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## Operational Elements Influencing the Occurrence of Unfavorable Incidents in the Railway System.



**Abstract:** - The article delves into the intricacies of rail transport, addressing the repercussions of adverse events such as delays, incidents, and accidents within the railway system. It explores the impact of disruptions on the day-to-day responsibilities of railway employees, with a primary focus on Station managers. The study employs two distinct approaches: first, an experimental analysis involving traffic management personnel, where factors contributing to failures are examined through a questionnaire survey. Second, a comprehensive perspective is taken by leveraging expert knowledge, combined with Fault Tree Analysis and Event Tree Analysis methodologies. This combination is used to illustrate how alterations in the system, including erroneous decisions, can lead to subsequent undesirable events.

**Keywords:** Undesirable railway events, Rail traffic operations, human factor

### I. INTRODUCTION

The rail transport system possesses various characteristics, with the timetable playing a central role by encompassing network and rolling stock boundaries to cater to both passenger and freight demands. In socio-technical systems, boundaries are viewed as inter-dependencies, representing relationships between components or systems in terms of their states [1]. However, operational models often overlook functional dependencies, focusing on essential qualities such as arc capacities in the railway system [1]. Predominantly, undesirable events in railways, leading to disruptions and subsequent delays, constitute around 98%, but they are generally categorized as safe, warranting no further investigation [2].

Despite this, akin to a chain reaction with domino bricks, seemingly minor events can contribute to accidents. The recovery from operational inaccuracies, often neglected in resilience research, emerges as a pivotal factor in accident prevention.

Train operation disruptions can be classified into two areas, with the first directly tied to human factors [3]. Traffic interference can result in numerous small failures, potentially culminating in accidents. Speeding and maintenance errors, attributed to human error, may stem from train delays, where exceeding speed limits might be intentional to make up for lost time. Incorrect decisions at signal boxes can also lead to delays. Traffic disruptions also impact staff decision-making under stress and time constraints.

Delays or disruptions invariably deviate from the planned schedule, leading to changes in the train's movement, staff, or track. Such deviations disrupt the designed operation schedule, removing a barrier that aids in preventing accidents [2]. Process schedule changes may indirectly contribute to signals being passed at dangerous events. Railway signaling staff faces challenges in managing disrupted traffic, as standard procedures may not apply.

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It is evident that reconfiguration, atypical situations, and human factors play a role in undesirable events. Therefore, this paper aims to identify operational and human-oriented factors influencing the occurrence of undesirable events, with a specific focus on the critical safety area of traffic management in railway operations and the associated employees.

## II. LITERATURE REVIEW

The safety of railway traffic relies on the collaboration of train staff with signaling, safety, and communication equipment, following local regulations, international standards, and technical documentation. The railway system is inherently anthropotechnical, encompassing both human and technological elements. Within this system, adverse events may occur. Leitner, in [3], identifies root causes of hazardous events as technological factors, external factors, or human factors. Wencheng et al. further elaborate on this classification, identifying five factors: human, machine, materials, environment, and management. Loza-Hernandez et al. [4] also emphasize the impact of the human factor.

Crawford [5] categorizes factors into human error, design errors, control room errors, and maintenance errors. Khalid et al. [6] suggest a division based on error, inexperience, or fatigue. Rungskunroch et al. [7] present a more comprehensive classification with seven groups, including driver error, signal operator error, infrastructure failure, equipment failure, human error, natural causes, and contributory factors. Szacillo et al. [8] propose nine factors, encompassing risk assessment at level crossings [9, 10], causes of railway accidents [11], [12], [13], and the reliability of railway infrastructure [14, 15, 16, 17].

The human factor is a consistent element in all categorizations, implying that railroad personnel can potentially have a negative impact on railroad safety due to human errors leading to accidents or incidents. Humans are subject to various influencing factors within their environment, affecting their actions, decisions, and behaviors. Numerous studies, including [18, 19], identify causes of hazardous events related to the human factor, such as the physical and mental state of individuals, as well as their abilities and skills. Leitner in [3] provides a detailed breakdown of causes of dangerous situations attributed to the human factor, including information recognition errors, circumstantial judgment errors, decision-making errors, performance errors, miscommunication, procedure/regulation violations, alcohol consumption, disease, congestion, and visible/audible handicaps.

Huang et al. in [20] and [21] highlight risk factors and sub-risk indicators caused by humans, such as the illegal stealing of dangerous goods by non-railway personnel, improper loading or overloading of goods by manufacturer staff, lack of technical knowledge during transportation processes, inaccurate work attitudes and operations, and poor working environments for staff. Rungskunroch et al. in [7] list sub-causes of accidents related to signalmen's errors, including signal equipment failure, loss of communication device, track geometry, and human errors such as cab signals, employee physical condition, flagging, fixed, hand and radio signals, general switching rules, loading procedures, main track authority failure to stop the train in clear, miscellaneous issues, speed, switches, and train handling or makeup.

While previous works have predominantly focused on the role of drivers [22, 23, 24], it is crucial to recognize the responsibility of other employees involved in running trains, such as traffic wardens, signalmen, and switchmen. Currently, there is a gap in research addressing the role of railroad infrastructure manager's employees in ensuring railroad traffic safety and analyzing the influence of factors on the quality of work of individuals in positions related to the safe operation of railroad traffic.

Considering the insights from the literature, the paper aims to identify operational factors and human qualities influencing the frequency and severity of undesirable events. The research will be conducted in two steps: a detailed experiment involving employees in traffic management (Section III) and a comprehensive analysis using expert knowledge, Fault Tree Analysis, and Event Tree Analysis to understand the impact of system changes and wrong decisions on further undesirable events (Section IV).

## III. EXPERIMENTS WITH STATION MANAGERS

### A. Description of the survey

A total of 335 active railway personnel employed across various roles and entities participated in the survey, with 146 individuals holding positions directly responsible for railway traffic safety, including Station managers, signalmen, and switchmen.

The survey comprised several sections. The initial part involved gathering fundamental information about respondents, such as age, gender, job position, tenure in the railway industry, and daily working hours. The second segment focused on job responsibilities, exploring primary duties related to traffic management and additional roles. Respondents were also queried about challenges encountered at work, with no prompts provided, and their responses were subsequently categorized.

The third section inquired about the number of accidents and incidents in which respondents had been involved during their service, irrespective of whether they were the cause. The survey aimed to discern how the accident and incident rates varied based on the length of service and the perception of job responsibilities among employees tasked with ensuring railway safety.

Responses to open-ended questions were systematically classified to analyze the impact of job perception on accident rates. Main and supplementary responsibilities were categorized into distinct groups, including running trains, supervising traffic safety, informing passengers, ensuring cleanliness, inspecting and maintaining railway tracks, performing formal duties, operating level crossings, engaging in teamwork, and providing training.

For the question on the primary activity, responses were grouped into three classes: organizational activities unrelated to the position, equipment verification, and assuming duty while familiarizing oneself with the traffic situation. Challenges at work were classified into stressors, excessive stimuli and responsibilities, understanding and applying rules, traffic disruptions, external factors, and others. Regarding job satisfaction, responses were grouped into categories such as correctly completing timetable tasks, interacting with people, gaining recognition, finding satisfaction, addressing material and financial aspects, feeling challenged, being of service, experiencing calmness, and treating work as a passion.

Success at work was perceived in terms of security, satisfaction, fulfillment, peace of mind, conscientiousness, responsibility, recognition, respect from others, and opportunities for promotion. Respondents identified activities during non-task times as having no downtime, engaging in further training, performing non-basic work activities, and pursuing non-professional goals. Challenges at work were classified into six groups: stress and time pressure, track closures, ensuring safety and task completion as planned, maintaining composure and focus, remembering all tasks, and other challenges.

### ***B. Compilation of the Results***

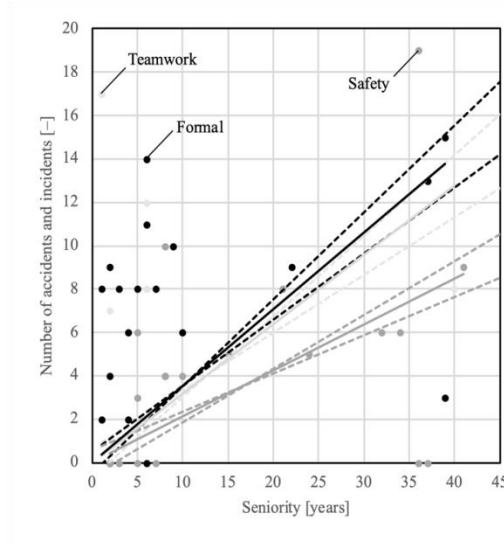
The analysis focused on the number of responses within each category provided by respondents. Only groups with a sufficiently large number of responses were considered statistically viable. The employee's length of service was plotted on the abscissa axis, while the sum of accidents and incidents in which the respondent participated was plotted on the ordinate axis.

Respondents were categorized based on their perception of main responsibilities (in three categories: teamwork, formal issues, safety), additional responsibilities (in three categories: cleanliness of the workspace, skill improvement, formal issues), and the most significant difficulties on duty (in three categories: stress, cooperation issues, traffic disruptions).

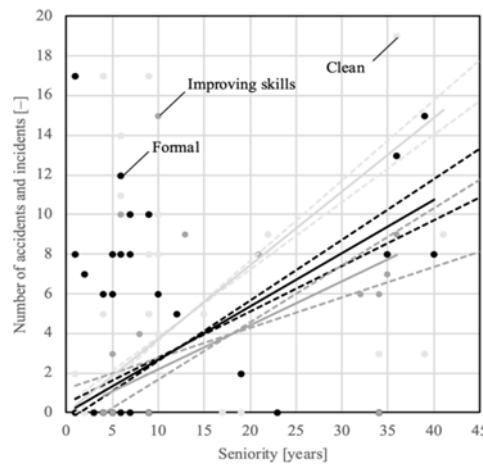
Subsequently, a parametric test for two mean values was employed to assess the mean number of accidents and incidents per year. The results, with a significance level of 0.05, indicated that the mean values across all pairs of categories for the given quality were not equal, signifying that the identified categories influence failure intensity. Additionally, a parametric test for the correlation rate was conducted, confirming applicability for regression at a significance level of 0.05.

Linear regression functions ( $F(x) = A(x) + B$ ) were estimated for the obtained samples, considering the nature of the data where incidents and accidents were zero at the start of the worker's career. The regression confidence curves were determined at a confidence level of 0.95. The results were summarized in graphs, comparing simple linear regressions.

Main responsibilities considered were teamwork (1), formal work (2), and supervision of train traffic safety (3). The directional coefficients of the linear regression line were obtained as follows:  $A_1=0.3188$ ,  $A_2=0.3533$  and  $A_3=0.2118$  (Figure. 1). These results indicate that individuals who primarily listed formal work (related to record-keeping) as their main duties were more frequently involved in railway accidents and incidents. In contrast, respondents who identified ensuring railway traffic safety as their primary duty were, on average, almost twice less frequently involved in accidents and incidents than those emphasizing the importance of documentation. Moreover, those who highlighted the need for cooperation with other employees experienced adverse incidents 10% less frequently than their counterparts who were more documentation-oriented.



**Figure 1. Result analysis of respondents' answers to the question about their primary job responsibilities**



**Figure 2. Result analysis of respondents' answers to the question about their secondary job responsibilities**

An examination was conducted to analyze responses to the question regarding additional responsibilities, allowing for a comparison of three distinct duties:

1. Maintaining workplace and environmental cleanliness (including tasks like cleaning rail grooves, workplace maintenance, and tending to greenery near stations and signal boxes)
2. Performing formal record-keeping tasks
3. Undergoing training to enhance skills.

The directional coefficients of simple linear regression for the periodic performance of these duties as referred in Figure 2, were determined as follows:

$$A_1=0.3722$$

$$A_2=0.2691$$

$$A_3=0.2212$$

It was observed that employees listing cleaning among their additional responsibilities experienced the highest frequency of adverse events, while those prioritizing skills improvement and training reported the fewest incidents throughout their careers.

Furthermore, an analysis of responses addressing the primary challenges encountered by railway safety staff was conducted. Responses were grouped into four categories: 1. Stress

2. Disruptions in traffic leading to increased duties and environmental stimuli

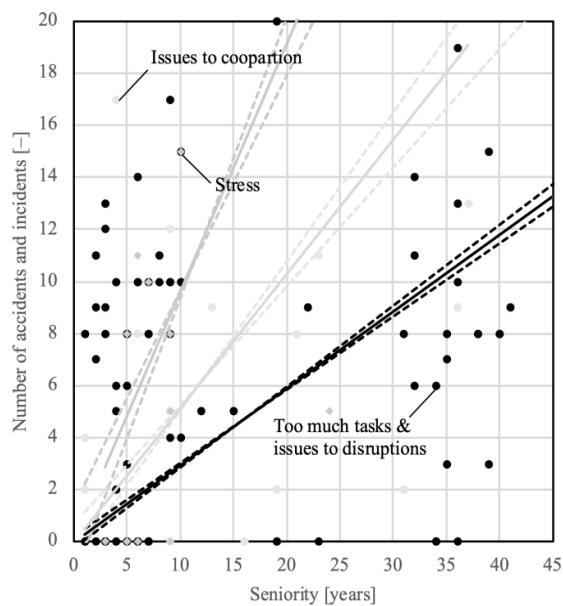
3. Collaboration issues (highlighting superiors' inappropriate attitudes and communication difficulties with employees from neighboring signal boxes).

The directional coefficients of simple linear regression for these factors as referred in Figure 3. were determined as follows:

$$A_1=0.9537$$

$$A_2=0.2956$$

$$A_3=0.5152$$



**Figure 3. Result analysis of respondents' answers to the question about biggest difficulties on the job.**

The employees most frequently associated with a higher number of adverse events are those who identified stress as the primary challenge in their workplace, according to the survey. The second most prevalent group comprises employees facing difficulties in collaborating with their railway colleagues. Interestingly, individuals citing an excessive workload as a challenge are involved in railway accidents and incidents at a rate 3.5 times lower than those reporting high stress levels. This represents the lowest incidence rate among the obtained results.

#### IV. IDENTIFICATION OF THE REMEDIAL MEASURES INFLUENCING UNDESIRABLE EVENT OCCURANCE

The primary strategies employed in system management to restore the effective functioning of the system involve the options of rerouting, rescheduling, and adjusting timings, provided that sufficient capacities are available.

Conversely, if capacities are insufficient, the decisions may involve the cancellation of trains or connections. Each decision carries subsequent implications and outcomes.

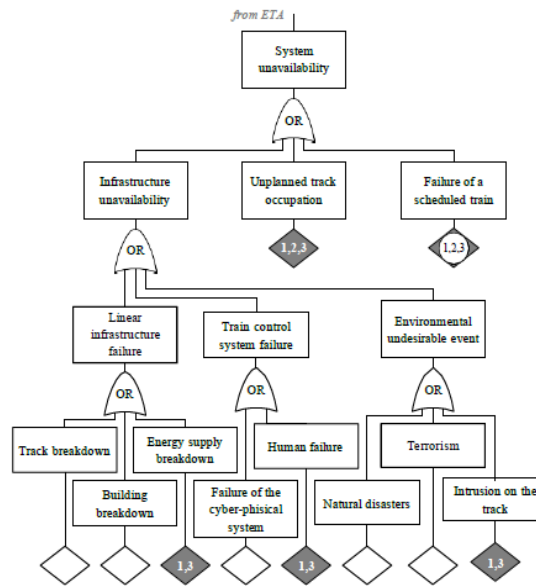


Figure 4. Fault tree analysis of failure spreading up to system unavailability

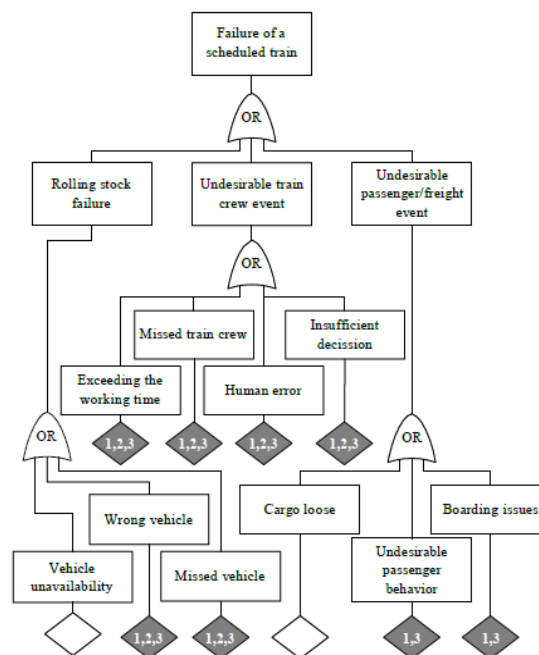


Figure 5. Fault tree analysis of failure spreading up to system unavailability

Hence, a comprehensive analysis employing fault tree and event tree methodologies was conducted to identify the sequences and patterns of failures. The key outcomes of the fault tree analysis are depicted in Figure 4 and Figure 5, the latter illustrating a branch specifically related to train failures.

The analysis initiates with Non-extended events, visually represented in grey and labeled with corresponding numbers. The numerical sequence, when read from bottom to top, is irrelevant in the initial reading but gains significance in subsequent examinations. During the second reading, these numbers denote specific situations identified in the event tree analysis, presented in Figure 6, thereby influencing the occurrence of initial events in the fault tree analysis.

At the apex of the fault tree is the top event, symbolizing system unavailability attributed to system damages or traffic-related challenges. In essence, this encompasses any undesirable event limiting the system's capacity. In instances of traffic difficulties, the primary delay aligns with the time required to repair the system (TTR).

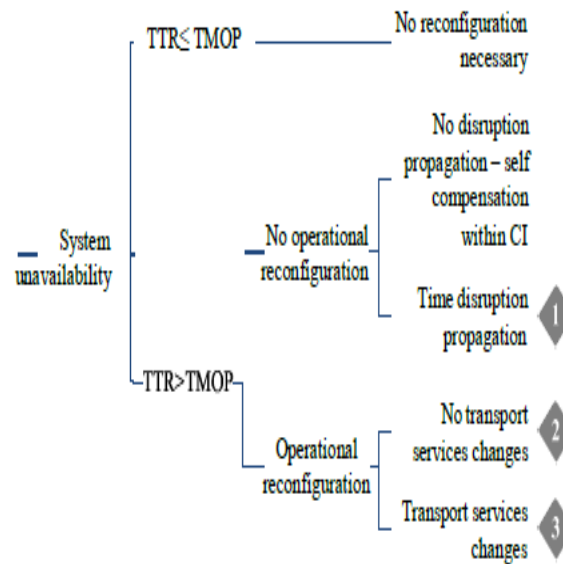
On the flip side, operational reconfiguration has the potential to mitigate the impact of traffic disruptions. In such instances, passengers and freight customers may remain unaffected by the unforeseen events.

However, this comes at the cost of disrupting system operations due to the reconfiguration of vehicle or staff circulations and alterations in track usage.

Operational reconfiguration coupled with traffic disruptions entails deviations from the schedule concerning both customers and overall system functioning.

The execution of reconfiguration measures can introduce additional undesirable events, such as constraints on train staff working hours, limitations on vehicle mileage between maintenance intervals, incorrect assignment of vehicles or train staffs, and the absence of a daily routine. It is presupposed that operational processes are intricately linked to railway lines.

Consequently, reconfiguration involves changes in process orders, the modification or cancellation of interconnections, adjustments to train staffs or vehicles etc.



**Figure 6. Event tree analysis of situation development after system unavailability**

V. CONCLUSION

A well-functioning system is defined by its ability to meet operational requirements, encapsulated in key functionality qualities:

**1. Quantitative Implementation of Scheduled Processes:**

This involves executing the predetermined number of processes within the established schedule.

**2. Qualitative Implementation:**

- Punctuality: Ensuring processes are implemented according to the schedule.
- Staff Assignment: Aligning train staffs with processes in accordance with the schedule.
- Vehicle Assignment: Assigning vehicles to processes in accordance with the schedule.
- Track Assignment: Aligning tracks with processes as per the schedule.

These factors contribute to employee stability and the creation of a predictable environment. However, the introduction of reconfiguration disrupts these advantages.

The impact of reconfiguration on subsequent failures varies based on employees' personal characteristics, particularly in the context of Station managers. Therefore, three specific qualities have been scrutinized concerning Station managers.

It has been substantiated that the intensity of failures is influenced by the perception of main responsibilities, with those emphasizing formalities and checklist points exhibiting the highest failure intensity. Consequently, reconfiguration emerges as a primary challenge for this group, leading to increased failures. Conversely, employees prioritizing safety have the lowest failure intensity. Additionally, an analysis of the correlation between the perceptions of additional responsibilities undertaken by Station managers reveals that those focusing on workspace cleanliness display the highest failure intensity, while those emphasizing skill improvement exhibit the lowest failure intensity. Lastly, an examination of the perception of main difficulties indicates that individuals identifying stress as a weakness exhibit the highest failure intensity. Consequently, There will be increased number of failures.

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