Research Article

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Analysis and assessment of the human factor as a cause of occurrence of selected railway accidents and incidents

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Abstract: Ensuring safety is the key factor in the development of rail transport. For this reason, the railway market is heavily regulated, including recording and analysis of railway accidents and incidents. The article presents analysis of 148 final reports of accidents and incidents that occurred in the year 2020 in the Polish railway network and whose direct cause was human factor. The analysis looks at the age and experience of railway employees, as well as analyses human error using the Human factor analysis and classification system (HFACS) model and included train drivers and infrastructure-related stuff. It is pointed out that the available publications are generally focused on signal passed at danger accidents and incidents, which relate to passing through a stop signal, or another stop location, most often caused by an error of the train driver. Therefore, these analyses ignore accidents and incidents related to an improperly prepared and protected route, e.g. failure to close the level crossings boom barriers or incorrectly placed junction point, which under minimally different circumstances could have led to a tragedy. The causes of such accidents and incidents are also related to the human factor and therefore should have been identified and classified. The article identifies weaknesses in the investigations, including the quality of the documentation prepared. Such documentation most often focuses on the factors and causes directly related to the site of the accident or incident, while neglecting the factors at the organisational level.

Keywords: HFACS, railway safety, dangerous points, human errors, infrastructure-related staff, suprastructure-related staff

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1 Introduction

Safety of the railway transport, including analysis of human factors, is attracting the attention of an increasing number of researchers. However, analysis of the available publications from the last 20 years shows that there is still lack of publications that analyse human factor in the transport processes carried out and the decisions taken during the performance of duty that directly affect rail safety. In this respect, rail transport is lagging behind compared to the analysis available in the aviation or road transport [1,2].

When analysing the issue of rail transport safety in the European Union, it is necessary to start with the legal requirements. Currently, directive [3] and the implementing act [4] are binding for the member states of the European Union. The law requires railway entities to, among others, record and analyse railway incidents, including considerations of the human factor. The preamble of the directive indicates that if the direct causes of the incident appear to be related to human conduct, special consideration should be given to issues related to the routine actions of employees, the human–machine interface and other factors such as work load, stress, fatigue, or external factors that could affect the efficiency and quality of the human performance. One of the key responsibilities of rail market entities is to have a systemic concept for the support and management of the human factor, in particular from the point of view of ensuring railway safety, which means focusing on reducing the number of railway incidents and other situations, which under minimally changed circumstances could lead to such accidents and incidents.

Various methods have been developed to identify the human factors that have been the causes of railway accidents and incidents. Many of these methods have their origins in aviation, the branch of transport where the human factor has been analysed from the earliest and where the conclusions of the analysis that specifically relate to the conduct and errors of workers are well recognised and better adhered to than in rail transport. One such method is the Human factor analysis and classification system (HFACS) [5]. The method was developed by Americans, Shappell and Wiegmann, after research of an extensive set of aviation accident reports, the method is based on Reason's concept of latent and active failures [6,7]. Today, the method is widely used in various transport and industrial sectors to identify and classify the human role in the occurrence of accidents and incidents, primarily in aviation, maritime, mining, construction, and the gas industry [1,8,9]. In some publications, the HFACS method is also applied to the analysis of railway accidents and incidents [10–12]. However, considering the specific procedures and responsibilities occurring in this branch of transport, other methods are also being developed, for example, the Factor Analysis and Classification System for Rail Accidents (HFACS-RAs) [13], the Factor Analysis and Classification System for Railroad Industry (HFACS-RR) [14], which extend the commonly used HFACS method with knowledge specific to railway transport. In addition, a combination of other various available models is also used to analyse rail incidents and events, thus creating a comprehensive analysis dedicated to rail transport incidents and events [15].

For the purpose of this analysis of railway incidents, it was decided to use the standard HFACS method, which is mostly used to analyse the human factor in transport accidents and incidents. Consequently, the results of the analysis will be comparable to previously developed studies in the transport sector and in particular, in the rail market. The HFACS method, shown in Figure 1, is based on four levels of human error, i.e. organisational influences, unsafe supervision, precondition for unsafe acts, and unsafe acts, which are later divided into additional subcategories. It should be noted that errors that fall into the unsafe acts category are characterised by their direct impact on the occurrence of the railway accident or incident, whereas the subsequent categories including organisational influences focus on factors that gradually move away from the actual scene of the accident or incident, pointing at the overall functioning of the company and its immediate environment.

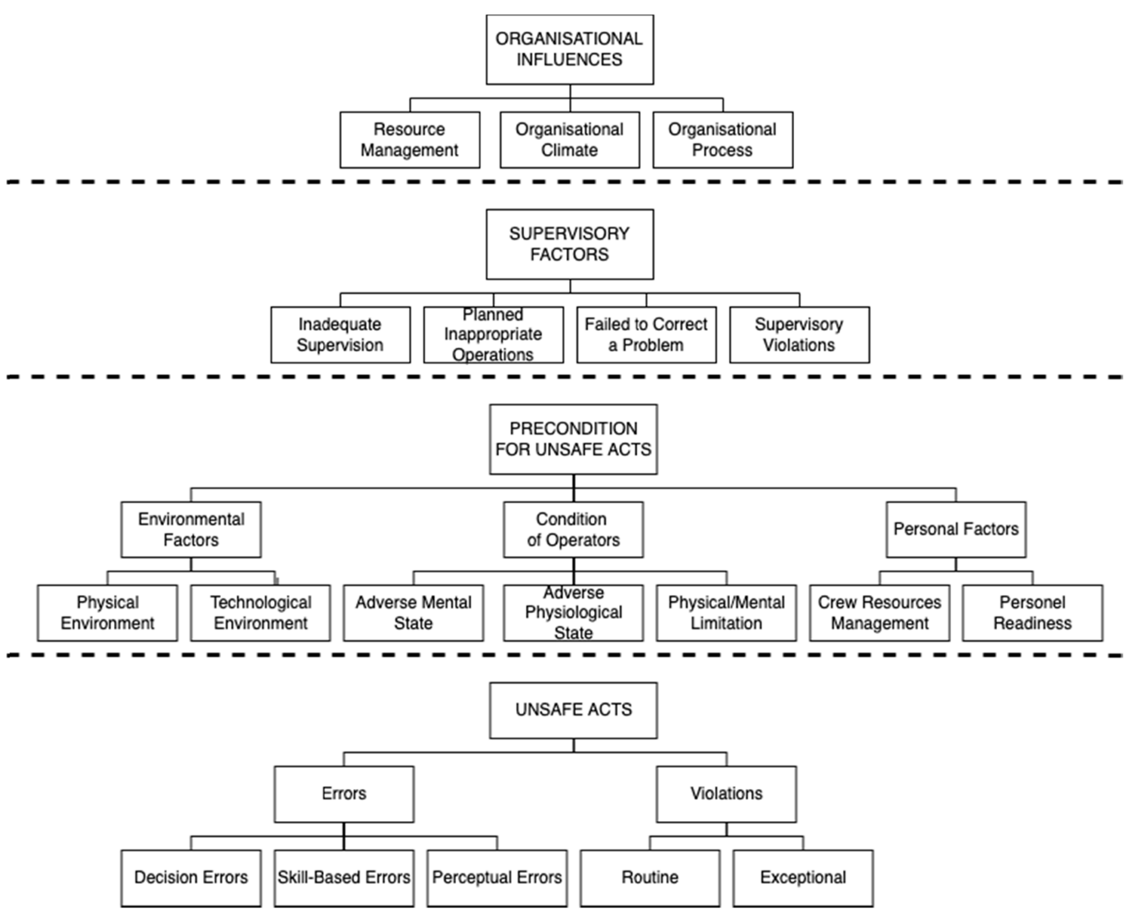

Figure 1: HFACS model [5].

2 Analysis of the documentation from railway accidents and incidents

The analysis covers selected categories of railway accidents and incidents that occurred in 2020, which are based on the categories presented in Regulation [16] and which are caused due to a human error. All railway undertakings and infrastructure managers operating in the territory of Poland were included in the analysis. A total of 148 final reports of incidents including categories C44 (failure of a railway vehicle to stop before the signal "Stop" or in the place, where it should stop, or starting of a railway vehicle without required permission), C43 (departure, arrival, or driving of a railway vehicle on an improperly laid, unsecured runway, or improper operation, or lack of operation of signalling equipment), as well as, accidents B03 and B04, whose causes of occurrence coincide with the abovementioned incidents; however the consequences in terms of their impact on safety of the transport system and damage to property are rated much higher. It is worth noting that despite the fact that causes of incidents in categories B01 and B02 are also related to the human factor, there were no such incidents reported in the year 2020 and therefore they are not included in this analysis [17].

2.1 Preliminary analysis

The first stage of the analysis covers conduct of the employees directly involved in their occurrences. It has to be noted that the division into occupational groups presented in the study is based on the provisions of Regulation [18] which divide the positions directly related to the operation and safety of the railway traffic. In particular, attention was paid to the age and experience of the employees carrying out these roles. Figure 2 shows the structure of particular age groups in the selected railway posts in total employment in Poland [19] together with the share of employees in particular age groups in the accidents and incidents that occurred in 2020 [17]. The only group that is not dominated by the workers aged 50 and over are drivers of passenger trains. It should be noted that the rail market is facing a generation gap and there are significant problems with recruitment to replace aged employees that are due to retire in the next few years or even to extend their working time. Regarding rail accidents and incidents, it should be stated that they occur among employees of all

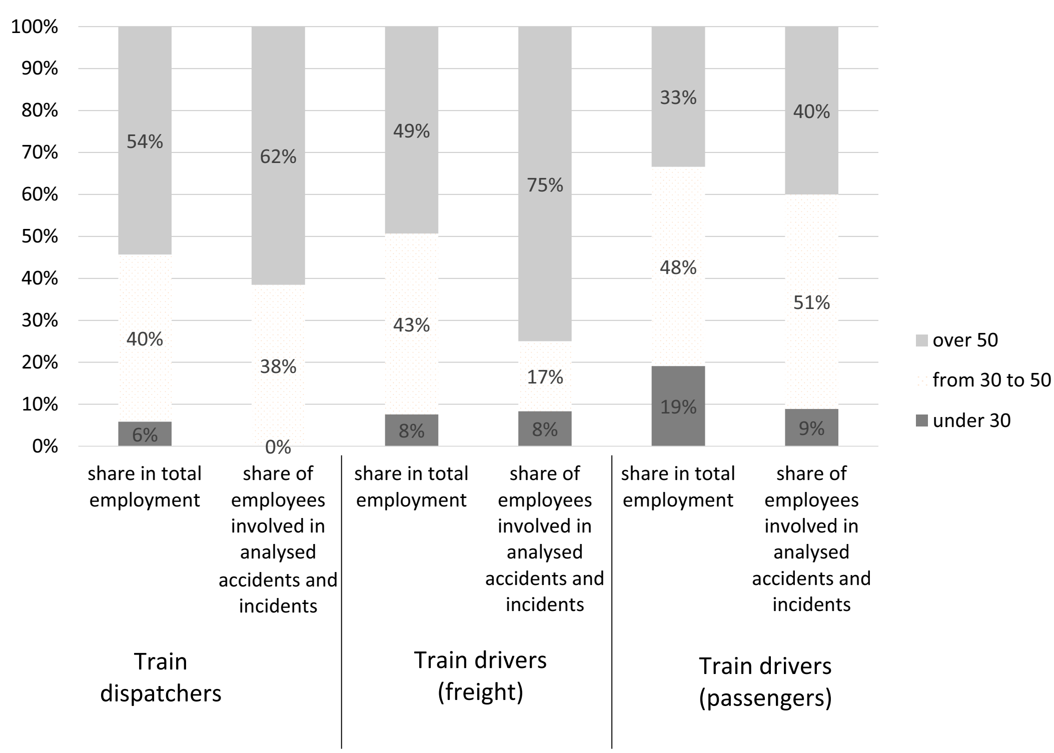

Figure 2: Age distribution of railway employees [17,19].

Table 1: Employees involved in accidents and incidents: age and experience structure [17]

Position	Number of employees	Average age (years)	Median age (years)	Average experience (years)	Median experience (years)	Pearson correlation coefficient between age and experience
Crossing keeper	25	51.41	56.50	20.09	24.00	0.46
Train dispatcher	29	51.27	53.50	18.25	14.00	0.62
Signalman	10	46.44	49.00	18.16	26.00	0.27
Foreman shunter	20	54.00	54.00	12.08	12.00	0.24
Train driver	77	46.67	47.00	13.32	8.90	0.71
Other positions directly related to the operation and safety of the railway traffic	9	46.33	49.00	18.16	26.00	0.51

age groups, and its percentage distribution is consistent with the distribution of employment by the age groups.

When analysing the correlation between an employee's age and experience, it should be emphasised that, as shown in Table 1, the correlation between these variables is in the range of 0.27–0.71. This means that, in the case of the analysed group of employees, a person's age should not be unequivocally identified with their experience in a given position. The highest correlation between worker's age and experience is found amongst train drivers and train dispatchers. Table 1 shows representative group of workers involved in the railway incidents and it highlights the fact that a significant number of all railway workers fall into above 50 years old age category.

A conclusion can be drawn that the most common outcome of the accidents and incidents analysed in this article is “an entry at a danger point”, both when viewed in the context of the rail transport system (SPAD: signal passed at danger) and at the interface of the transport systems, when incidents occur at level crossings. The literature [12,20–22] points out that available research on SPAD accidents and incidents, which consider incidents involving a train passing a planned stopping point, e.g. a commercial stop or a shunting or forbidding signal, as precursors to serious railway accidents with grievous consequences. However, when it comes to data relating to incidents and accidents in circumstances when a train passes through locations which are poorly prepared, or there is a high likelihood of unauthorised trespassing, it seems that there is no data available that would be collected directly from train drivers and there is lack of research which focuses on their interviews, feedback, and experience. Figure 3 confirms that this group of incidents represents a very high proportion, and that even a small deviation in local conditions related, for example, increased traffic within a level crossing or lack of an adequate response by a driver, could lead to a serious accident or even a tragedy. In the case of accidents and incidents at level crossings, the focus is put on investigating the mistakes of drivers of road vehicles who, through a lack of vigilance and violation of traffic regulations, enter the dangerous area of a level crossing when train is approaching, which in many cases causes a collision between the vehicles and as a consequence very often ends up with fatalities and/or significant material damage [23–26]. However, in the case of safety, geodetic and diagnostic measurements on level crossings are implemented. An important example would be devices that measure actual state of the geometry of visibility triangles or gauge measure for measuring track and turnout parameters, in addition, laser distance meters can also be used [27].

2.2 Implementing the HFACS model

The analysis of the human factor in railway accidents and incidents in this article was based on the HFACS model described earlier. Based on the verification of 148 final reports, human factor-related causes of accidents and incidents were identified and assigned to the relevant categories of the model in Table 2. It should be noted that the causes were considered for two groups of employees, infrastructure-related workers and the train drivers, but some of the causes are common to both the groups. The broadest group of factors is categorised as skill-based errors and organisational process; however, in this article, repetition of the occurrence of the individual factors in a given category is not shown, but their diversity is.

Further analysis focuses on the frequency of occurrence of each category of errors among the accidents and

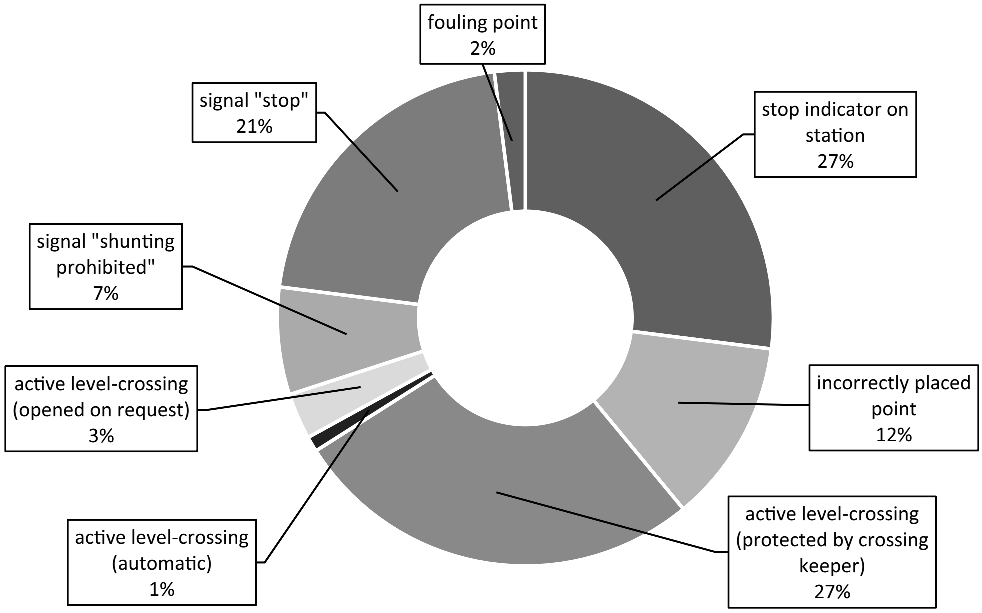

Figure 3: Share of dangerous points passed during the accidents and incidents [17].

incidents analysed. Skilled errors have the highest share, as they triggered the occurrence of approximately 50% of the analysed railway accidents and incidents. Decision errors and perceptual errors were also highly significant in the occurrence of events analysed in the Polish railway infrastructure. In the analysed reports, references to errors related to unsafe supervision was found least frequently, but the source documentation does not indicate that there was an extensive analysis of this area (Table 3).

3 Conclusion of the analysis

3.1 Quality of available data

As indicated earlier, the railway commissions prepare documentation following any occurrence of accidents and incidents by completing a template which is prescribed in the Regulation [16] adopted in Poland. However, preparing documentation by staff from different railway companies and with different levels of experience and knowledge in the field of railway systems or issues related to social sciences, significantly affects the depth and quality of the conclusions of these investigations. Informal language and simplifications are used repeatedly in the documentation, which makes it almost impossible to understand and interpret what really has happened by the person analysing the final report and not having actively participated in the proceedings. Furthermore, the analysis of the final reports revealed many cases of inconsistent cause-and-effect analysis, as well as the appearance of contradictory entries in some cases, which also has a negative impact on the ability of the collective analysis of documents to draw comprehensive conclusions.

The scheme adopted in Poland to identify causes of the railway incidents indicates their four stages: direct causes, root causes, indirect causes, and operational causes. Amongst 148 train accidents and incidents analysed, operational causes were indicated in only 7 cases, on the contrary, indirect causes were indicated in as many as 72 cases, which had an impact on accidents and incidents. In the author's opinion, such a result in the context of problems at the system level is misleading and indicates that the current approach to post-incident investigations is focused solely on identifying circumstances at the scene and causes that directly influenced the occurrence of the accidents and incidents. The investigations carried out do not comprehensively analyse the situation of the factors at an organisation-wide level (lack of a “bigger picture”), which is also confirmed when using the HFACS’s method. Factors of operational nature are inadequately disclosed in the documentation, which is also evidenced by the negligible or even lack of reference to issues related to the psycho-physical state with health and safety regulations, with a high proportion of responses being: no objection, not applicable, or retained. While individual railway undertakings or

Table 2: Human error identification using HFACS model [17]

Error category	Error type	Infrastructure-related staff	Train drivers
Unsafe acts	Errors: skill-based errors	– Distraction, momentary lapse in attention	
		– Failure to restore the facilities to their default condition – Failure to assess the conditions of the infrastructure before issuing the movement authority signal – A mistake in operating switch levers – Pressing the button to operate the equipment too lightly – Not checking the traffic situation when starting a shift, failure to inform the next shift employee in charge of any issues /lack of handover	– Starting to drive without having received the movement signal, failure to observe the route properly, inadequate knowledge of the timetable
	Errors: decision errors	– Simplifying tasks by deviating from the regulations (e.g. using radiotelephone instead of light traffic signals) – Opening the boom barriers after only one of the two expected railway vehicles has passed – Starting the closure of boom barriers too late	– Braking procedure implemented too late – Use of a braking technique not suited to the weather conditions – Simplifying tasks, failure to change the driver's cabin
	Errors: perceptual errors	– Weather conditions reducing visibility (glaring sunshine, heavy rainfall, fog)	
		– Incorrect assessment of the operations already carried out, incorrect assessment of the distance between a train and the danger point – Insufficient observation of monitor/relay panel	
	Violations: routine	– Failure to obey radiotelephone communication guidance and regulations – Arbitrary actions without supervisor's approval	
			– Exceeding the maximum permitted speed
	Violations: exceptional	– Use of a mobile phone instead of the radio communication equipment while on duty	– Running out of battery in a service device – Use of mobile phones for private conversations
Preconditions for unsafe acts	Condition of operators: adverse mental states	– Problems in private life	
		– Rush	– Train delay
	Condition of operators: adverse physiological states	– Bad health – Weakening – Drowsiness – Poor state of mind – Fatigue due to night duty – Monotony	
	Condition of operators: physical/mental limitation	–Reduced responsiveness after a break/reduced level in rail traffic – Long train limiting visibility	

(*Continued*)

Table 2: *Continued*

Error category	Error type	Infrastructure-related staff	Train drivers
	Personal factors: crew resource mismanagement	– Failure to discuss/inadequate workload – Poor communication – Unauthorised entry of a member of staff into the employee's room/driver's cabin	
	Personal factors: personal readiness		– Alcohol consumption
Unsafe supervision	Inadequate supervision	– Inadequate supervision of the railroad shunting team	– Inadequate supervision of train driver trainee during driving a railway vehicle
	Planned inappropriate operations		– Too short breaks between services – Incorrectly planning for a test run for a new set of vehicles
	Failed to correct problem		– Failure to establish guidelines to confirm an exact place in the driver's console to hold the documents and paperwork necessary for driving
	Supervisory violations		
Organisational influences	Resource management	– Failure to report deteriorating mental and/or physical state – Performing duties for which the employee is not qualified, e.g. the employee responsible for maintenance of the infrastructure being the shunting manager	
	Organisational climate	– Allowing behaviour that does not comply with the guidelines of internal regulations	
	Organisational process	– Wrong stipulations in internal regulations – Wrong station/stop scheme diagrams – Inconsistency of messages sent to a driver for example requirement to stop at a station but an allowance signal on an exit semaphore – Excessive workload for one employee, e.g. operation of level crossings, megaphone announcements, etc. during peak hours – Lack of suitable/incorrectly placed signs – Large number of semaphores in one place	– Lack of uniform rules regarding communication between the control centre and the driver during driving – Incorrect knowledge of the driving section – Different stopping places for passenger trains and fast trains of the same carrier

infrastructure managers involved have the opportunity to implement appropriate corrective and preventive actions related to an accident or incident by having the comprehensive knowledge of the incident or accident, in a systemic view of all railway undertakings the way in which documentation is drawn up and the inadequate treatment of superficially non-influential factors significantly hinders the continuous improvement of the whole railway transport system.

3.2 Recommendations for railway undertakings and infrastructure managers

One of the objectives of this article is to provide recommendations for railway undertakings and infrastructure managers on solutions that should be implemented to minimise the human-caused railway accidents and incidents. That would be:

Table 3: Frequency of human errors identified by HFACS model [17]

Error category	Error type	Number	Frequency (%)
Unsafe acts	Errors: skill-based errors	74	50
	Errors: decision errors	29	20
	Errors: perceptual errors	19	13
	Violations: routine	9	6
	Violations: exceptional	2	1
Preconditions for unsafe acts	Condition of operators: adverse mental states	4	3
	Condition of operators: adverse physiological states	8	5
	Condition of operators: physical/mental limitation	2	1
	Personal factors: crew resource management	23	16
	Personal factors: personal readiness	2	1
Unsafe supervision	Inadequate supervision	2	1
	Planned inappropriate operations	2	1
	Failed to correct problem	3	2
	Supervisory violations	3	2
Organisational influences	Resource management	4	3
	Organisational climate	3	2
	Organisational process	13	9

a) Improving data collection, the legal requirements in Poland for preparing railway accidents and incident reports are very vague and do not provide answers to key questions related to human behaviour. Despite the fact that references to the human factor exist in legislation, i.e. the psychophysical state of the worker, the environment and ergonomics, the observance of health and safety regulations, the answers provided by the railway committees indicate their downplaying or even contradictory with other provisions of the prepared documents. Only the wording of the provisions is systematised by law, but no additional explanation or interpretation is provided, to precisely indicate what statements should be included in the individual paragraphs of the report. For this reason, it is recommended that railway undertakings develop their own catalogues of questions for railway committees, which would take into account the specifics of their operations, including specification of jobs and postings which are linked to the highest frequency of incidents. Such catalogues could be used across a number of companies to improve the reporting process and quality of data and to share good practice in the railway market.

b) Strengthening the emphasis on improving soft skills related to better communication between employees, using tools provided for this. A significant factor that has an influence on occurring accidents and incidents is bad communication between employees in relation to employees of the same company and employees working for different ones. Miscommunication and misinterpretation are sources of further errors committed during the transport process.

c) Building staff awareness in respect to the impact and their responsibility for the safety of the rail transport system. In railway organisations, it is perceived that employees do not have a required attitude towards compliance with internal regulations. However, there may be an issue of a wider concept of the workplace culture to be considered.

d) Bespoke training and staff development: training for staff who recently joined the company should be of a slightly different nature than for staff in a posting for a number of years, as it is proved that they face errors due to different reasons. In the case of the more experienced workers, these are mainly errors related to monotony of work, routine operation, developed bad working habits, and simplification of certain activities. Employees with a shorter period in service tend to make mistakes mainly due to lack of awareness of correct procedures, not being able to anticipate any potential problems in advance when on duty, which is linked to a lack of relevant experience, as well as the adoption of inappropriate working habits.

4 Conclusion

This article addresses the area of rail incidents that is currently overlooked in scientific publications. Railway accidents and incidents related to an improperly protected route with increasing allowed speeds of passenger and freight trains increase risks and can lead to incidents with significant consequences in the future. Therefore, causes of these incidents should be adequately investigated, bearing in mind in particular that, as in the case of SPAD incidents, the dominant cause of these accidents is human factor. A step-by-step analysis and understanding of human error will allow the introduction of appropriate, systemic, corrective, and preventive measures that will positively affect the safety level of rail transport. In the context of railway accidents and incidents, future research should bear in mind a "risk of homeostasis," both in terms of human error by railway workers and also other traffic participants. In addition, attention should be paid to the "behavioural adaptation" in the context of routine, work fatigue, as well as adaptation to traffic conditions, which, when minimally changed, can lead to serious consequences.

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Data availability statement: The data that support the findings of this study (final protocols of accidents and incidents) are available from National Investigation Body of Poland (Państwowa Komisja Badania Wypadków Kolejowych) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of National Investigation Body of Poland (Państwowa Komisja Badania Wypadków Kolejowych). The datasets analysed during the current study are available in the National Safety Authority of Poland (Urząd Transportu Kolejowego) repository.

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