| 14  | 23        | collision of railway vehicle with road vehicle (other road construction equipment, agricultural machinery) outside level crossings in stations and routes or on the communication and access track to the siding | 3       |
| 15  | 34        | collision of a railway vehicle with persons when crossing the tracks at level crossings or crossings at stations or on the routes | 1       |
| 16  | 35        | events with persons related to the movement of a railway vehicle (jumping, falling from a train, railway vehicle, strong approach or sudden braking of a railway vehicle) | 1       |

Source: own study based on: [41], [52].
4.2. Mapping of accident categories to risk areas

Based on the causes of railway accidents in the railway transportation system in 2019, the publicly available statistics list the risks \( F \) assigned to the following areas:

- employees \( (F_p) \)
- rolling stock \( (F_t) \)
- surface, subgrade, tunnels and civil engineering structures \( (F_n) \)
- level crossings and level track crossings \( (F_k) \)
- unauthorised persons on railway premises \( (F_i) \)
- other \( (F_o) \)

A broader set of risks comprehensively addressing adverse events in the railway transport system is presented in the risk register contained in [41].

4.3. Analysis and evaluation of the cost of delays associated with the risk of adverse events

Rail freight transport delays are also affected by passenger and work-related incidents. The Office for Railway Transport has provided the cost of the parameter of one minute’s delay for a freight train, which amounts to EUR 44.74 [44]. Table 5 shows the minute ranges of delay together with the delay costs assigned to them (based on the arithmetic mean of the interval).

Table 4. Mapping of accident categories to risk areas

| Kind of risk \( F \) | Railway lines | Railway sidings |
|----------------------|--------------|------------------|
| Risk areas           | \( F_p \)     | \( F_t \)         | \( F_n \) | \( F_k \) | \( F_i \) | \( F_o \) | \( F_p \) | \( F_t \) | \( F_n \) | \( F_k \) | \( F_i \) | \( F_o \) |
| Category             | 03, 04, 06, 15, 17, 35 | 08, 10, 11, 13, 24 | 09 | 18, 19, 20, 21, 23, 31, 32, 33, 34 | 00, 41 | 03, 04, 07, 15, 17, 35 | 08, 10, 11, 13, 24 | 09 | 21, 23, 34 | - | 00, 12 |

Source: own study

Table 5. Delay costs

| Minute range | 1-9 | 10-19 | 20-29 | 30-39 | 40-49 | 50-59 | 60-69 | 70-79 | 80-89 | 90-99 |
|--------------|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Arithmetic mean of the range (EURO) | 223.700 | 648.729 | 1096.128 | 1543.527 | 1990.926 | 2438.325 | 2885.725 | 3333.124 | 3780.523 | 4227.922 |

Source: own study based on [44]

Fig. 5. Risk related to the cost of delays of freight trains on railway lines in Poland \( (P>0.03) \) in a given minute range
Source: own study

Fig. 6. Probability of occurrence of a given accident category on railway lines in Poland in 2019 \( (P>0.03) \)
Source: own study
where:
- $R_{ko}$ - the level of risk associated with the cost of delays of a freight train,
- $\overline{x}_{a,b}$ - average costs of delay for the minute range (a,b),
- $P_{kat}$ - the probability of the cause of the selected category, affecting train delay in 2019.

The presented approach allows to estimate the potential risk level for different delay ranges. In order to perform a detailed analysis of the cost matrix, it would be necessary to determine the probability density function for the time of delay as a result of an accident caused by a given cause. Table 6 provides an assessment of the risk associated with the cost of train delays in 2019 as a result of incidents occurring on railway lines. The colour scale in Table 6 reflects the level of risk, with green being acceptable and red indicating the need for intervention e.g. by the rail operator or the terminal operator or transhipment centre operator. Based on the expert assessment and the estimation of the expected value of delays for an event of a given category, it is possible to identify the main areas requiring improvement actions. The risk associated with delay costs and the probability of an accident of a given category are shown in Figures 5 and 6.

As can be seen from the data presented, the highest level of risk associated with the cost of delays on railway lines was identified in category 34, i.e. collision of a railway vehicle with persons when crossing the tracks at level crossings or crossings at stations or on the routes. In 2019, probability of occurrence on railway lines that exceed a factor of 0.03 occurred for categories:

- 04 – failure of a railway vehicle to stop before a “stop” signal or in a place where it should stop, or starting a railway vehicle without required authorisation,
- 09 – damage or poor maintenance of the surface, bridge or overpass, including also improper execution of works, e.g. improper unloading of materials, surface, leaving materials and equipment (including road machines) on the track or within the clearance of the railway vehicle, or running the railway vehicle over elements of the structure,
- 11 – damage or poor technical condition of a car (including running over a structural part of the car)
- 13 – collision of a railway vehicle with a railway vehicle or another obstacle (e.g. brake skid, luggage trolleys, postal cart, etc.)
Table 7. Risk assessment of delay costs in 2019 based on events occurring on railway sidings

| Accident category | 1-9 min | 10-19 min | 20-29 min | 30-39 min | 40-49 min | 50-59 min | 60-69 min | 70-79 min | 80-89 min | 90-99 min |
|-------------------|---------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 00                | 5.88683119 | 17.07181 | 28.84547 | 40.61914 | 52.3928  | 64.16646 | 75.94012 | 87.71378 | 99.48745 | 111.2611  |
| 03                | 33.3587101 | 96.74026 | 163.4577 | 230.1751 | 296.8925 | 363.6099 | 430.3274 | 497.0448 | 563.7622 | 630.4796  |
| 04                | 11.7736624 | 34.14362 | 57.69095 | 81.23827 | 104.7856 | 128.3329 | 151.8802 | 175.4276 | 198.9749 | 222.5222  |
| 07                | 1.9627706  | 5.690603 | 9.615158 | 13.53971 | 17.46427 | 21.38882 | 25.31337 | 29.23793 | 33.16248 | 37.08704  |
| 08                | 1.9627706  | 5.690603 | 9.615158 | 13.53971 | 17.46427 | 21.38882 | 25.31337 | 29.23793 | 33.16248 | 37.08704  |
| 09                | 47.0946495 | 136.5745 | 230.7638 | 324.9531 | 419.1424 | 513.3317 | 607.521  | 701.7103 | 795.8996 | 890.0889  |
| 10                | 1.9627706  | 5.690603 | 9.615158 | 13.53971 | 17.46427 | 21.38882 | 25.31337 | 29.23793 | 33.16248 | 37.08704  |
| 11                | 11.7736624 | 34.14362 | 57.69095 | 81.23827 | 104.7856 | 128.3329 | 151.8802 | 175.4276 | 198.9749 | 222.5222  |
| 12                | 1.9627706  | 5.690603 | 9.615158 | 13.53971 | 17.46427 | 21.38882 | 25.31337 | 29.23793 | 33.16248 | 37.08704  |
| 13                | 51.0192036 | 147.9557 | 249.9941 | 352.0325 | 454.0709 | 556.1093 | 658.1477 | 760.1861 | 862.2245 | 964.2629  |
| 15                | 1.9627706  | 5.690603 | 9.615158 | 13.53971 | 17.46427 | 21.38882 | 25.31337 | 29.23793 | 33.16248 | 37.08704  |
| 17                | 1.9627706  | 5.690603 | 9.615158 | 13.53971 | 17.46427 | 21.38882 | 25.31337 | 29.23793 | 33.16248 | 37.08704  |
| 21                | 23.5473247 | 68.28724 | 115.3819 | 162.4765 | 209.5712 | 256.6658 | 303.7605 | 350.8551 | 397.9498 | 445.0444  |
| 23                | 5.88683119 | 17.07181 | 28.84547 | 40.61914 | 52.3928  | 64.16646 | 75.94012 | 87.71378 | 99.48745 | 111.2611  |
| 34                | 1.9627706  | 5.690603 | 9.615158 | 13.53971 | 17.46427 | 21.38882 | 25.31337 | 29.23793 | 33.16248 | 37.08704  |
| 35                | 1.9627706  | 5.690603 | 9.615158 | 13.53971 | 17.46427 | 21.38882 | 25.31337 | 29.23793 | 33.16248 | 37.08704  |

Source: own study

Fig. 7. Risk related to the cost of delays of freight trains on railway sidings in Poland (\(P > 0.03\)) in a given minute range

Source: own study.

– 20 – collision of railway vehicle with road vehicle (other road construction equipment, agricultural machinery) on a level crossing equipped with automatic crossing system with traffic lights and without grade-crossing gate (cat. C),
– 21 – collision of railway vehicle with road vehicle (other road construction equipment, agricultural machinery) on a level crossing not equipped with a crossing system (cat. D),
– 34 – collision of a railway vehicle with persons when crossing the tracks at level crossings or crossings at stations or on the routes,
– 35 – events with persons related to the movement of a railway vehicle (jumping, falling from a train, railway vehicle, strong approach or sudden braking of a railway vehicle).
| No. | Year | Accident category | Date       | Venue                                                                 | Carrier                                                                 | Restrictions on train traffic                                                                 | Injuries, Injuries and fatalities and fatalities |
|-----|------|-------------------|------------|----------------------------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|-----------------------------------------------|
| 1   | 2014 | B10               | 31.08.2014 | On route at km 12.629 of railway line No. 100 Kraków Przecim – Kraków Płaszów | PKP CARGO S.A.                                                          | Delays of freight trains – 9, total number of minutes of delay – 1109                          | None                                          |
| 2   | 2016 | B13               | 02.12.2016 | On the route Myszków – Zawiercie, at track no. 2, at km. 263.830 of railway line no. 1 Warszawa Zachodnia – Katowice | PKP CARGO S.A., “EURONAFT Trzebinia” Sp. z o.o. | Delays of passenger trains – 201, total number of minutes of delay – 8082; delays of freight trains – 62, total number of minutes of delay – 15,304 | None                                          |
| 3   | 2017 | C52               | 16.05.2017 | At Podstolice station, in station track no 2, at km 262.500 of railway line no. 3 Warszawa Zachodnia – Kownowice | PKP CARGO S.A.                                                          | Delays of passenger trains – 18, total number of minutes of delay – 1226; delays of freight trains – 18, total number of minutes of delay – 1,701 | None                                          |
| 4   | 2017 | A04               | 30.08.2017 | On Nysa – Nowy Świeciów route, in line track no. 2, at km 129.650 of railway line no. 137 Katowice – Legnica | "Cargo Przewozy Towarowe Transport Sp. z o.o., Sp. k. | Delayed freight trains – 1, total number of minutes of delay – 735                           | None                                          |
| 5   | 2017 | B37               | 10.11.2017 | On the Warlubie – Laskowice Pomorskie route, track no. 2, at km 457.485 of railway line no. 131 Chorzów Batory – Tczew | STK S.A. Wrocław, PKP INTERCITY S.A.                                    | Delayed passenger trains – 34, total number of minutes of delay – 1193; delayed freight trains – 31, total number of minutes of delay – 4508 | None                                          |
| 6   | 2017 | B13               | 24.11.2017 | On the Warlubie – Laskowice Pomorskie route, track no. 2, at km 424.208, railway line no. 131 Chorzów Batory – Tczew | POL MIEDŻI TRANSPORT Sp. z o.o., LOTOS Kolej Sp. z o.o.               | Delayed passenger trains – 8, total number of minutes of delay – 66; delayed freight trains – 3, total number of minutes of delay – 166 | None                                          |
| 7   | 2018 | B11               | 10.05.2018 | On the Taczanów – Pleszew route, at track no. 1, km 107.985 of railway line no. 272 Kluczbork – Poznań Główny | CTL Logistics Sp. z o.o.                                               | Delayed passenger trains – 253, total number of minutes of delay – 8016; delayed freight trains – 24, total number of minutes of delay – 3540 | None                                          |
| 8   | 2019 | B11               | 17.03.2019 | At Rybnik Towarowy station, on track no. 308 of railway line no. 140 Katowice Ligota – Nędza | PKP CARGO S.A.                                                          | Delayed passenger trains – 308, total number of minutes of delay – 1797; delayed freight trains – 167, total number of minutes of delay – 16733 | None                                          |
| 9   | 2019 | B13               | 19.05.2019 | On Tarnów Opolski – Opole Grodzowice route, at track no. 1, at km 87.973 of railway line no. 132 Bytom – Wrocław Główny | PKP CARGO S.A.                                                          | Delayed passenger trains – 419, total number of minutes of delay – 3469; delayed freight trains – 34, total number of minutes of delay – 1857 | None                                          |
| 10  | 2019 | B11               | 08.08.2019 | On Tarnów Opolski – Opole Grodzowice route, at track no. 1, at km 87.973 of railway line no. 132 Bytom – Wrocław Główny | PKP CARGO S.A.                                                          | Delayed passenger trains – 419, total number of minutes of delay – 3469; delayed freight trains – 34, total number of minutes of delay – 1857 | None                                          |
Similar analyses were conducted for adverse events occurring at railway sidings. Table 7 provides an assessment of the risk associated with the cost of train delays in 2019 as a result of incidents occurring on railway sidings. Figures 7 and 8 show the risk associated with delay costs and the probability of the accident category.

The highest level of risk associated with the cost of delays on railway sidings was identified in category 13, i.e., collision of a railway vehicle with a railway vehicle or other obstacle (e.g. brake skid, luggage trolleys, postal cart, etc.), which was identified in category 13. In 2019, the probability of occurrence on railway sidings that exceeds a factor of 0.03 occurred for the following categories:

- 03 – dispatching, accepting or driving of a railway vehicle on an incorrectly planned, unsecured route or incorrect operation of traffic control devices,
- 04 – failure of a railway vehicle to stop before a “stop” signal or in a place where it should stop, or starting a railway vehicle without required authorisation,
- 09 – damage or poor maintenance of the surface, bridge or overpass, including also improper execution of works, e.g. improper unloading of materials, surface, leaving materials and equipment (including road machines) on the track or within the clearance of the railway vehicle, or running the railway vehicle over elements of the structure,
- 11 – damage or poor technical condition of a car (including running over a structural part of the car)
- 13 – collision of a railway vehicle with a railway vehicle or another obstacle (e.g. brake skid, luggage trolleys, postal cart, etc.)
- 17 – improper loading, unloading, irregularities in securing the cargo or other irregularities in cargo operations
- 21 – collision of railway vehicle with road vehicle (other road construction equipment, agricultural machinery) on a level crossing not equipped with a crossing system (cat. D).

Reports covering freight, passenger and work traffic are only submitted to ERA for selected major accidents, other accidents and incidents. Detailed reports in this regard can be found on the website of the State Commission for the Investigation of Railway Accidents [30]. They provide knowledge about the most serious events in the railway transport system in Poland in freight transport.

The authors of this article analysed 31 reports of the State Commission for Investigation of Railway Accidents (report no. PKBWK/01/2015 – report no. PKBWK/10/2020) during the study period involving freight trains are shown in Table 8. Rail freight delays expressed in the number of freight trains involved and the total number of minutes of delay associated with ERA-reported accidents are shown in Figure 9.

In 2019, the total number of delays for freight trains taking into account adverse events involving passenger and freight trains was 19,819 minutes (the analysis does not take into account delays of cancelled and diverted freight trains). Data from the Office for Railway Transport show that 333,795 domestic freight trains were launched in 2019 [42]. On average in 2019, there will be approximately 16 minutes of delay per freight train running as a result of adverse events reported to ERA.

5. Conclusions

The risk analysis for the operation of rail freight transport operations has shown that undesirable situations on the railway network occur as a result of various events. For the smooth running of the train traffic, work on risk assessment should be carried out continuously.

As the market of rail freight transport includes among others: managers of railway lines, railway transport operators, operators of railway service infrastructure facilities, for proper estimation of the risk of occurrence of adverse events it is necessary to have a reliable database divided into areas and categories of adverse events.

Delays in train traffic are the consequence of adverse events. It is therefore substantiated to carry out extensive risk assessment analyses on rail freight transport, including assessment of the risks associated with train delays. In 2019, the total number of delays for freight trains taking into account adverse events involving passenger trains and freight trains was 19,819 minutes, while the average delay per freight train running was about 16 minutes.

Based on the collected data on the occurrence of adverse events on railway lines and sidings of PKP, the authors proposed some approach to estimate the potential level of risk for different ranges of delays. According to the authors of the article, for a detailed analysis of the cost matrix, it will be necessary, in future research, to determine the probability density function for the delay time as a result of the accident caused by a given cause.

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