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RESISTANCE AND SAFETY OF THE RAILWAY TRANSPORT SYSTEM IN THE CONTEXT OF DISRUPTIONS OCCURRING DURING RAIL FREIGHT TRANSPORTATION

Summary. This article presents an approach to planning rail freight transport taking into account the disruptions that occur during their implementation. The issues raised are related to the multi-aspect perception of factors influencing the organization of transport, in which immunity and safety play significant roles. The authors present an analysis of disruptions relating to the causes and effects of adverse events for selected traffic and operational parameters, including delays of freight trains in Poland from 2019-2022. The analysis of adverse events (accidents and serious accidents) in the rail transport system made it possible to present the rates of accidents when crossing tracks in prohibited places, at crossings on the public and separate networks, related to signals passed at danger events, and related to track works and the technical condition of rolling stock. In the case of the effects of adverse events, a rate was determined for freight train delays. The authors also developed a method for determining the value of disruptions in rail freight transport. A case study containing disruption quantification for a given freight train route is presented. The article emphasizes that a significant challenge in the rail transport sector is the proper organization of the operational activities of railway carriers concerning disruptions occurring during transport.

1. INTRODUCTION

Disruptions in freight transport affect the process of implementing planned freight transport. Any discussion of the problem of disruptions in rail transport requires a definition and description of the process of transport forecasting (i.e., developing one of the elements of train traffic organization), which requires determining transport needs. Hence, transport tasks are permanently related to the transport needs of contractors, which are expressed in the weight of goods planned for transport or the number of wagons needed to transport a specific volume of cargo. Transport takes place between individual railway stations. Determining the mass or number of wagons needed to carry out transport tasks is necessary to develop forecasts for the organization of freight train traffic.

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Transport needs reported by contractors constitute input data necessary to analyze the problem of disruptions in rail transport. Transport estimations are essential for the management, operational planning, and optimization of resource use. The highly unpredictable nature of goods streams is influenced by many market factors, which requires the use of forecasting models [11]. There may be risks during the planning stage (e.g., in the context of threats and opportunities) which, if implemented, will influence them. This justifies analyses that will enable specific events to be predicted in due time and allow appropriate remedial measures to be taken [8].

Disruptions in the forecasted transport result from a number of factors that must be taken into account in order to efficiently perform the tasks. They concern many economic, organizational, and technological aspects. Different problems occur when transporting full train shipments and dispersed traffic [5]. The transport technology used depends on the size of the batch of goods reported by the contractor. For large volumes, compact technology trains are launched. Trains run from the origin station to the destination station without any modifications at intermediate stations. Small batches of cargo are transported using distributed technology. Transport takes place with processing at intermediate stations between the station of origin and the station of destination of the cargo. Because goods transport currently takes place almost entirely in a compact system, dispersed traffic is omitted in this article. The full-train transport system is an economical cargo transport system. These transports are characterized by a technology in which the entire train of wagons is transported in one train, using one locomotive, without the need to perform financially and time-costly shunting work at intermediate stations. Such transport also helps to improve its quality and accelerate cargo transport times. This implies the most effective form of transport. Various types of disruptions may occur during transport using the technologies described above.

Due to the need to maintain the highest level of safety, the transport of goods on a railway network must be carried out according to orderly rules. The rail safety management system consists of the organization, measures, and procedures adopted by both the infrastructure manager and the railway undertaking to ensure the safe management of their activities [6]. In each situation, appropriate transport technology must be developed. Due to the presence of many factors on which the implementation of transport depends, it is a challenge for entities operating in the rail freight market. Of particular importance to this article is the analysis of capacity lines and railway stations in the context of occurring disruptions.

When discussing the issue of disruptions during rail freight transport and their impact on the safety of rail transport, it is also worth referring to the role and significance of the railway in the functioning system of the state itself. Railway infrastructure is one of the key elements supporting the functioning of the state, given that it is a pillar of security, a key factor of economic development, and an element of the transport network. Therefore, modern railways face serious challenges related to ensuring the proper implementation of the above-mentioned functions.

Railway reliability is closely related to the implementation of the strategic interests of the state and society, and disruptions occurring during rail transport, including freight transport, reduce the safety of the rail transport system and may have negative consequences for the security of the state itself. Railway infrastructure is an essential element of the state's critical infrastructure. Its proper functioning is also important to ensure effective logistics of the supply of goods and strategic resources important for the functioning of the state, such as energy or fuels. Disruptions in the transport of goods may have negative consequences for the functioning and development of the economy, and in the case of threats related to natural disasters or military crises, for the security of the state and its citizens. Thus, railways play an indispensable role in securing the strategic interests of the state, its economy, and society [9].

The article is divided into four main parts. The first part introduces the issues of disruption, resilience, and safety in rail freight transport. An analysis is done on freight train delays in Poland from 2019-2022, and a review of the state of the literature is presented. The second part contains a presentation of the method for determining the disturbance value for rail freight transport. Reference was made to serious accidents and accidents in rail transport, on the basis of which the accident rate was determined in individual areas related to the railway system. The delay rate for freight trains was also determined. The third part of the article includes the implementation of the method in a case study in which the disruptions occurring on the route of a freight train on the Małaszewicze to Południowe-Okrzeja route were quantified. At the end of the article, conclusions and a list of references are presented.

2. DISRUPTIONS AND THE IMPLEMENTATION OF RAILWAY FREIGHT TRANSPORTATION

2.1. The significance of disruptions in railway freight transport

There are various types of disruptions in rail transport. The causes of disruptions may come from the internal environment (railway infrastructure, railway carriers) or external environment (railway accidents, track closures, and sabotage and sabotage activities, which are clearly visible given the ongoing armed conflict beyond Poland's eastern border). In the case of railway networks, the causes of disruptions focus on the condition of infrastructure facilities. First, the poor condition of the infrastructure (tracks, turnouts, subgrades, sleepers, bridges, and viaducts), as well as sudden emergencies, damage these elements. Railway tracks and trackside facilities are often renovated or modernized, which causes track works to be carried out, which often causes disruptions. Railway accidents are most often the result of lack of service, damage to barriers, or reduced visibility. Failure of rolling stock during its use, lack of power on electrified lines, and weather factors (e.g., snow, heavy rainfall, deformation of rails due to high temperatures in summer) often cause deviations from transport plans. Sabotage and sabotage activities lead to significant damage or destruction of railway infrastructure, which has a destructive impact on rail transport, including freight transport necessary to conduct these activities, which is particularly important from the perspective of military operations.

The basic effects of the resulting disruptions are a reduction in the capacity of stations, a reduction in the capacity of railway lines, which causes delays, and in the case of sabotage and sabotage activities, their temporary exclusion from use, and, consequently, higher transport costs. A tool in the hands of railway operators that is used to minimize the effects of disruptions is restrictions on sending. This is, for example, a ban on sending trains on specific transport routes where an accumulation of shipments has been identified. Perceptions of disruptions as phenomena that violate the adopted transport technology are based on two essential elements of assessing their significance. The first is the probability of disruptions, and the second is the impact on business continuity. The identification of business processes allows one to indicate the most essential elements where threats occur. This analysis is used to find possible disruptions and assess their importance. Several strategies can be adopted to respond to disruptions. It is possible to prevent interference. Disruptions may occur at any stage of the transport process and, as a result, a correction of the plan is most often necessary (Fig. 1).

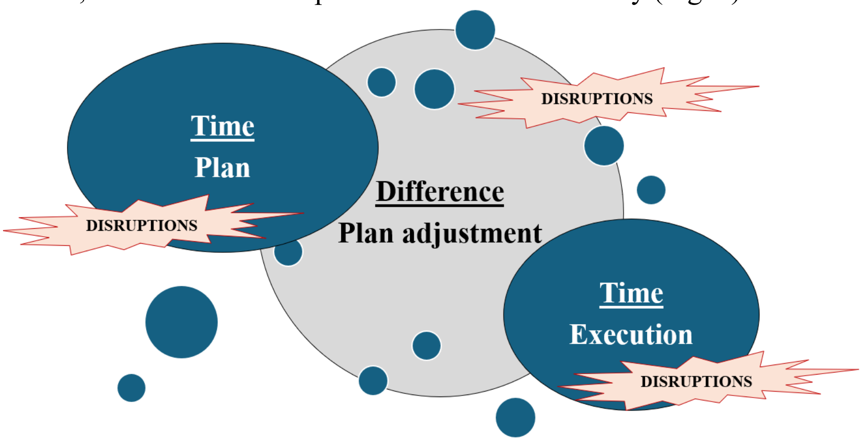

Fig. 1. Correcting plans during their implementation. Source: own study

Referring to the issue of disruptions in rail transport technology in relation to freight trains running on the railway network, we most often deal with capacity limitations at destination stations. In this case, these are disturbances that require remedial or preventive actions.

2.2. Train delays and their impact on the timeliness of services

Rail transport plays a significant role in the movement of people and goods. One of the important criteria for assessing the quality of services is the punctuality of the train's arrival at the destination station. In Poland, this criterion is a challenge because there are numerous disruptions during rail freight transport. According to data from the Office of Rail Transport, 446,839 freight trains were launched in 2022, and 41,927 freight trains were canceled [19]. Fig. 2 shows the number of all trains launched, divided into the number of on-time trains and delayed trains.

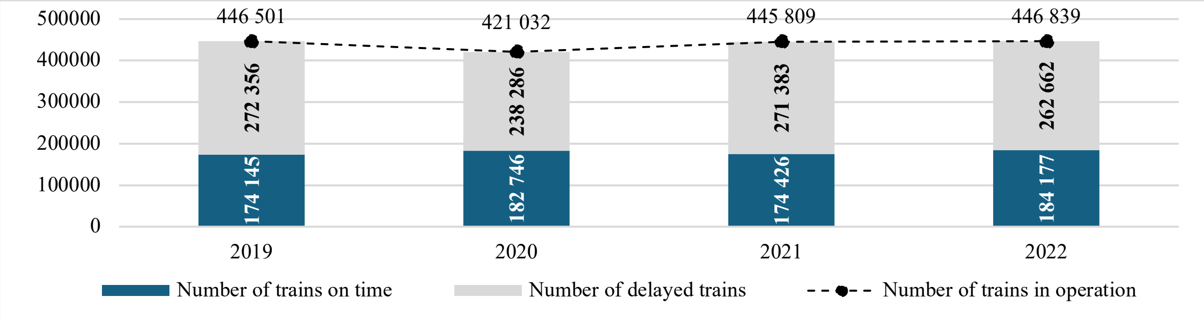

Fig. 2. Number of trains launched from 2019-2022 divided into on-time trains and delayed trains. Source: own study based on [19]

From 2019-2022, the number of trains launched increased slightly (0.08%). The share of delayed trains in 2019 in relation to all trains in operation was 61%, while in 2022, this value was 59%.

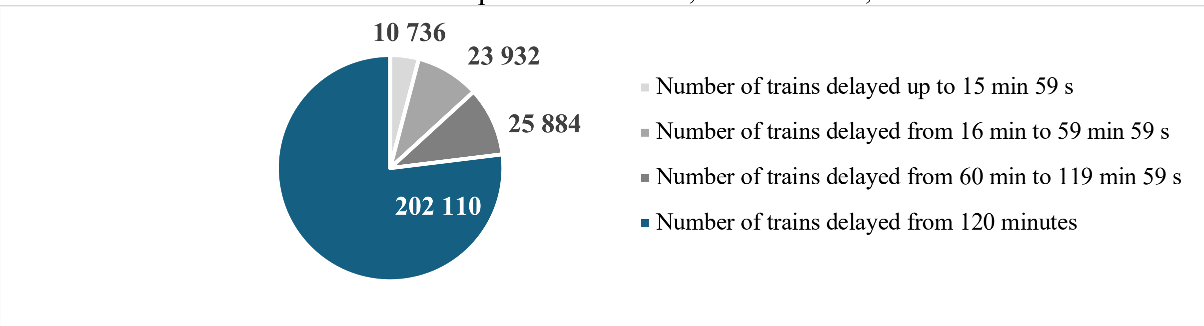

Fig. 3. Freight trains delayed by time slots in 2022. Source: own study based on [19]

Fig. 3 shows the ranges of freight train delays. It is noticeable that in 2022, 77% of all delays were in the upper range from 60 min to 119 min 59 s. The lower range of freight train delays (up to 15 min 59 s) included 4% of all delayed trains.

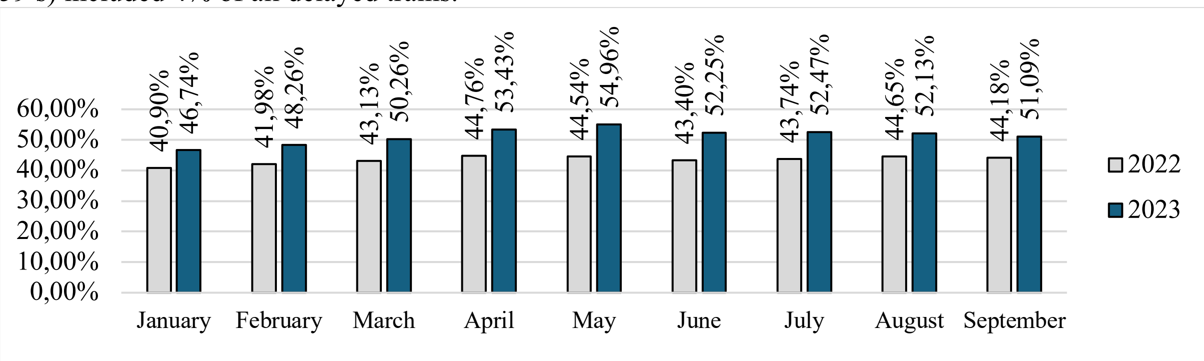

Fig. 4. Punctuality of trains on arrival from December 2022-August 2023. Source: own study based on [19]

According to Fig. 4, over the course of nine months from 2022-2023, there was a noticeable increase in the value related to punctuality year to year between each period. The greatest improvement for this parameter was recorded in May (an increase of 10.42 percentage points).

3. LITERATURE REVIEW

3.1. Resistance of the railway transport system to disturbances

The degree of maturity of organizations operating in the area of rail freight transport and mechanisms maintaining an acceptable level of risk constitute significant advantages in the cargo transport process. As indicated in the article [28], the way enterprises operate is crucial to the development and implementation of an overall strategy for maintaining risk within the organization. The authors of the publication defined five areas of enterprise maturity: knowledge, risk assessment, process risk management, cooperation in the event of risk, and risk monitoring.

Research [24] shows that in conditions of uncertainty, decisions should be made based on an individual approach to the problem, past experience, and memories of individual events, not based on economic theories. This is especially the case because uncertainty is an element accompanying every decision, including decisions made in the area of rail freight transport.

An analysis of resilience in a specific geographical region focusing on the decision-making factors determining the choice of rail transport when transporting cargo is presented in [24]. The authors described disruptions affecting demand (in a six-year perspective), with particular emphasis on rail transport. Rail transport has been identified as particularly susceptible to disruptions in cooperation with other sectors. This approach to the problem made it possible to present rail freight transport as susceptible to the impact of disruptions identified in the environment. The publication [25] emphasizes that complex transport tasks occurring in rail transport involve stakeholders from the private and government sectors. Therefore, multi-sector cooperation is perceived as an important element of risk management in rail freight transport. The authors of the article [10] indicate that maintenance is a key factor influencing the safe operation of railway vehicles. They proposed a method for assessing threats and possibilities of reducing them in the design, operation, and maintenance of railway vehicles. Particular attention was paid to issues related to brake blocks and the safety of freight wagons.

Issues related to planning effective modular supply chains so that they are resistant to adverse events are discussed in [26]. The analysis confirms the importance of creating effective and reliable supply chains that are flexible and responsive to specific needs and adapt to the changing conditions in which they operate.

3.2. Impact of disruptions on the safety of the rail transport system

The railway is an element of the state's strategic critical infrastructure that is important from the point of view of its security and proper development of the economy. It is particularly important for the functioning of society. The term "critical infrastructure" has been in use since major power grid failures in the United States in the 1990s, which brought significant disruptions to millions of citizens and also had a negative impact on all other systems in the country [17]. Critical infrastructure is a set of sectors and systems whose functioning is needed for the efficient operation of the state and society. It involves systems and their functionally related objects, including buildings, devices, and installations used to ensure the efficient functioning of public administration bodies, institutions, and entrepreneurs.

An important element of critical infrastructure is transport systems [29], an integral part of which is the railway, which is a key element of the state's economy, as it is assumed to ensure efficient transport of passengers and goods. It is, therefore, a critical infrastructure of crucial importance for the country in the civilian and military aspects, which is particularly important in times of threat to state security. Railways are a strategic means of transport ensuring the continuity of supplies of goods and energy, as well as maintaining communications within the country. They are used to transport people, food and raw materials, fuels, and other strategic resources important for the functioning of the economy and the state, which is key to ensuring security and stability in the state.

The European Union draws attention to the particular importance of railway infrastructure as an element of critical infrastructure, and European critical infrastructure is designated into two sectors: energy (electricity, crude oil, and natural gas) and transport, including rail transport [18, 29]. The protection of critical infrastructure, including transport, aims to prevent threats, risks, and weaknesses and to limit and neutralize their effects, as well as to quickly restore it in the event of a failure and other events disturbing its proper functioning. The safety management system in rail traffic, including rail freight transport, consists primarily of safety policy, plans, and procedures for the quantitative and qualitative objectives of the organization related to maintaining and improving the state of safety. It also consists of the methods for determining risk, assessing it, and applying risk control measures, procedures for reporting and documenting security incidents, action plans in the event of emergencies, and training programs for employees [28]. All these issues are important for the proper conduct of railway traffic, including freight transport, prevention responses to incidents, and the required level of safety in railway traffic.

3.3. Specificity of disruptions in the railway transport system

Disruptions related to extreme factors in rail freight transport were presented, among others, in [3, 30]. More disruptions can be expected in the future due to system failures as well as climate change. These events result in delays and cancellations of trains. Based on a British case study of disruptions to the rail network resulting from the closure of key railway lines, the authors conducted an analysis taking into account the impact on the provision of rail freight services in the context of the entire supply chain. The extensive consequences of disruptions that affected the number and punctuality of freight trains were also pointed out [30]. The publication [3] also draws attention to the issue of growing demand for transport, resulting in an increase in traffic on the railway network, which makes it more interdependent and complex to operate. The article [11] uses time series analysis to present the impact of the economic disruptions of the 2007-2009 Great Recession and the COVID-19 pandemic on rail and intermodal transport.

The transport of cargo based on several modes of transport in the context of disruptions occurring at their interface, as well as in the entire logistics chain (affecting the delivery time of the shipment) has been described, for example, in [7, 14]. The authors of the article [13] indicated that an important issue is a situation in which cargo is transported in a way that ensures continuity and reduces the negative effects of disruptions. This problem is presented in the framework of optimization and regression analysis for data recovery from occurring railway accidents at intermodal terminals. The authors presented two programming models containing simulations in the event of normal operations and actions after disruptions. However, in publication [7], the authors drew attention to disruptions during the transport of dangerous goods by bimodal transport consisting of road and rail connections. The location of transshipment facilities and the possibility of disruptions to these facilities were also considered. A dual-stage stochastic planning model was prepared for the indicated decision-making problem.

The article [14] presents a risk mapping method in multimodal transport systems designed to assess the risk of reducing the quality of logistics services (on-time delivery, etc.). The method links aspects usually contemplated separately in studies of individual modes of transport. The article [2] put particular emphasis on the identification of risk factors in rail transport and demonstrated that the non-existence of necessary identification of threats in individual phases of transport has an impact on the implementation of this type of transport. The publication [4] presents reliability and availability analysis using the Markov model for data transmission in the railway system with four conditions: correct system state, presence of disturbances in the system, prohibited (dangerous) system state, and system blocked state. The realization of transport processes is correlated with the risk of a lack of timeliness (quality), risks to people and cargo (safety), and dangers from human, technical, organizational, and global influences (e.g., pandemic, war) [14, 27]. When forecasting transport, one should first remember the need to efficiently meet the reported transport needs, and disruptions are perceived as factors hindering the achievement of the planned goal (i.e., transporting a specific volume of cargo) [16]. The process of responding to disruptions in the implementation of planned transport is a complex decision-making problem.

An important factor influencing the level of risk during transport is the nature of the cargo being transported. Hazardous materials are a special type of cargo that generates an excessive level of risk. Research often aims to introduce a new method of estimating and optimizing the risk of transporting this type of goods. One of the methods proposed in [12] is a model aimed at minimizing the probability of an accident occurring in the transport of dangerous goods. The research was based on the analysis of a selected region of Poland using the heuristic ant algorithm and Dijkstra's algorithm.

4. PROCEDURE FOR QUANTIFYING DISRUPTIONS FOR A FREIGHT TRAIN ROUTE

4.1. General assumptions of the method

In this research, an original method was developed to determine the parameters for a given freight train route. This allows us to compare key variables over the years. A method consisting of five basic stages was developed in order to describe and calculate the disruption rate that may occur on a given route (as shown in Fig. 5).

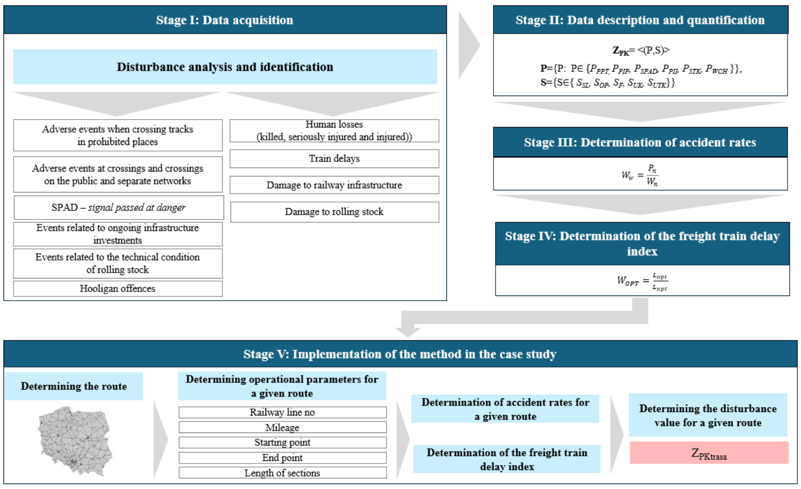

Fig. 5. Procedure for determining the disturbance value for a given route. Source: own study

The procedure specifies the procedure and scope of data necessary to determine the rate of freight train delays. The first stage involves the analysis of data published as part of the reports presented by the Office of Rail Transport [21]. Then, the parameters determining the causes and effects of adverse events in the rail transport system are quantified. In the third stage, based on previously defined parameters, a calculation is made for accident rates (when crossing tracks in prohibited places, at crossings and transitions on public and separate networks, related to SPAD events, related to track works, and related to the technical condition of rolling stock). The fourth stage involves determining the freight train delay index. The last stage of the method is the calculation of values for the given route. Calculations can be made by defining the operating parameters for a given route.

4.2. Data identification and analysis as an element of a method for assessing interferences

The implementation of rail freight transport is associated with the occurrence of events that may weaken the effectiveness and efficiency of the transport service. The above situation may occur at the point of origin, destination, or reloading, as well as on railway lines. In this context, disruptions should be viewed as an unplanned and undesirable activity that changes the way a task is performed. In order to specify disruptions in rail freight transport, this article reviews publicly available statistical data published by the Office of Rail Transport in [21, 20].

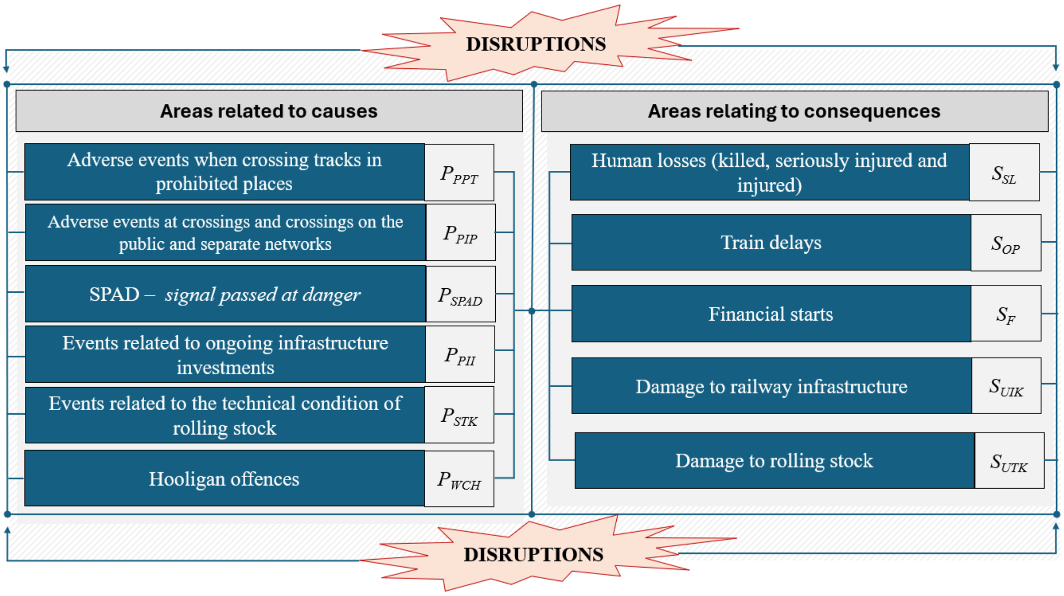

Fig. 6. Disruptions in rail transport in the context of the causes and effects of adverse events. Source: own study

The analysis of statistical data made it possible to isolate the causes and effects of adverse events in rail transport. The issue of disruptions can be perceived in many aspects because they can occur in each element of the rail transport system and during each stage of the transport task. The causes and effects during rail transport are presented in Fig. 6.

In this context, according to the theory related to risk, disturbances can be presented as an ordered sequence whose elements are the products of the Cartesian product **P×S**,

$$Z_{PK} = <(P,S)> \\ P=\{P:\ P\in \{P_{PPT}, P_{PIP}, P_{SPAD}, P_{PII}, P_{STK}, P_{WCH}\}\}, \\ S=\{S\in\{S_{SL}, S_{OP}, S_F, S_{UK}, S_{UTK}\}\} \quad (1)$$

where:

Z_{PK} – disruptions in rail transport,
P_{PPT} – adverse events when crossing tracks in prohibited places,
P_{PIP} – adverse events at level crossings on the public network and separated,
P_{SPAD} – passing “Stop" signals (SPAD events),
$P_{PI}I$ – events related to ongoing infrastructure investments,
P_{STK} – events related to the technical condition of rolling stock,
P_{WCH} – hooligan crimes,
S_{SL} – human losses (killed, seriously injured, and wounded),
S_{OPT} – train delays,
S_F – financial starts,
S_{UK} – damage to railway infrastructure,
S_{UTK} – damage to rolling stock.

Disruptions may affect both the causes and effects of adverse events in rail transport. They may also be the consequences of each of the causes and each of the effects. Proper identification of disruptions when organizing and implementing railway transport enables a quick response to disruptions in the acceptable level of effectiveness and efficiency of the service provided and ensures an appropriate quality that satisfies the final customer.

4.3. Causes of adverse events in railway freight transport

According to the definition presented in the Railway Transport Act [15, 22], a serious accident is any accident caused by a collision, derailment, or other event that has an obvious impact on railway safety regulations or safety management:

a) with at least one fatality or at least five seriously injured persons or
b) causing significant damage to a railway vehicle, railway infrastructure, or the environment, which can be immediately estimated by the accident investigation committee to be worth at least EUR 2 million.

According to data from the Office of Rail Transport, in 2022, 644 accidents (including serious accidents) were recorded on railway lines (517) and railway sidings (127). In recent years, there have been no significant fluctuations in the number of adverse events in rail transport. Most accidents occur at crossings on public and separate networks. It was assumed that disruptions in railway transport, due to the availability of data, would be presented jointly for the areas of railway lines and railway sidings.

The numbers of accidents that occurred from 2019-2022 are presented in Fig. 7 in order to determine the accident rate for individual types of causes specified in Chapter 4 of this article.

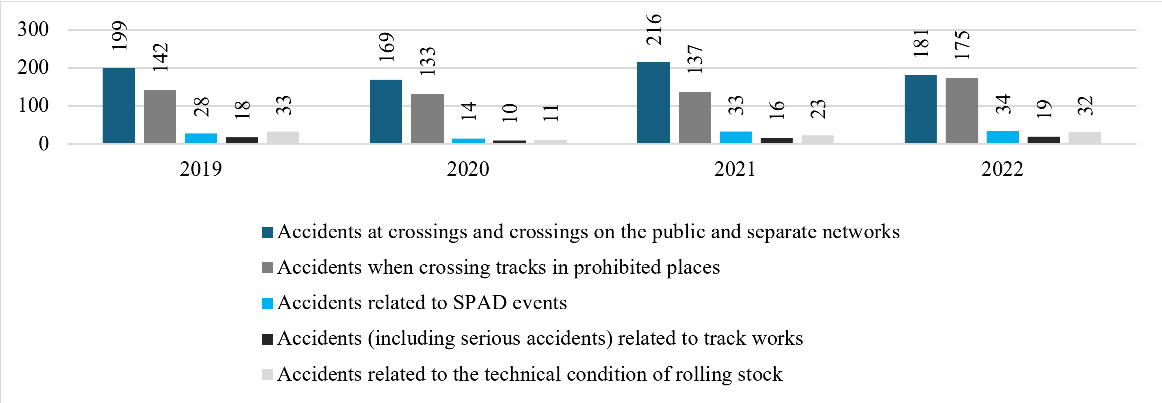

Fig. 7. Types of accidents (including serious accidents) in rail transport. Source: own study based on [21]

Based on the analysis of the number of railway accidents (also taking into account serious accidents, which are marginal events in railway transport), Formula (2) is presented based on assumptions, thanks to which the accident rate was calculated for each area of causes included in Fig. 6. It took the following form:

$$W_w = \frac{P_n}{W_n} \tag{2}$$

W_w – accident rate,
P_n – number of serious accidents and railway accidents that occurred in year n caused by cause P,
W_n – number of serious accidents and accidents that occurred in year n.

In the rest of the article, the area of causes related to hooligan offenses is omitted because it refers to incidental events rather than serious accidents and accidents.

The highest average accident rate for the years 2019-2022 was recorded for the area related to crossings on the generally accessible and separate networks. The lowest average accident rate for identified events relates to undesirable events in the area related to track works.

Table 1

Accident rates related to the most common types of adverse events

Year	**Accident rate when crossing tracks in prohibited places**	**Accident rate at crossings on public and separate networks**	**Accident rate related to SPAD events**	**Accident rate related to track works**	**Accident rate related to the technical condition of rolling stock**
2019	0.2212	0.3100	0.0436	0.0280	0.0514
2020	0.2578	0.3275	0.0271	0.0194	0.0213
2021	0.2069	0.3263	0.0498	0.0242	0.0347
2022	0.2717	0.2811	0.0528	0.0295	0.0497
Average value	0.2394	0.3112	0.0433	0.0253	0.0393

Source: own study based on [21]

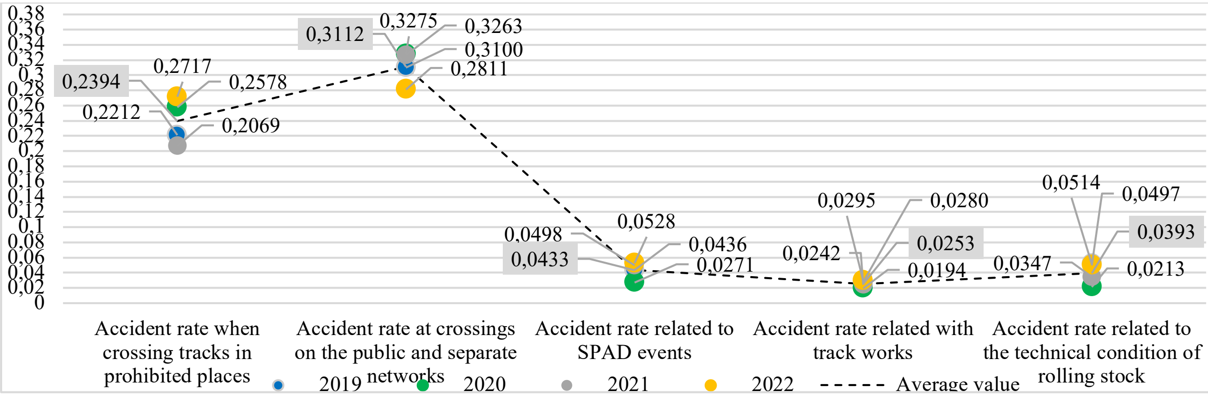

Fig. 8. Accident rates related to the most common types of adverse events. Source: own study based on [21]

4.4. Effects of delays in freight trains

The freight train delay rate was determined based on the data presented in Section 2.2. It takes the following form:

$$W_{OPT} = \frac{L_{opt}}{L_{upt}} \quad , \tag{3}$$

where:
W_{OPT} – freight train delay rate,
L_{opt} – number of delayed freight trains in year *n*,
L_{upt}– number of freight trains launched in year *n*.

Table 2

Freight train delay rate

Year	Freight train delay rate
2019	0.6100
2020	0.5660
2021	0.6087
2022	0.5878
Average value	0.5931

Source: own study based on [19]

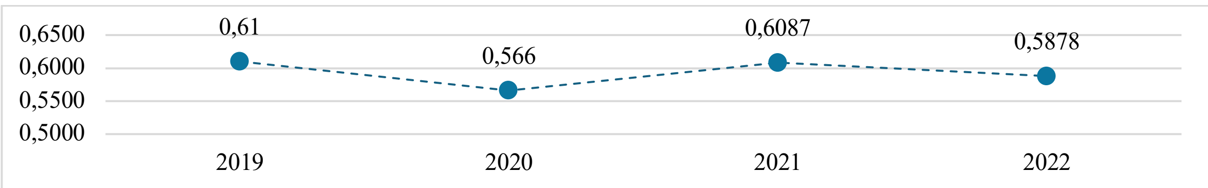

Fig. 9. Freight train delay rate. Source: own study based on [30]

The highest delay rate (0.6200) was recorded in 2019, while the lowest rate (0.5660) was recorded in 2020.

5. IMPLEMENTATION OF THE METHOD ON REAL DATA

As part of a case study for a given transport relationship, possible disruptions were identified (included in Chapter 4). The route of a freight train from the Małaszewicze Południowe freight station to the Okrzeja freight station was analyzed using the website (https://www.plk-sa.pl/klienci-i-kontrahenci/serwis-kalkulacja) and PKP Polskie Linie Kolejowe S.A. calculation [22]. The total length of the route is 110.42 km (Fig. 10).

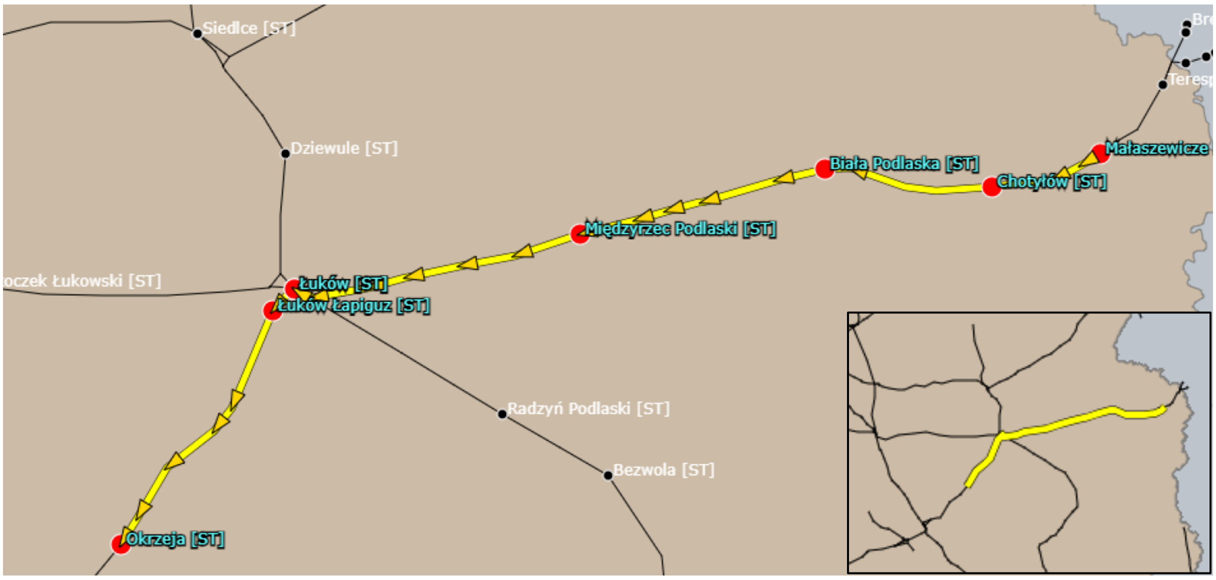

Fig. 10. Freight train route for the Małaszewicze-Południowe-Okrzeja route. Source: own study based on [22]

As part of the route of the freight train on the Małaszewicze Południowe-Okrzeja route, the following parameters enabled the quantification of disruptions related to the reasons for the occurrence during transport:

- Area related to crossing the tracks in prohibited places: the product of the route length and the accident rate when crossing the tracks was assumed in prohibited places.
- Area related to accidents at level crossings on the public network and separated: the product of the route length and the accident rate at crossings on the public and separated networks was assumed.
- Area related to SPAD events: the product of the route length and the accident rate related to SPAD events.
- Area related to track works: the product of the number of track works on the Małaszewicze Południowe-Okrzeja route (in accordance with [23]) and the accident rate, which is related to track works. It was established that there are sections on the route where modernization is taking place, resulting in the complete exclusion of the tracks from use. For the purposes of the case study, it was assumed that the transport takes place after the modernization of the railway line. Due to the availability of data, planned track closures were analyzed.
- Area related to the technical condition of the rolling stock: the product of the route length and the accident rate related to the technical condition of the rolling stock was assumed.

In the case of disruptions related to the effects of the analyzed case, due to the availability of data, the value for freight train delays was determined as the product of the route length and the average value for the freight train delay rate (according to Table 2). The calculation results are presented in Table 3.

Using the data from Table 3, the disturbances were quantified in accordance with the assumptions presented in the procedure of the method for determining the disturbance value for a given freight train route.

$$Z_{PKtrasa\ MP\text{-}O} = [(0{,}2394\cdot 110{,}42) + (0{,}3112\cdot 110{,}42) + (0{,}0433\cdot 110{,}42) + (0{,}0253\cdot 0) + (0{,}0393\cdot 110{,}42) + (0{,}5931\cdot 110{,}42)] = 138{,}2017$$

$$\mathbf{Z_{PKtrasa\ MP\text{-}O} = 138{,}2017} \tag{4}$$

Based on Equation (4), it was calculated that disruptions on the freight train route from Małaszewicze Południowe to Okrzeja have a value of 138.2017. By quantifying disruptions during rail freight transport, it is possible to analyze the values for selected disruptions on a specific day of the year. The use of the above calculations may help determine train routes and select alternative routes due to the criterion of minimizing the occurrence of disruptions or eliminating disruptions that are particularly burdensome from the point of view of the transport provider or organizer.

Table 3

Parameters enabling the calculation of the value of disruptions occurring on the route of a freight train from Mąłaszewicze Południowe to Okrzeja

Accident rate when crossing tracks in prohibited places	**Accident rate at crossings on the public and separate networks**	**Accident rate related to SPAD events**	**Accident rate related to track works**	**Accident rate related to the technical condition of rolling stock**
0.2394	0.3112	0.0433	0.0253	0.0393
Freight train delay index – average value				
0.5931				
Length of the Małaszewicze Południowe-Okrzeja train route				
110.42				

Source: own study

6. CONCLUSIONS

The importance of an effective railway system and the ability to ensure the continuity of supplies, including the continuity of product transport, is visible primarily during natural disasters, economic crises, and military threats to the state. A well-organized railway, including the transport of goods, means not only greater stability of the economy but also much greater opportunities for mobilization, which is important from the perspective of state defense. Its role is strategic in matters related to ensuring security and responding to various threats. In the event of threats to state security, railways play a key role in the transport of troops, heavy equipment, supplies, ammunition, and fuel (i.e., all goods that are necessary to conduct military operations). The railway plays a significant role in peacetime because it ensures the efficient transport of both passengers and goods, which affects the quality of life of society and the functioning of the state's economy.

Disruptions accompanying the organization of the transport process constitute a significant challenge for entities operating in the rail freight market. The causes of disruptions can be identified subjectively, functionally, or locally (e.g., through railway infrastructure, railway carriers, contractors, and transport organizations). Disturbances can also be generated directly from the environment (e.g., through serious railway accidents, railway accidents, sabotage and sabotage activities, incidents, and potentially dangerous events. Particular attention should be paid to disruptions related to transport technology because their consequences may result in capacity limitations of stations and railway lines, and in the case of sabotage and sabotage activities, their temporary exclusion from use.

The negative effects of disruptions are reduced by introducing transport restrictions by railway carriers. This is done by prohibiting the sending of trains on specific transport routes along which the accumulation of shipments at stations or railway lines has been identified. Issues related to the resilience and safety of railway traffic should also be taken into account, which, as indicated in this article, is important at various levels: state security, proper development of the economy, which is related primarily to rail freight transport, and the implementation of social needs. A problem that requires further analysis is the allocation of train routes, which may also affect the occurrence of disruptions in rail traffic and, thus, translate into the implementation of rail freight transport.

The quantification of disruptions related to the causes and effects of adverse events in rail transport enables the analysis of freight train routes in terms of acceptable boundary conditions. The presented method of determining the disturbance value for a given route may be helpful in planning and organizing the transport process. Comparing disruption parameters for specific routes over the period under study may enable the determination of long-term trends. The method can be used among railway carriers and managers of line or point infrastructure and values and enables the degree of resistance and safety of the rail transport system to be determined on a nationwide scale.

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