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THE RISK OF DAMAGE TO RAILWAY INFRASTRUCTURE DUE TO THEFT AND DEVASTATION

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Abstract

Theft and devastation of railway infrastructure are one of the most important factors that affect the safety of the railway transport system. In Poland, the railway transported 245.1 million passengers and 243.6 million tons of cargo in 2021, so it is extremely important to ensure the maximum possible safety standards. Theft and devastation of railway infrastructure contribute to significant material damage to railway network managers. The costs of rebuilding railway equipment are estimated at millions of zlotys every year. They also influence the proper functioning of railway traffic. Due to this phenomenon, there are delays of passenger and freight trains, the total of which amounted to over 100,000 minutes in 2021. Therefore, the effects of such hooligan acts also affect passengers and commercial customers of the railways. The article is an attempt to describe the impact of theft and devastation of railway infrastructure on its safety and the operation of railway lines in Poland. By analyzing the available statistical data and using the CSM method, as well as applying certain simplifications, it was possible to determine the approximate level of risk using techniques used in practice. Based on the adopted risk reference levels, a systematic reduction in both the probability of occurrence of negative phenomena and their consequences was observed.

Keywords: railway, transportation, railway infrastructure, risk assessment, theft and devastation

1. INTRODUCTION

The rail transportation is a key element of the economy of Poland and the European Union. Its infrastructure is a critical transport infrastructure for the country security and defence. Therefore, it is important to ensure the greatest possible safety for passengers and railway employees. Its level is inextricably linked to the irregularities of all elements constituting the railway system in Poland. Among them, irregularities affecting the railway infrastructure have the greatest impact. One of the most widespread problems that affect the safety standards of the rail transport system are thefts and devastation of railway infrastructure.

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The safety of railway operations is a widely discussed issue, which is reflected in numerous domestic and foreign papers [35]. Among them, can be find works that discussed topics related to the theft of railway infrastructure: metal elements [41], correlation of thefts and the location of scrap purchases [1], the relationship between copper prices and thefts of copper elements of railway infrastructure [24], as well as the problem of detecting such events [21] and problems with diagnostics and securing railway traction against thefts [16]. The risk of theft of cargo transported by rail is also discussed.

Safety can be defined in many ways, but usually it is closely related to a certain risk, the level of which determines the limit of safe operation of railway infrastructure. When analysing risk, it is first of all necessary to determine the changes and potential impact on the safety of the railway system. These changes can be classified as significant or insignificant, that is those that affect safety and those that do not. Risk is also inherent in other aspects of rail transport.

Risk in rail transport is presented in various aspects. Many studies relate to the safety of rail transport as a whole system [19]. In relation to the railway infrastructure, the risk was considered in relation to the impact of climate change [18] or natural factors on it [10]. Approaches to detecting the risk of railway track damage due to surface defects have also been proposed [8]. Risk is also considered regarding the occurrence of natural disasters, such as assessing the risk of the impact of a lightning strike on railway signalling and railway control devices [23]. The issue of attacks and the risk of damage to the railway road and its security and protection was also noted in the work [3], which presents a method of estimating the consequences of this type of phenomena.

A similar approach, which links safety with risk, is also presented in national [34] and international regulations related to the operation of rail transportation [5]. The description of the phenomenon as a function of risk is a good, commonly accepted way to practically determine the permissible threshold levels of undesirable phenomena that may affect individual elements of rail transport [11,12,25,26]. The level of these values will determine whether the safety requirements are met (acceptable or negligible risk) or not (unacceptable risk). The limit value is commonly called the risk reference level [13].

This research aim is to analyze the risk of damage to railway infrastructure as a result of theft and devastation. This analysis will be carried out on the basis of events occurring on the railway network managed by PKP Polskie Linie Kolejowe S.A. To determine risk will be used the CSM method (Common Safety Method for risk evaluation) [2].

2. RAILWAY TRANSPORTATION IN POLAND

Rail transport has a significant role in the transport of people and goods, both over short and long distances. The railway meets transport needs related to daily commuting, as well as seasonal needs, such as during winter or summer travel. The following elements are distinguished in the rail transport system: railway infrastructure (point and line), rolling stock and institutions and companies operating on the railway market [15].

Since 2014, the number of rail passengers in Poland systematically increased until 2019. The upward trend was stopped in 2020 due to travel restrictions during the global Covid-19 pandemic. In the peak year of 2019, railway in Poland carried 335.9 million passengers. The number of transported passengers between 2010 and 2021 is shown in Figure 1.

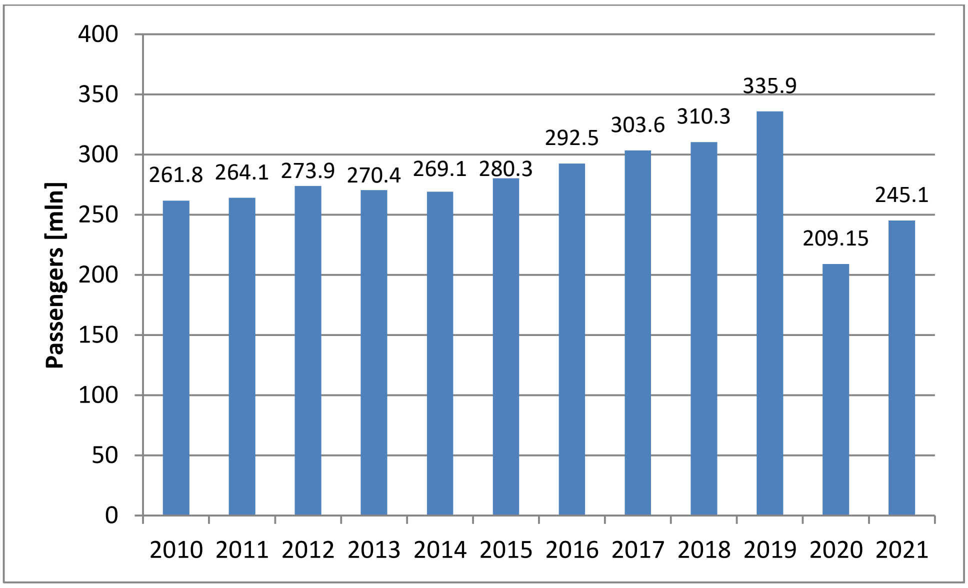


Fig. 1. Passengers in millions in Poland between 2010 and 2021 [27]

In the case of the analysis of rail freight transport, the key indicator is the weight of transported cargo and the transport performance. Unlike passenger rail, the statistics of the weight of cargo transported by rail in Poland varies greatly in subsequent years. A clear upward trend occurred between 2016 and 2018, when the weight of transported cargo increased by 28.1 million tons over two years. Then, over the next two years, there was a decrease in cargo weight by 27.1 million tons. Transport performance has remained at a similar level over the last decade. As in the case of the weight of transported goods, 2018 is also a record year in terms of transport performance. This indicator reached the value of 59.6 billion tonne-kilometers. In the remaining years, the indicator ranges from 50 to 60 billion tonne-kilometers. In 2021, 243.6 million tons of cargo were transported in Poland and 56 billion tonne-km of transport work was performed. The weight of transported loads is presented in Figure 2, and the transport performance is shown in Figure 3.

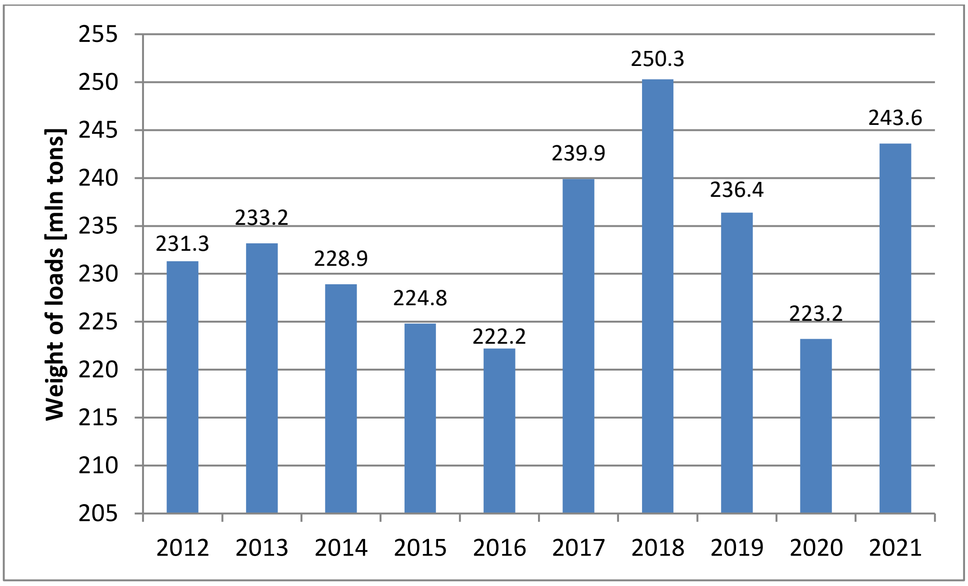


Fig. 2. Weight of transported loads by railway in Poland between 2012 and 2021 [27]

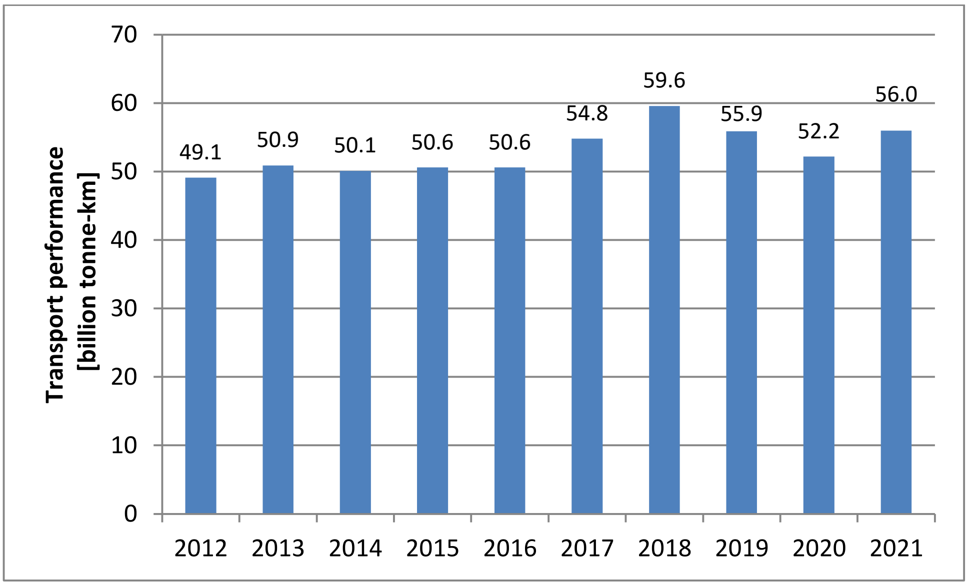


Fig. 3. Freight railway transport performance in Poland between 2012 and 2021 [27]

According to the Act [34], railway lines in Poland are divided into lines of state importance and other lines. The railway infrastructure consists of point and linear elements. In accordance with Annex No. 1 to the Act [34], elements of railway infrastructure should be understood as all devices and structures that are necessary to conduct railway traffic. Similar provisions can be found in Community regulations of European Union [5], specifying that the concept of infrastructure should be understood as, among others, tracks, turnouts, crossings, engineering structures (bridges, tunnels, etc.), railway-related station elements (including entrance doors, platforms, access areas, service points, toilets and information systems, as well as their functions to facilitate access for disabled persons and persons with reduced mobility), safety and protective devices.

Linear infrastructure consists of an interconnected network of railroads along with the adjacent strip of land, buildings, structures and devices used for efficient and safe train traffic management. Parameters that characterize the railway network may include factors affecting the availability of railways for passenger traffic, such as: density of the railway network - different for each region in the country, in Poland it is approximately 6.9 km of track per 100 km^2 and is higher than the average density of the network for European Union countries, which is 6.2 km of track per 100 km^2, and the average distance from the railway line - for Poland, which is approximately 15 km, with an area of 312,683 km^2 and approximately 19,000 km of standard-gauge lines. Additionally, the lines are categorized by division according to specific technical and operational parameters, such as: transport intensity, maximum speed and maximum speed of freight trains. In accordance with the European Union law and the directive on railway interoperability, the railway system must ensure compatibility with older systems in use and interoperability, i.e. the interoperability of various European systems, ensuring the highest safety standards [5].

There are 19,300 km of railway lines in Poland. It is the fourth longest railway network in the European Union [24]. Germany has the longest network of railway lines (39.2 thousand km), followed by France (28.7 thousand km) and Italy (20.0 thousand km). Figure 4 presents a summary of the length of railway lines in individual European country.

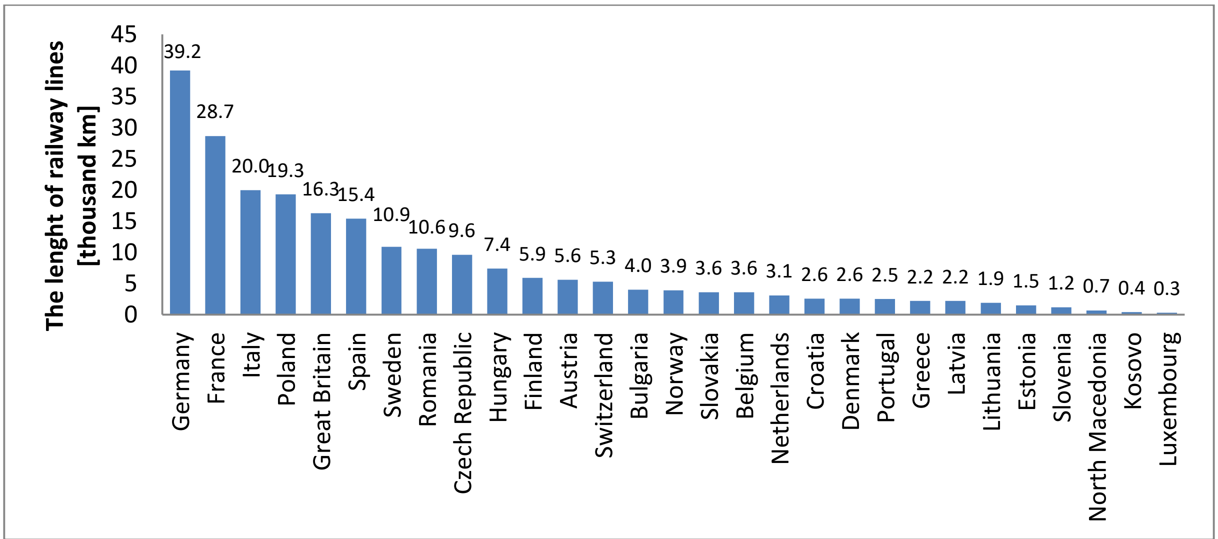


Fig. 4. The length of railway lines in European countries [27]

According to Polish regulations [34], the administrator of railway infrastructure is the entity that deals with its management, operation, maintenance, renewal and development. The largest Polish manager is PKP Polskie Linie Kolejowe, which operates 18,634 km of railway lines [38]. This translates into almost 96.5% market share among all enterprises managing railway infrastructure in Poland [27].

3. STRUCTURE OF THEFT AND DEVASTATION OF RAILWAY INFRASTRUCTURE IN POLAND

Among the important factors that influence the safety of railway line operation and railway traffic is efficient railway infrastructure. Its proper maintenance is the responsibility of the infrastructure administrator, but there are situations that cannot be predicted well in advance. Such events include various types of hooliganism, such as theft and devastation.

Theft is construed as permanent taking and misappropriation of someone else's property. Devastation involves the destruction and damage of a certain element of infrastructure, which often makes it unfit for further use in full working order. Legally, the above-mentioned acts are regulated, among others, by the Penal Code. According to the relevant law (article 254a), persons who take away, destroy or damage elements of a railway line and thereby disrupt the operation of part or the entire system are subject to the penalty of imprisonment from 6 months to 8 years [33]. Examples of the effects of theft and devastation of railway infrastructure are shown in Fig. 5, 6, 7.

Fig. 5. Railroad after the act of stealing rails [40]

Fig. 6. The effects of theft of railroad elements (rail fastenings, screws, base plates) [39]

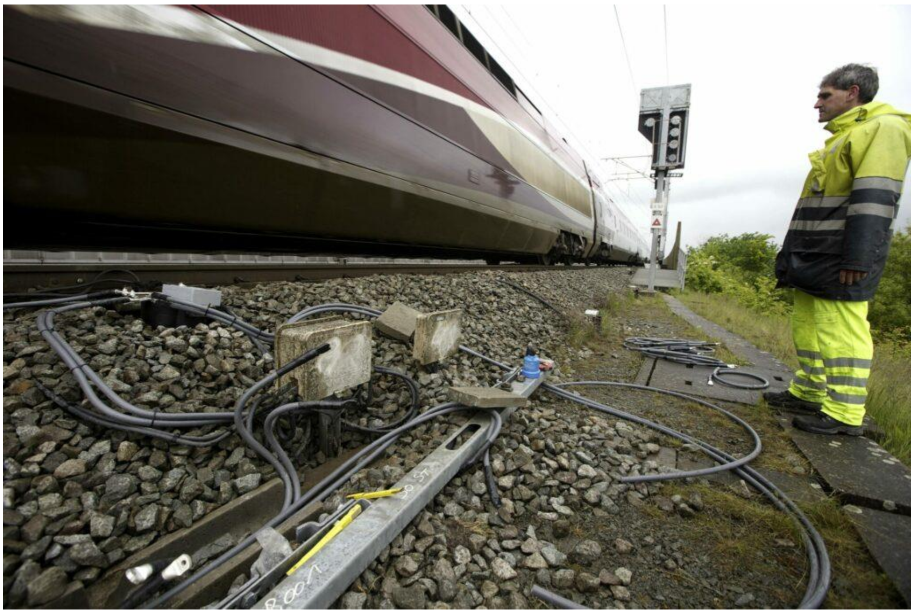


Fig. 7. Devastated cables and control command and signalling devices [36]

According to the “Report on the railway traffic safety in 2021” [32] the effect of hooligan offenses was distinguished as events significantly affecting the safety of the rail transport system. This category includes: obstacles on tracks, thefts and devastation of infrastructure, unauthorized emitting of alarm signals, attacks on trains, devastation of vehicles and shooting at trains. A list of individual hooligan offenses along with the percentage share of each category is shown in Figure 8.

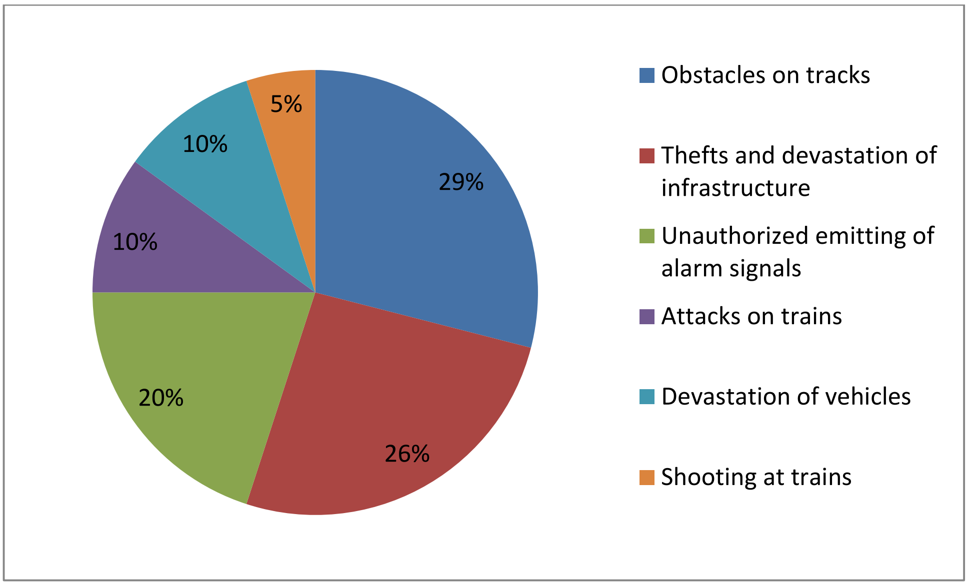


Fig. 8. List of hooligan offenses in Poland in 2021 [32]

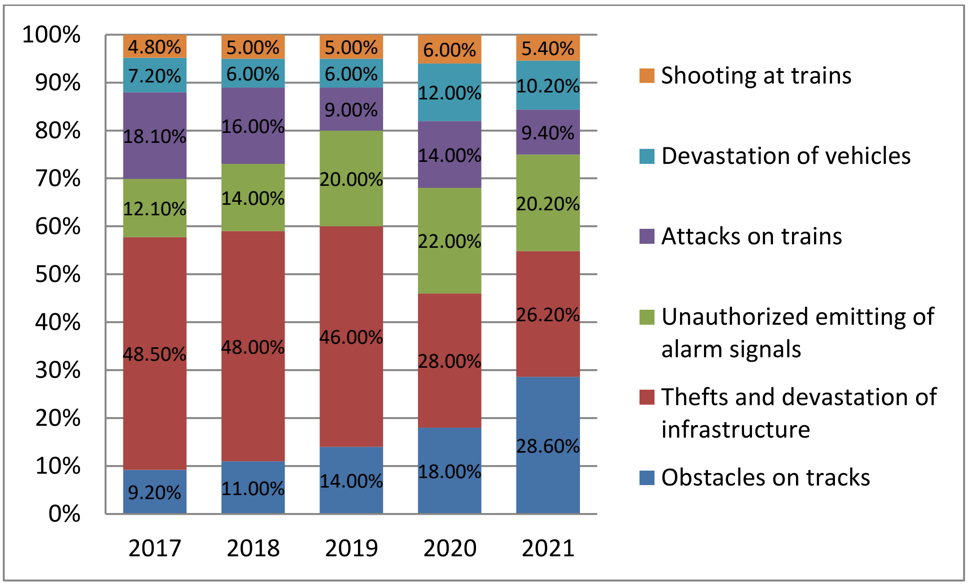


Fig. 9. List of hooligan offenses in Poland between 2017 and 2021 [32]

Thefts and devastation of railway infrastructure constitute the largest or second largest share of hooligan crimes on the railway network in Poland in 2017-2021 [28, 29, 30, 31, 32]. From 2012 to 2021, there was a decrease in the number of these events from almost 5,000 to 723. However, between the last analysed years of 2020 and 2021, an increase of 59 cases was recorded. The number of cases of theft and devastation of railway infrastructure in Poland is presented in Figure 10.

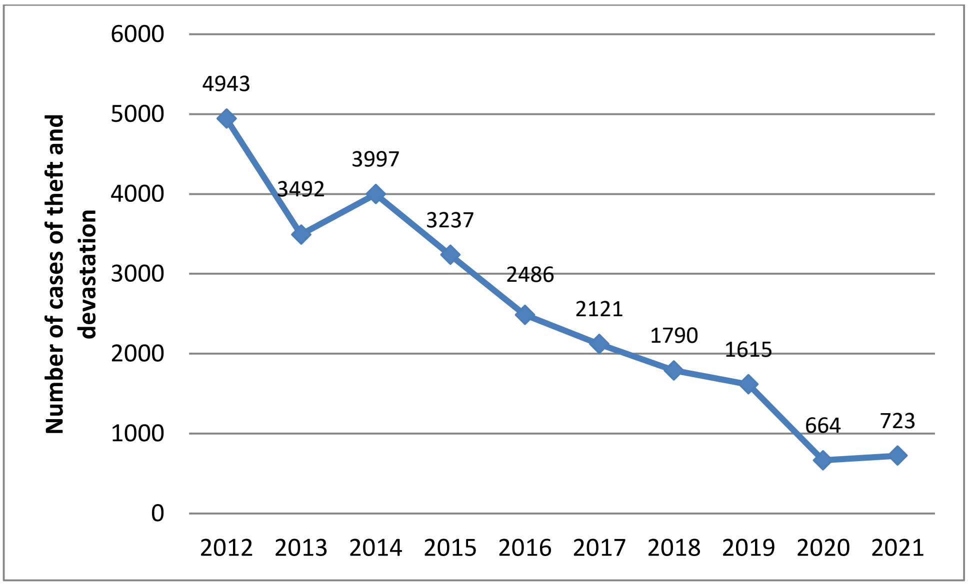
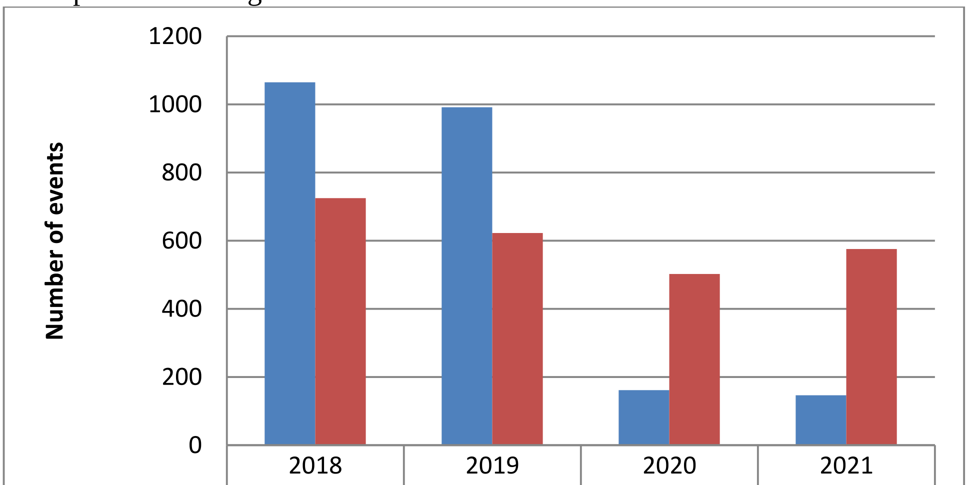


Fig. 10. The number of cases of theft and devastation of railway infrastructure in Poland between 2012 and 2021 [32]

The number and proportion of incidents on railway infrastructure have changed in recent years. Until 2019, there were more devastations than thefts, 47% respectively in 2018 and 59% in 2019. In 2020, there was a significant decrease in the share of devastation in the total number of events. There were 162 cases of devastation and 502 thefts (310% more thefts), while in 2021 there were 147 devastations and 576 thefts (392% more thefts). The number of hooligan offences (theft and devastation) in 2018-2021 is presented in Figure 11.



	2018	2019	2020	2021
Devastations	1065	992	162	147
Thefts	725	623	502	576

Fig. 11. The number of theft and devastation of railway infrastructure in Poland between 2018 and 2021 [32]

The main elements of railway infrastructure that are exposed to theft and devastation are: railway control command and signalling equipments, railway power engineering, railway ICT and track surface elements (Fig. 12). Therefore, metal elements, especially copper, are particularly exposed, because of their weight and dimensions, they can be easily dismantled and transported. Reports from the Polish Railway Transport Office [32] show that this type of crimes in Poland are most often targeted at railway traffic control command devices and signalling (41% in 2021), electricity devices (22% in 2021) and ICT devices (21% in 2021). Additionally, thefts of road surface elements can be noticed, but their share is much smaller compared to the other analyzed elements of railway infrastructure.

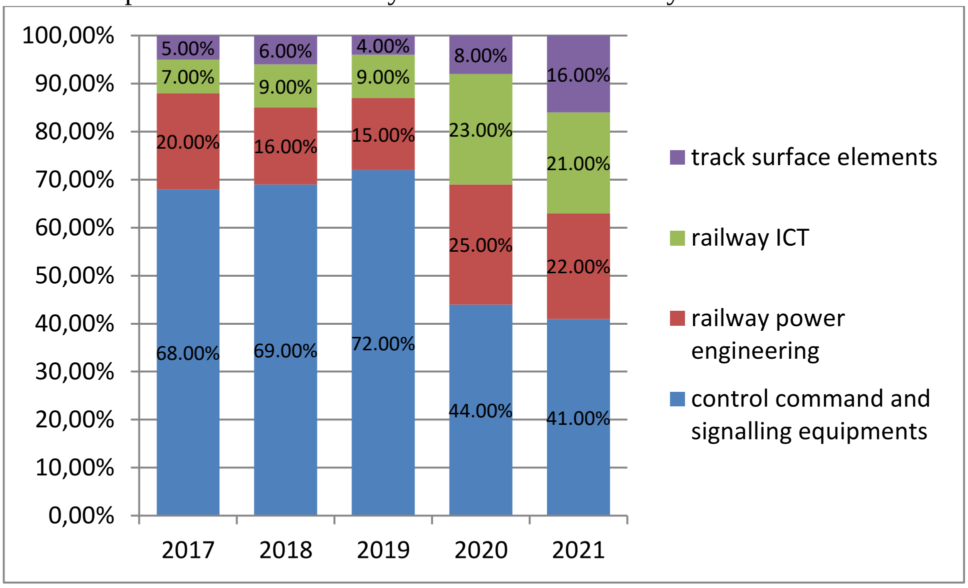


Fig. 12. The share of theft and devastation of railway infrastructure elements between 2017 and 2021 [32]

Despite reducing the number of events, they cause significant material losses for infrastructure administrators, which are associated with certain costs. These costs were divided into internal, or direct for the manager, e.g. replacement of damaged equipment, and external - related to other entities operating on the railway market: carriers (e.g. damage to rolling stock) and passengers (e.g. delays and cancellations).

For this reason, ensuring the security and safety of the railway area, which covers a large area of land, and determining the risk of infrastructure damage due to theft is a very important issue. In the context of safety, the solution may be traditional such as fences, lighting, service patrols or modern industrial monitoring systems or the use of unmanned flying devices – drones [37].

4. CONSEQUENCES OF THEFT AND DEVASTATION ON THE FUNCTIONING OF RAILWAY INFRASTRUCTURE

Among the numerous consequences of theft and devastation of railway infrastructure, important are those that directly affect railway traffic and, consequently, affect the level of safety. These include, the cost of restoring devices and delays caused by hooligan crimes. In addition these offenses result in a temporary or complete suspension of railway traffic on a specific part of the railway network. Such events therefore have consequences both for the railway system and for rail passengers and customers. In the case of passengers, this may involve significant delays, train cancellations and the part of the route covered by replacement bus service. For customers in freight transport, it may result in problems with the arrival of cargo on time and the continuity of supply chains.

An important indicator of the consequences of theft and devastation is the cost that have to be borned by railway infrastructure administrators in Poland due to the reconstruction of devices used for efficient and safe railway traffic management. This cost varies in the subsequent analyzed years (2017-2021) and depends on the number of events and the type of damaged or stolen devices. The largest cost for the reconstruction of railway traffic control equipment, railway power engineering and ICT equipment had to be borne by the managers in 2018. It was almost PLN 10 million, while in 2021 the cost was PLN 4.8 million. The replacement costs of these three categories of devices altogether in subsequent years are shown in Figure 13.

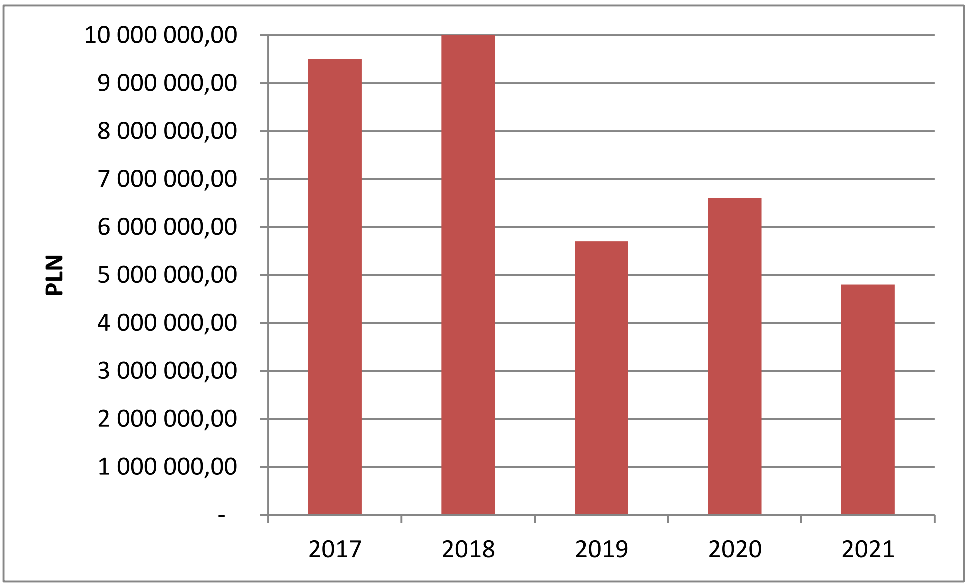


Fig. 13. Replacement costs of significant railway devices between 2017 and 2021 [28, 29, 30, 31, 32]

Additionally, such events significantly contribute to difficulties in the normal (standard) operation of train traffic, forcing railway employees to use emergency (non-standard) procedures and increasing the risk of dangerous events occurring in the rail transport system. The analysis shows that in each year under review, there were a significant number of train delays due to theft or devastation of infrastructure which was important for the efficient and safe operation of railway traffic. These delays are counted in tens of thousands of minutes [28, 29, 30, 31, 32]. Despite a clear downward trend in the overall number of such crimes, it is not noticeable in the overall number of train delays on the railway network in Poland. Delays caused by theft and devastation are shown in Figure 14.

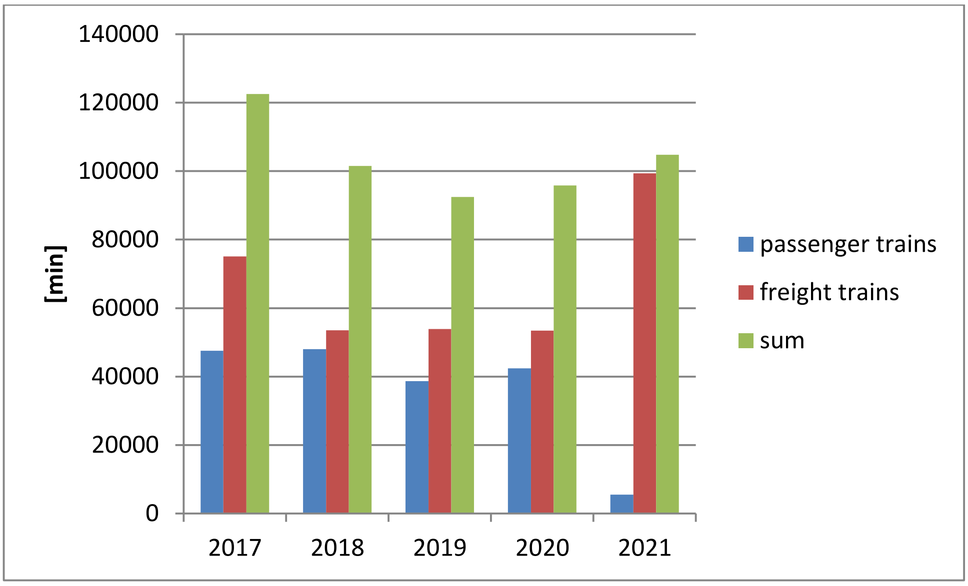


Fig. 14. Delays of passenger and freight trains caused by theft and devastation in Poland between 2017 and 2021 [28, 29, 30, 31, 32]

Identified train delays caused by thefts and devastation may affect the total running time of trains and, consequently, translate into their punctuality. An important element on the railway is its punctuality. Table 1 shows punctuality indicator along with the number of trains launched in 2017-2022.

Table 1. Punctuality indicator and the number of trains launched in Poland between 2017 and 2022

Year	**Punctuality rate**		**Number of launched trains**		**Number of delayed trains (including delays <5 min 59 sec.)**	
	Passenger	**Freight**	**Passenger**	**Freight**	**Passenger**	**Freight**
2017	90.17 %	39.23 %	1 715 587	463 183	359 384	285 056
2018	88.54 %	36.09 %	1 783 210	481 567	419 074	310 971
2019	92.46 %	41.62 %	1 716 044	446 501	370 796	272 356
2020	94.62 %	46.11 %	1 581 087	421 032	280 584	238 286
2021	90.11 %	41.71 %	1 741 157	445 809	525 667	271 383
2022	88.62 %	43.62 %	1 823 322	446 839	607 069	262 662

The direct impact of hooligan offenses on train running times and potential delays is difficult to estimate and would require more detailed analyses. It was decided that the punctuality rate and the related train delays will not be taken into account as a consequence of theft or devastation of railway infrastructure.

5. DETERMINATION OF THE RISK OF INFRASTRUCTURE DAMAGE DUE TO THEFT OR DEVASTATION

Many risk assessment methods are used in rail transport. The final choice of a rail accident risk analysis method depends on both the specific situation and the context. A common safety method for risk assessment and valuation used by railway sector entities is CSM [2]. The purpose of the above method is to identify threats and introduce preventive measures to reduce the risk to an acceptable level. It is used to analyze risks related to technical, operational and organizational aspects, as well as to take actions aimed at minimizing risk. The CSM does not prescribe specific risk analysis techniques to be used [as above].

As a starting point for further considerations, a risk management strategy in accordance with the process presented in the ISO 31000 standard [20], as well as the use of techniques suggested by the accompanying document to the standard, i.e. the PN-EN IEC 31010:2020-01 standard [7] can be taken. This standard suggests several dozen tools and techniques that can be successfully used in practice. These include: decision trees [4], Bayesian networks [6], and Neural networks [17].

Due to the fact that the available data are not very precise, it was decided to estimate risk reference intervals based on three basic levels (acceptable, tolerated (acceptable) and unacceptable risk). The defined reference levels are presented in Table 2.

Table 2. The defined risk reference levels

Risk value	**Risk acceptability**	**Activities**
(0; 5000]	Acceptable	No action
(5000; 10000]	Tolerated (acceptable)	Risk monitoring
(10000; ∞+)	Unacceptable	Urgent action

To determine the risk, a function combining the probability of an event and its consequences was used [9]. The probability of an event will be the share of theft and devastation in the total share of hooligan crimes, multiplied by the number of thefts and devastation in a given year. The consequences will be understood as the sum of two factors: replacement costs of devices and the delay caused. The delay will be aggregated for work purposes without taking into account the characteristics of passenger and freight traffic. The risk is described in Formulae 5.1.

$$R_{dev} = P_{dev} * (C_{re} + D_{dev}) \tag{5.1}$$

Meaning of symbols:
R_{dev} – risk of theft and devastation;
P_{dev} – probability of theft and devastation;
C_{re} – replacement cost of railway traffic control devices;
D_{dev} – delay caused by theft and devastation.

Data on the consequences of theft and devastation of control command and signalling devices will be used for further analysis. For the purposes of the work, it was also assumed that due to the highest share of that kind of devices in thefts and devastation among all elements of railway infrastructure, the value of train delays will be assigned as a consequence of the lack of this type of devices. It is also consistent with the general principle of railway traffic management, i.e. only the lack of railway traffic control devices allows train traffic, while the lack of other infrastructure elements (surfaces or power equipment) prevents or significantly impedes the passage of railway vehicles.

In order to determine the risk, the values of both consequences were defined and assigned numerical values from 1 to 5. The value of the replacement cost of control command and signalling devices (C_{re}) is presented in Table 3, while the values of train delays (D_{dev}) is presented in Table 4.

Table 3. The value of the replacement cost of control command and signalling devices

C_{re} **[mln PLN]**	**Value**
(0,00; 2,00]	1
(2,00; 4,00]	2
(4,00; 6,00]	3
(6,00; 8,00]	4
(8,00; 10,00]	5

Table 4. The value of train delays

D_{dev} **[min]**	**Value**
(0; 40000]	1
(40000; 80000]	2
(80000; 120000]	3
(120000; 16000]	4
(160000; 200000]	5

For these assumptions, the risk level (R_{dev}) was determined. The risk was determined for the years 2017-2022. The results of the risk analysis are presented in Table 5.

Table 5. Risk of damage to railway infrastructure due to theft in 2017-2021

Year	R_{dev}	**Risk acceptability**
2017	10 286,85	Unacceptable
2018	7 732,80	Tolerated
2019	5 200,30	Tolerated
2020	1 487,36	Acceptable
2021	1 515,41	Acceptable

Based on the determined risk level based on the assumed criteria, a significant change in the risk value can be observed over 5 years. This change is almost tenfold when comparing the value from 2021 to 2017. Both the number of events and the impact of the consequences of theft and devastation also decrease over the years. This state of affairs may result from many different factors that are not necessarily related to risk mitigating activities (investments under multi-annual programs, increasing the level of public awareness, etc.). Ultimately, the risk level for 2020 and 2021 is at an acceptable level. This level does not require additional activities from risk managers.

Even though the designated risk is acceptable, the fact is that thefts and devastation are crimes, their number should be constantly minimized and the practice itself should be monitored by decision-makers and the railway infrastructure administrators.

6. CONCLUSIONS

Following paper is an attempt to describe the impact of theft and devastation of railway infrastructure on its safety and the operation of railway lines in Poland. Despite access to data related to this type of phenomena, it is impossible to obtain precise results without additional information. However, by using simplifications and additional assumptions, it was possible to determine the approximate level of risk using techniques used in practice. Based on the adopted risk reference levels, a systematic reduction in both the probability of occurrence of negative phenomena and their consequences can be observed.

However, for more precise analyses, additional own research should be carried out to examine other features of the phenomenon in question. Among them, an important parameter is the ability to identify the threat, which allows carrying out a risk analysis using the FMEA method, commonly used in the standard CSM approach used by railway sector companies for safety testing.

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