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## NAVIGATING THE TEMPEST – A DECISIONAL PROCESS FOR STORM DAMAGE MANAGEMENT IN RAILWAY INFRASTRUCTURE

Vladimir VOICU, Anca DRAGHICI

**Abstract:** *This article examines the impact of severe weather on railway infrastructure and operational continuity, with a focus on the response to storm Zoltan in Germany in December 2023. The paper analyzes the direct and indirect effects of such events on rail services and emphasizes the importance of a swift and structured response from infrastructure managers to minimize customer impact, using Lost Units to gauge the impact. It also scrutinizes the decision-making process for addressing storm damage, highlighting the need for prioritized, strategic action. The proposed comprehensive approach demonstrates how strategic planning and prioritization can enhance the resilience of railway operations against extreme weather events.*

**Key words:** *decisional process, decision support system, storm damage, railway infrastructure, weather impact, rail operations*

### 1. INTRODUCTION

Although railway operations are generally less susceptible to weather-related disruptions compared to other modes of transportation, the advent of storms poses a significant challenge to the maintenance and resumption of rail services. This is largely due to the unique vulnerabilities of railway infrastructure to storm-related damage, such as fallen trees on tracks, damaged overhead lines, and flooded railway beds. Consequently, addressing these challenges requires a robust and adaptive approach to ensure the continuity and reliability of rail services during and after storm events.

This article aims to provide a comprehensive analysis of the impact of storms on railway infrastructure, with a particular focus on the challenges and strategies employed during the Storm Pia or Storm Zoltan event in Germany in December 2023. It seeks to explore both the direct and indirect consequences of such extreme weather events on railway operations and the efficacy of the mitigation and recovery

approaches implemented in response to these challenges.

An additional objective of this paper is to emphasize the significance of a prompt and organized response from the infrastructure management company during storm events, particularly in relation to achieving strategic objectives. This includes, for example, minimizing the impact on customers, as measured by metrics such as Lost Units. The article also focuses on illuminating the decision-making process regarding the sequence for addressing reported storm damage.

### 2. LITERATURE REVIEW

The topic of storm damage and in some cases also its consequences on railway infrastructure has been addressed in several articles in specialized literature. The prevailing consensus within the published papers is that climate change decisively contributes to an increase in the frequency and intensity of meteorological phenomena, including storms [1–3]. Storms usually result in significant socio-economic

impacts on the local community [4]. The impact of Storm Lothar in 1999 for instance resulted in a human toll of one hundred lives and incurred economic losses totaling 11.5 billion euros, of which 5.9 billion were insured [5].

The literature review has also resulted in relevant articles delving into the impact of storms on infrastructure. A 2014 article focuses on the impacts of storms in June 2012 on road and rail transports in the United Kingdom. It underscores the potential consequences, such as track closures or speed restrictions, which may extend to affect train traffic in other segments of the railway network [6].

In addition, the recent article [7] concluded that about 5% of all rail incidents registered in the Czech Republic between 2002 and 2021 were storm-related and 79% of the storm-related failures were registered in the summer.

Another significant finding of the study is the identification of storm-damaged vegetation, such as trees falling onto railway lines, as the primary cause of rail service cancellations [7]. Various papers have examined the assessment of the probability of tree falls in specific sections of the railway network, presenting different approaches to address this issue [8, 9].

Naturally, the pertinent literature has partially addressed the question of potential countermeasures for weather-related risks. The identified possible measures are tailored to the specific risk: for high temperatures, providing ventilation systems for railway indoor facilities or signals proves effective, while for snow, the deployment of snow deflecting covers on bogies on railway rolling stock has been deemed appropriate [10]. The same study identifies a generally valid option: implementing contingency planning as a proactive countermeasure for all weather-related hazards – therefore a viable solution for storm damage management as well.

### **3. STORM ZOLTAN – DAMAGES AND EFFECTS ON TRAIN SERVICES**

#### **3.1. Research methodology**

The authors initially conducted an analysis of the damages and consequences resulting from

the storm “Zoltan” in a specific section of the German railway network. The chosen region was in central Germany (Kassel district), as numerous major routes from North to South and East to West traverse this area. Data collection utilized newspaper reports, minutes from emergency conferences, and a database from the German infrastructure company.

Building upon decisions made by the on-call management during these emergency conferences, a theoretical decision-making process applicable to similar situations in all other network segments was formulated and visually depicted.

#### **3.2. Results**

Storm Zoltan, also known as Pia in northern Europe, emerged as a meteorological phenomenon with widespread impacts across Scandinavia, the UK, Netherlands, Austria, Germany, and Belgium from the 20th to the 22nd of December 2023. The storm exhibited significant intensity, evidenced by a maximum registered speed of 185 km/h, recorded in Cairn Gorm, Scotland [11]. The geographical scope of Zoltan/Pia encompassed a diverse range of countries, subjecting them to adverse weather conditions, extensively affecting pre-Christmas travel.

Several impactful incidents also affected the German railway network in the analyzed segment of the Kassel district. Over a time span of approximately 17 hours, 15 disruptions occurred on multiple routes within the Kassel network. Most of these disruptions were remotely identified through short-circuit notifications from the Central Activation Point (ZES) in Borken. In most instances, this signifies a lack of electric current flow through the overhead lines at specific locations, often due to the presence of an obstacle such as a fallen tree or its branches.

Other disruptions were reported through notifications from the emergency control center following hazardous events (such as a train colliding with a fallen tree) or through observations from pedestrians or passengers. In all scenarios, the technical availability constraint

resulted in an operational availability limitation in the form of closure of the affected track.

An emergency response team consisting of several managers of the infrastructure company DB Netz AG in the Kassel network created at the onset of the storm prioritized the constraints and deployed the personnel previously placed according to the given priority, thus managing to mitigate the consequences of the constraints. All impacted railway lines were returned to full operational status within 36 hours following the conclusion of the storm.

The process defined by the authors is illustrated in Figure 1. The design and depiction of the decision-making process primarily incorporates experiences from managing the aftermath of Storm Zoltan, as well as insights from previous storms in 2022 and 2023 recorded in Germany to ensure representativeness and deepen the understanding of the process.

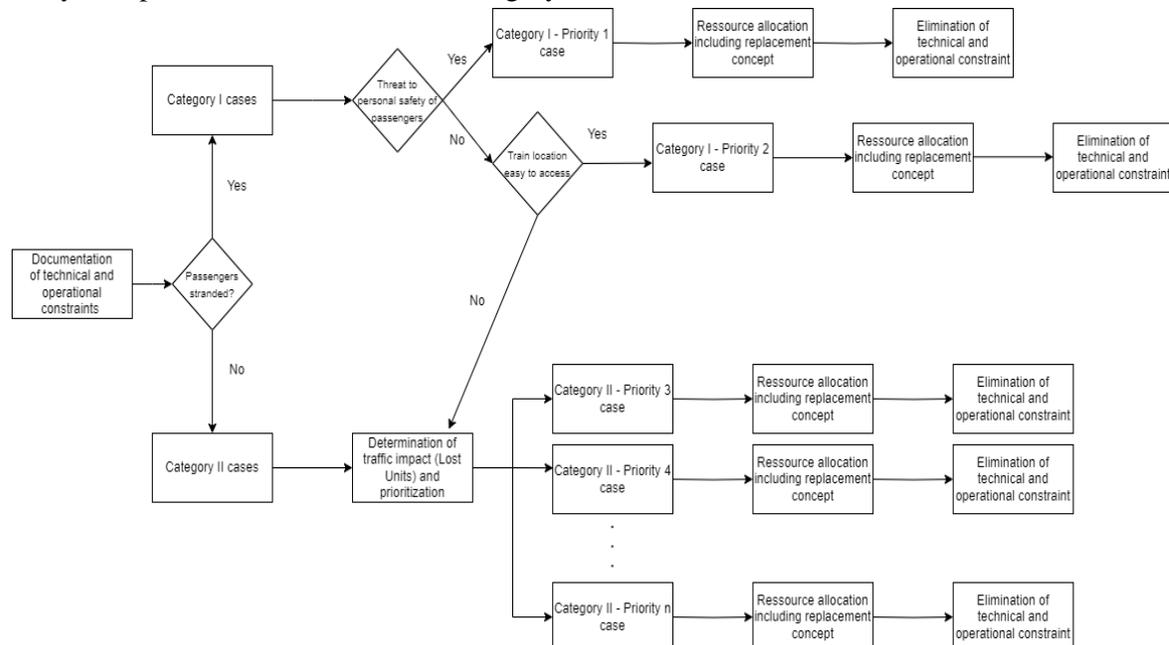
The initial phase of the process shown in figure 1 involves systematic documentation of all known technical and operational constraints. The subsequent crucial step involves categorizing the identified technical and operational constraints into two distinct groups: one category for incidents where passengers are stranded on a captive train and another category for situations where individuals were not directly impacted. This second category

includes, for example, instances where freight trains are unable to continue their journey due to fallen trees on the tracks (as no passengers are on board), as well as situations where passengers are in safety in a train station (therefore not stranded), but can not begin or continue their journeys because trains can not depart or arrive due to the railway tracks being obstructed as a result of storm damage.

In addressing the constraints, incidents within the first category are automatically assigned the highest priority. In the examined case study of the storm Zoltan, among the 15 incidents reported, there was only one incident that fell into Category I, thereby eliminating the need for further prioritization within this category.

If prioritization becomes necessary, the decision-making process will hinge on two key criteria. The primary consideration is the potential danger to passengers' safety.

Critical factors include the likelihood of a fire erupting due to a damaged overhead power line, the risk of passengers being subjected to extreme cold due to a train's power failure, lack of food or water on the stranded train or the presence of passengers with severe health conditions requiring immediate attention. Cases presenting any such dangers would be automatically escalated to priority one status.



**Fig. 1.** Decisional process during storm damage management (authors own development).

In the absence of immediate personal safety threats, the focus shifts to the second criterion: the accessibility of the train's location. If the stranded train is in a readily accessible area, it is assigned priority two, under the presumption that a swift rescue operation can be conducted. However, should the location prove to be difficult to access, then all the remaining cases are assessed using the principles applied to category II incidents and prioritized in an ascending sequence, beginning with priority 3 and continuing in numerical order as necessary. Throughout this process, it is a fundamental directive that any case involving passenger presence (but not having first or second priority – see figure 1) must be treated with higher urgency than those that do not involve individuals, ensuring human safety remains at the forefront of the prioritization protocol. It's crucial to acknowledge that any postponement in addressing incidents ranked with priority 3 or lower involving passengers, may necessitate an elevation in priority should circumstances deteriorate (for instance, if the train's water supply depletes or passengers begin to exhibit medical issues). This underscores the necessity for ongoing surveillance of all incidents to ensure timely intervention. Should the affected railway network's existing workforce be insufficient to promptly resolve the technical and operational issues, it becomes imperative to secure additional staff resources to facilitate the resumption of service for trains left stranded.

For incidents in Category II, the prioritization logic applied is based on the consequences of the operational constraints (such as track or line closures) they caused. The assessment of the consequences is conducted using the Lost Units logic, where a Lost Unit „is generated whenever the travel time between two operational points is at least 90 seconds longer than the scheduled time according to the timetable” [12]. The prioritization within this second category is based on a forecast of Lost Units, starting from the specific constraint (track closure or route closure), as well as from the still feasible mode of operation (for example, the length of single-track operation), and utilizing a database

containing a minimum expected number of trains per track per hour. The incident anticipated to result in the greatest number of Lost Units per hour is allocated the subsequent highest level of priority. This method is consistently applied in descending order of impact, assigning priorities down the line until all known constraints have been systematically prioritized.

In the analyzed case study, the two fully staffed units at hand were mobilized to address the incidents deemed most critical based on the outlined prioritization method – one category I case and the next category II case having the highest expected Lost Units potential. The ensuing phase in the process involved guaranteeing the rotation of these units upon the expiration of their duty period with either other staff members or additional units from adjacent networks (replacement concept). In the event of a shortfall in personnel resources, further prioritization at national level becomes imperative, calling upon units from regions unaffected by the storm to assist in the affected area.

The process for managing storm events is supported by a structured series of meetings. Therefore, in addition to the network's operational team, both regional and national operational teams have been established, which meet at fixed intervals depending on the intensity of the storm (e.g., every 2 or 4 hours) in a cascading sequence — starting with the local team, followed by the regional, and finally the national team. This structure ensures a steady flow of information towards the executive board and timely initiates escalations (such as regarding the mobilization of personnel resources from other networks).

In the study of Storm Zoltan, additional assistance was sought and obtained from the Hamm and Erfurt networks as per the established sequence of meetings. This support, in terms of personnel and machinery, was essential for substituting the Kassel network's workforce upon the completion of their allocated working hours and ensuring the quick alleviation of the remaining constraints.

Another significant aspect is communication during the storm. With passengers stranded at stations or on trains, the operational staff deployed for the various incidents prioritized according to the system we presented must make predictions about storm damage removal and the restoration of infrastructure availability for each incident separately.

These predictions should be communicated through the meeting cascade, enabling direct communication with customers and through the media. The predictions must be updated and if the need arises also corrected – this is the case when reprioritization ensues because of new constraints being discovered.

#### 4. CONCLUSIONS

The comprehensive analysis of the response to Storm Zoltan underscores the critical need for robust and adaptable management strategies in the face of severe weather events impacting railway operations. The swift restoration of full service across all affected tracks within 36 hours post-storm is a testament to the efficacy of the structured response and prioritization protocol developed and implemented by the infrastructure management teams.

This case study not only highlights the vulnerabilities of railway systems to extreme weather conditions but also shows the potential for minimizing disruption and enhancing service resilience through strategic planning and efficient resource allocation. The integration of insights from previous storm events, coupled with real-time decision-making and prioritization based on safety and operational impact, forms the cornerstone of the efficient response process formulated by the authors and shown in Figure 1.

Such strategies not only ensure the continuity of rail services during adverse conditions but also significantly reduce the potential impact on passengers, thereby maintaining public trust and service reliability. The employed procedure allows for a continuous update of the priority ranking of the technical constraints appearing during a storm event and funds a decision support system for similar emergency cases.

Furthermore, the collaborative approach adopted, involving additional support from neighboring networks, exemplifies the importance of inter-network cooperation in crisis management. The establishment of regional and national operational teams, meeting at regular intervals to assess the evolving situation and coordinate response efforts, ensures a cohesive and unified approach to infrastructure recovery.

This model of crisis management, underlined by a clear prioritization of incidents based on safety and operational impact, serves as a valuable blueprint for railway operators worldwide. It highlights the necessity of contingency planning (such as having enough personnel on-call and functioning machines available) and the benefits of a scalable and flexible response mechanism capable of addressing the multifaceted challenges posed by severe weather events on railway infrastructure and operations.

Training and collaborative work of the stakeholders could improve the system resilience [13, 14]. These measures should be considered in the long term strategy for health and safety.

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### **Navigând prin furtună – un proces decizional pentru gestionarea daunelor de furtună în infrastructura feroviară**

Acest articol examinează impactul condițiilor meteorologice severe asupra infrastructurii feroviare și a continuității operaționale, concentrându-se pe răspunsul la furtuna Zoltan în Germania din decembrie 2023. Lucrarea analizează efectele directe și indirecte ale unor astfel de evenimente asupra serviciilor feroviare și subliniază importanța unui răspuns rapid și structurat din partea managerilor de infrastructură pentru a minimiza impactul asupra clienților, folosind Unitățile Pierdute pentru a măsura impactul. De asemenea, se examinează procesul de luare a deciziilor pentru abordarea pagubelor provocate de furtuni, evidențiind necesitatea unei acțiuni strategice și prioritizate. Strategia de răspuns este ilustrată printr-un proces definit de documentare a constrângerilor, categorisirea incidentelor și prioritizarea pe baza siguranței și impactului operațional. Incidentele de Categoria I sunt acordate cea mai mare prioritate, cu o analiză de la caz la caz pentru Categoria II bazată pe accesibilitate și Unitățile Pierdute prevăzute. Studiul arată modul în care resursele au fost alocate incidentelor critice și subliniază importanța rotației personalului și a sprijinului la nivel național în situații în care resursele districtului afectat de furtuna sunt limitate. Această abordare cuprinzătoare demonstrează cum planificarea strategică și prioritizarea pot îmbunătăți reziliența operațiunilor feroviare în fața evenimentelor meteorologice extreme.

**Vladimir VOICU**, PhD Eng., DB InfraGo AG, [vladimir.voicu@deutschebahn.com](mailto:vladimir.voicu@deutschebahn.com), Adam-Riese-Str. 11-13, 60327 Frankfurt am Main, Germany

**Anca DRAGHICI**, Professor, Politehnica University of Timisoara, Faculty of Management in Production and Transportation, [anca.draghici@upt.ro](mailto:anca.draghici@upt.ro), 14 Remus str., Timisoara, Romania