ReMuNet
Pioneering resilient and adaptive multimodal transport networks

D1.4

Root-cause analysis of transport network disruptions

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ABBREVIATIONS

FGD	Focus group discussions
RCA	Root-cause analysis
AI	Artificial Intelligence
ACP	Panama Canal Authority

Executive Summary

The Horizon Europe project Resilient Multimodal Transport Networks (ReMuNet) aims to improve the resilience of the freight transport network in the EU in the face of disruptive events and enhancing sustainability. This is proposed to be achieved by offering network users alternate routing options and identifying disruptions and ways to mitigate their impacts.

One of the four core objectives of the ReMuNet project is to develop a standardized methodology to describe multimodal transport networks. The proposed standard is derived from existing approaches and developed together with critical stakeholders to ensure Europe-wide practicability and acceptance which can be easily transferred into appropriate regulatory frameworks ensuring more efficient communication and operational stakeholder inter-connectivity. The first task towards this core objective was to create a typology of disruptive events, which has been addressed in a prior report for Task 1.3. The task, addressed in this report, is **Task 1.4: Conduct root cause and impact analysis of disruptive events.** Building on typologies and classifications of disruptive events in Task 1.3, Task 1.4 reported in this deliverable focuses on tracing disruptive events back to their root causes, thus showcasing the effects of long-term transport policy, climate change, and other broad scale developments. This analysis will be utilized in Work Package 4.

This report presents different ways to analyse disruptive events, their (root) causes, consequences and impacts. The team at HUMLOG Institute (Hanken School of Economics) conducted a qualitative study that included 17 interviews, 2 focus group discussions and 53 student assignments. Five recent disruptions affecting the EU transport network were chosen and analysed for their root-causes. Root cause analysis is a systematic process used to identify the underlying causes of problems or incidents, rather than just addressing the symptoms. This study employed 5 Why's method to analyse root causes. The aim of these analyses was to highlight to the readers on how deep the actual cause of an event could be. An analysis of all related factors and causes of events that have happened can help prepare for the future and reduce losses to human life and materials. Further, our results show how seemingly different and distinct events might be correlated and cause further disruptions in the network.

The mega root causes analysed in this study are root causes ultimately underlying the causes of all disruptive events currently seen in the European transport network. This report identifies them as: climate change and biodiversity loss; infrastructure and maintenance; geopolitical conflict; human behaviour and social and economic changes. By building on the typology for disruptive events developed in ReMuNet Task 1.3, this report provides insights to impacts of disruptive events on different levels, individual actor, individual nodes and links, the entire transport network, supply chains and society as a whole. This study is an important part of achieving the ultimate goal of the project: **the building of a collaborative platform and taking the first steps towards an Artificial Intelligence (AI) based self-learning transport network to promote synchro-modal relay transport across European rail, road, and inland waterways to improve network resilience, reduce emissions, and boost corridor efficiency during disruptive events**. The root causes identified here, along with the terminology and typology developed in the previous task in this qualitative study will be a critical input to the mathematical models that follow in subsequent work packages.

1. Introduction

With increasing complexity of global supply chains and closely timed transport schedules, the vulnerability of European trade to disruptive events will continue to increase unless transport networks become more resilient. ReMuNet identifies and signals disruptive events and assesses their impact on multimodal transport networks. This report is part of WP1, and describes a qualitative study conducted by the team at Hanken on analysis of root causes and impacts of disruptive events in European multimodal freight network. By focusing on tracing disruptive events back to their root causes, this report shows the effects of long-term transport policy, climate change, and other broad scale developments.

This report presents different ways to analyse disruptive events, their (root) causes, consequences and impacts. By building on the typology for disruptive events developed in ReMuNet Task 1.3, this report aims to provide insights to impacts of disruptive events on different levels, individual actor, individual nodes and links, the transport network as a whole, supply chains and society as a whole. This report also presents the identified mega root causes that ultimately underly the causes of all disruptive events currently seen in the European transport network.

While much emphasis has been placed on response to disruptions, through this work, we attempt to highlight the importance of studying the root causes and how they can guide operational strategies and policies to improve resilience, safety, and sustainability. Analysing root causes facilitates determining the systemic causes and prevent recurrences of adverse disruptive events in European multimodal freight network.

An example of the importance of analysing root causes of disruptive events in transport networks can be the recent disruptive events to traffic in the Suez Canal. In March 2021, the container vessel Evergiven got stuck in the canal and blocked all traffic for 6 days (Schiffling & Kanellos, 2021). In December 2023, traffic on the canal was once again disrupted, this time because major shipping companies halted their vessels in response to attacks on passing ships by Houthi rebels from Yemen (Bubalo, 2023). Given that 90% of global trade is conducted via sea routes (*Ocean Shipping and Shipbuilding - OECD*, 2023) and the Suez Canal facilitates around 12% of it (Brigham, 2021), the importance of the disruption is apparent and similar across both incidents as halting all or some ships passing the Suez Canal has major impacts on a key transport link in the global maritime transport network. While the disruption is geographically constrained in both cases, cascading effects on global supply chains and societies are manifold. However, the root causes for the 2021 and 2023 events are vastly different. The incident with the Evergiven in 2021 was caused by bad weather and human error, ultimately related to economic change driving the need for bigger ships and denser traffic on outdated transport infrastructure (Kanellos & Schiffling, 2023). In 2023, ships are subject to targeted attacks due to geopolitical conflicts in Yemen and Gaza. Root causes influence crucial elements of the disruptive events, such as the time taken to resolve the disruption and steps taken to avoid a recurrence. In 2021, it took 6 days to refloat the Evergiven and subsequently major investments were made to widen the canal and address the underlying root cause of infrastructure and maintenance (Lewis, 2021). In 2023, the underlying root cause of geopolitical conflict was much more difficult and potentially lengthy to address. In response to shipping lines halting their vessels, the US military announced an expanded maritime protection force in the region, aptly named Operation Prosperity Guardian (Wintour, 2023).

A series of interviews conducted with infrastructure managers, logistics operators, government agencies, and other stakeholders in the EU transport network revealed that most of the stakeholders prioritized response to disruptions over root-cause analysis (Kulkarni et al., 2023). However, on probing further, the participants agreed that identifying causes of disruptions was an important step in risk assessment and deciding future operational strategies. As mentioned by a participant, logistics operations are guided by financial incentives and often identifying and addressing root-causes is not always the economically viable alternative. Downtimes in businesses have direct financial implications and hence the focus of stakeholders is always on finding immediate solutions to get the transport networks operational as soon as possible.

The research for this deliverable was conducted in collaboration with the masters students of the *"Supply Chain Strategy for Sustainability*" course at Hanken School of Economics. The course introduces students to the concepts of supply chain management in the context of sustainability. Through a series of interactive guest lectures with researchers and practitioners, the students are exposed to topics in risk, resilience, disruptions, circular economy, and sustainable practices in different transport domains from road, rail, to maritime shipping. The class of 60 students participated in Focus Group Discussions (FGD) on defining, classifying, and analysing disruptive events, with a focus on the impact of sustainability. Participants identified multiple disruptive events in the last 5 years in the EU and in small groups of 5-8 people, discussed the causes, impact, and response for each event. At the end of the discussion, each group came up with a list of categories in which these disruptive events can be placed. Further, each student wrote a nearly 3000-word essay on root-cause analysis of a disruptive event (chosen from a list of six options) affecting the EU transport network in the recent past.

For performing the root-cause analysis (RCA) with the participants from the course, three methods were chosen: brainstorming, analysis of case studies, and the 5-why method. The participants brainstormed in small groups of 6-8 people as part of the FGD. Further, both as part of the FGD and the written assignment, they analysed disruption case studies affecting EU transport networks and presented their findings. For the FGDs, these findings were presented as flipcharts accompanied with a short presentation. The RCA essays submitted by the students included a dedicated section to analysis of a selected scenario using the 5-why method.

An important contribution of this analysis is the identification of multiple levels of causes underlying a single disruptive event. This highlights the multi-dimensionality of disruptions and how they require conscious, collaborative efforts from various stakeholders to mitigate their risks of recurrence. At least two of the examples of disruptions discussed are cases where inadequate risk assessment has resulted in recurrence of the disruption with greater intensity. The data from the qualitative study will help build the foundation for an AI-based platform to be developed later in the project, providing crucial information for disruption modelling.

2. Literature review

2.1 Causes for disruptive events

The work described in this report is a focused study on analyzing disruptions in the context of resilience and sustainability which have affected or can affect the EU multimodal transport network. The methods used and the analysis performed are based on some of the recent academic research in generic transport networks and supply chains. Some of the relevant articles are presented here, to provide a theoretical basis for the discussions that follow in the remainder of this report. A recent study conducted in 2022 (Serdar et al., 2022) presents an overview of resilience in urban transportation networks by reviewing literature on reliance indicators, disturbances, and assessment methods. The authors refer to disruptions as *resilience disturbances* and have identified four potential groups of causes for the urban transport networks as shown next in a table from their article (Figure 1).

Disturbance category	Scale	Affected parts	Impact
Natural hazards	Large	Random, sometimes predictable	Vary
Intentional attacks	Small-medium	Predictable	Medium-High
Accidents	Small	Random	Low-medium
Failure propagation	Vary	Predictable	Vary

Figure 1: Disturbance categories (Serdar et al., 2022)

The article further mentions different assessment methods to estimate resilience of transport networks. Among the approaches mentioned, simulation modelling is also discussed as a suitable method, particularly for intermodal transport with disruptive events. This approach is also the selected approach of the ReMuNet project, where a simulation model will be developed in the later stages, based on the inputs of this work package. Another recent article from 2020 (Gu et al., 2020) studies the performance of transport networks under perturbations. The article reviews several scientific works relating to reliability, vulnerability, and resilience in transport networks. The authors refer to disruptions in transport networks as *perturbations*. The following table (seen in Figure 2) from their work gives a useful comparison of the three aspects of disruptions they have reviewed:

	Reliability	Vulnerability	Resilience
Definition	Probability of network to remain satisfactory under perturbation	Susceptibility of network to perturbations	Ability of network to resist, absorb, adapt to, and recover from perturbations
Measurement	Probability of remaining certain level of network performance under perturbation	Decrease of network performance under perturbation	Remained network performance under perturbation and the extent of restored network performance after perturbation
Applicable scenarios	Both recurrent and non-recurrent perturbation	Specific non-recurrent perturbations	Unspecific non-recurrent perturbations

Figure 2: Comparison of reliability, vulnerability, and resilience (Gu et al., 2020)

The article by Mattsson & Jenelius, 2015 refers to disruptions as *vulnerabilities* and investigates the causes and the characteristics with a review of literature. The authors present the following table (seen in Figure 3) to describe this:

Cause	Accidental event	Intentional interference
Internal	Technical failures, mishaps	Labour market conflicts
External	Adverse weather conditions, natural disasters	Pranks, antagonistic attacks

Figure 3: Causes of disruptive events (Mattsson & Jenelius, 2015).

Internal causes may originate from mistakes and accidents caused by staff or users, technical failures, components that break down, faulty constructions, overload, etc. External causes may be related to natural phenomena including various degrees of adverse weather and natural disasters: heavy rains, snowfalls, thunderstorms, floods, wildfires, landslides, tsunamis, volcanic eruptions, earthquakes, etc. One specific long-term threat in-between internal and external is global warming, which is partially a consequence of human activities in the transport sector (Mattson and Jenelius, 2015). External causes also include antagonistic actions ranging from sabotage, terrorist attacks to war. Importantly, antagonistic attacks are difficult to predict both with respect to frequency and location as compared to natural threats and technical and human failures for which it may be possible to collect statistics that are useful for prediction and prevention, emphasizing the need for understanding the root causes.

As observed in the previous report from this work package (Del 1.3), disruptions can be both planned and unplanned and both can significantly impact transport networks. This point is clearly emphasized by the authors of the review article on planned and unplanned disruptions to transport networks (Zhu & Levinson, 2010). The authors argue that network disruptions impact not just the traffic flows but also the behavior of the users of the systems. They analyze multiple disruptions such as the collapse of a bridge and earthquakes and study the impacts of both on traffic and behavior.

The causes and impact of disruptions (also referred to as vulnerabilities, perturbations, or resilience disturbances) is a well-researched topic in academia. Although all articles unanimously mention that there is no consensus in the terminology, the underlying discussions often converge to similar sets of ideas. The four review articles studied the connections between network resilience (and in two cases, sustainability as well) with disruptions. Together, these four review papers cover over 500 scientific articles on transport disruptions, their causes, impact, and resilience over the last two decades. This strongly emphasizes the importance placed by the academic community on researching ways to improve resilience and sustainability in transport networks. Another key takeaway is that the main cornerstone of the discussion on improving resilience is disruptive events. This aligns well with the proposed plans of the ReMuNet project, which invests the early months of the project timeline on defining, classifying, and analyzing disruptive events.

ReMuNet's Task 1.3 developed a typology of disruptive events based on the extant literature and the primary data collected and analysed as part of this study. Figure 1 presents the typology of disruptive events developed in Task 1.4 of WP 1 of the ReMuNet project. First, the typology acknowledges the importance of both the physical and the information layer. It then includes the ten categories of disruptive events by causes that were identified in this research. These result in disruptive events that can impact transport nodes, transport links, or both. Based on both literature and findings from the primary research conducted as part of this study, the typology also includes multiple dimensions of events that will ultimately determine the disruptive event's impact. These include time duration and geographical extent of the disruptive event, the criticality of the disrupted node(s) and/or link(s) and the existence and number of alternative options for example to reroute freight on the same transport mode or to switch it to an alternative mode, as well as the probability of the disruptive event and its predictability. Importantly, the typology acknowledges that the impact of disruptive events can be manifold. While it includes direct impacts on individual actors, nodes and links, it also includes cascading effects that impact the entire transport network, supply chains, and society before a disruptive event results in an impact on the transport network. The causes for disruptive events identified in this report all have underlying root causes. Root causes will be discussed further in this report.

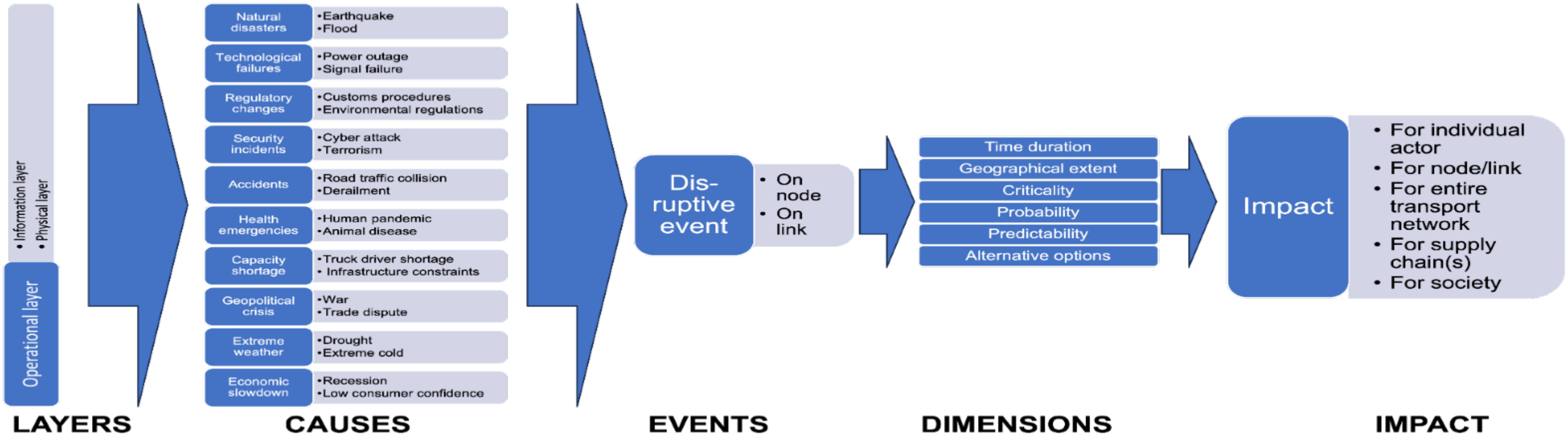


Figure 1: Typology of disruptive events

2.2 Root cause analyses

Root cause analysis (RCA) is a systematic process used to identify the underlying causes of problems or incidents, rather than just addressing the symptoms. The goal of root cause analysis is to determine what factors contributed to an issue or event, with the aim of preventing its recurrence. RCA facilitates determining the systemic causes and prevent recurrences of adverse event or disruptions.

This study employs 5 Why's method to analyse root causes. It is an iterative interrogative technique used to explore the cause-and-effect relationships underlying a particular problem (Gangidi, 2018). The tool was refined by Sakichi Toyoda and was used within the Toyota Motor Corporation during the evolution of its manufacturing methodologies. Also known as a Why Tree, it is a simple form of root cause analysis. By repeatedly asking the question, "Why?" layers of issues and symptoms are peeled away that can lead to the root cause (Gangidi, 2018). Using the 5-Whys is a simple way to try solving a stated problem without a large, detailed investigation requiring many resources.

The choice for the methods was based on a survey conducted in 2017 by a team from Poland with 50 senior and mid-senior managers on 10 key RCA methods from literature (Wieczerniak et al., 2017). **Figure** 4 shows the results from the survey. The orange bars indicate the efficiency of the RCA method as reported by the respondents and the blue bars indicate how often these methods were used by the respondents.

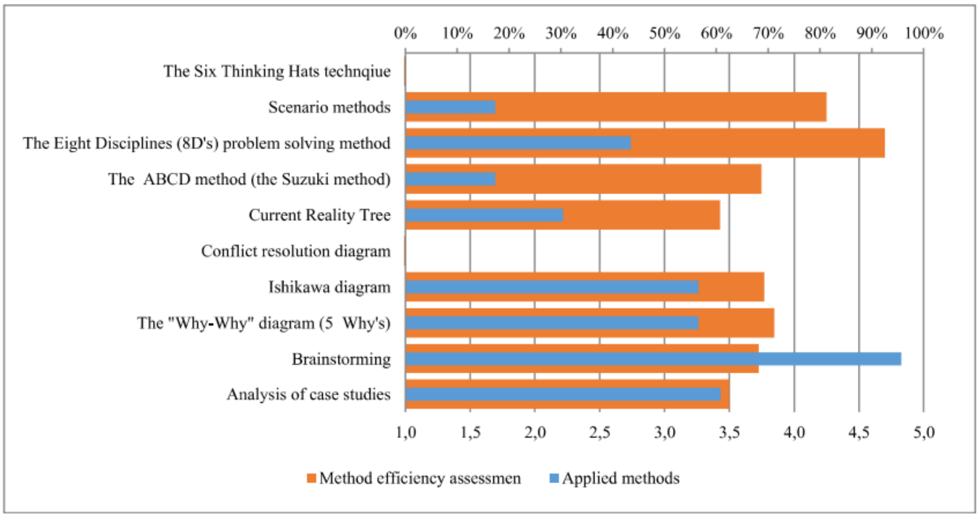


Figure 4: Use of RCA methods by managers in Poland.

While this survey is not exhaustive, it provided a basis for selecting the methods that would be easiest to follow and implement for the large number of participants in a short time, as required by the FGD. 5-Whys is one of the simplest root cause analysis techniques at the same time very effective if used correctly (Gangidi, 2018).

The participants were also given the option of choosing any other alternative RCA method for their essay, if they were convinced of better results. However, all participants chose to use the 5-why method.

3. Interconnected disruptions: causes and impact analysis

This section analyses the interrelationships between some disruptions affecting the EU transport networks in recent years, studying their causes and impact. As part of the course on “Supply Chain Strategy for Sustainability”, master's students at the Hanken School of Economics participated in a Focus Group Discussion (FGD) on analysis of disruptive events with a focus on European disruptions in the last 5 years. The students were divided into groups of 6-8 people each. They were asked to choose 2-4 recent disruptive events in Europe and analyze the following: the cause, impact, response, geographical extent, and time duration of the disruption. They were given an option to analyze the events in any format and using any theory they preferred. This discussion focused on a higher level, considering multiple disruptions and their overall analysis with respect to the European transport network. The next section in this report presents an in-depth analysis of individual disruptive events, examining their root causes. In this section, three different analyses are presented, from the results presented by the 6 participating groups.

3.1 The hourglass effect

The analysis revealed the hourglass relationship between multiple disruptions. Figure 5 visualizes this concept.

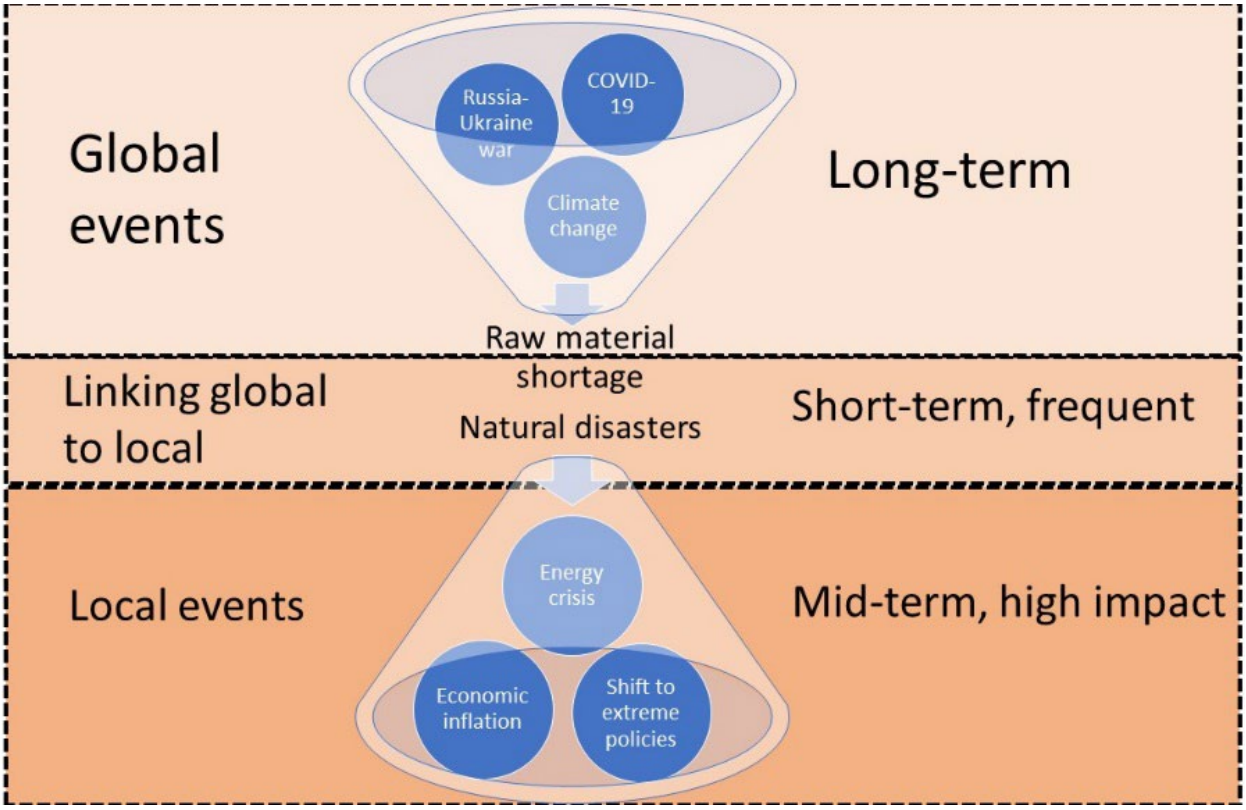


Figure 5: Hourglass relationship between disruptive events

The top half of the hourglass includes multiple disruptions that are global in nature, affecting several countries at once. These disruptions are persistent, lasting months, or years at a time (long-term). Recent examples of such disruptions are the pandemic caused by the COVID-19 virus, the Russia-Ukraine war, and the climate crisis. The direct impact of these three disruptions were extended illness, loss of life, and extreme weather. However, these events also triggered another set of shorter duration disruptions which had their own consequences. One such series of events is the shortage of raw materials in different countries. Global supply chains were greatly affected by both the pandemic and the war, which changed sourcing patterns of important raw materials drastically. Due to climate change, the occurrence of short but extreme weather situations amounting to natural disasters has increased, such as flash floods and droughts. These events are more localized than the larger global events that caused them. Finally, in the lower half of the hourglass are a series of highly localized, high impact disruptions which have stemmed from a combination of the global and intermediate events. Examples include energy crises (due to raw material shortages or natural disasters, as well as the structure of national energy networks), economic slowdowns resulting in loss of employment and increased prices of essential commodities, and the implementation of extreme policies.

This short analysis highlights the complicated nature of disruptions and their causes. When assessing risks and designing risk mitigation strategies, it is important to understand the underlying causes and trace the chain back to root cause, to have effective solutions.

3.2 Parallels between geo-political and natural disasters

Another discussion in the FGD compared two seemingly different types of disruptions for their impact on sustainability and the response measures required. On the one hand, there is the increased frequency of flash floods in Europe, most recently in countries such as Slovenia, Austria, and Hungary in 2023. On the other hand, is the Russia-Ukraine geo-political crisis, which has been ongoing since February 2022. Participants used flipcharts and post-it notes to chart out the causes, impact, response, geographical extent, time duration, and implications for sustainability for each of the disruptions, as shown in Table 1.

Table 1: Comparing geo-political crisis and natural disasters.

Disruptive event	Cause	Impact	Response	Geographical extent	Duration of time	Sustainability impact	Category
Flooding in Europe	Heavy rains→ climate change	Infrastructure damage, workforce affected, loss of raw materials	Restoration of infrastructure, operational changes, military, and humanitarian aid	Italy, Austria, Slovenia, Croatia	July-Aug 2023	Rebuilding required	Environmental, natural

Russia-Ukraine war	Escalation of political tension	Energy price increase, Raw material supplies affected	Humanitarian aid, military intervention	Global	Feb 2022-ongoing	Energy pricing and supply, restructuring supply chains	Geo-political

While one event is environmental and the other political, both situations required humanitarian aid, military interventions, and collaboration of multiple countries. Although it may appear as though the flash flood was a one-time event, it is observed to be a part of a series of floods and droughts occurring frequently in Europe in the region. Both disruptions require continuous efforts at rebuilding cities, leading to extensive impact on sustainability, since construction activities require high energy consumption and result in high volumes of carbon emissions. Moreover, the destruction of existing infrastructure changes the normal operating routes for transport systems. The impact is even more severe for transport modes such as railways, which are highly sensitive to infrastructural changes. Further, due to inaccessibility to certain regions (either due to war or natural disasters), immediate rerouting or change of transport modes (or both) are required to ensure continuity of transport networks that passed through these regions. Both these disruptions bring with them the risk of spread of diseases and other health emergencies which can affect the workforce of the transport systems. Moreover, the biodiversity of the regions experiencing these disruptions is often destroyed, bringing about adverse effects on the climate. Some of these zones are also important sources of critical raw materials and their destruction can change the economics of the transport systems. Government action and close cooperation of multiple countries is required to control these events and find resolutions.

> This discussion brought about an interesting perspective that although disruptions may have significantly different causes, their impact, and the nature of response they evoke might be quite similar.

3.3 Planned and unplanned disruptions

The third discussion was a hugely contested debate on whether disruptions, by definition, are unplanned and unexpected. Of the six groups, four groups concurred that disruptions are unexpected events, while two groups maintained that any event causing a change in operations can be a disruption. Figure 6 shows the flipchart made by one of the groups, discussing an example of a foreseen and unforeseen disruption. According to those groups supporting the notion that disruptions can also be planned or foreseen, examples such as workforce strikes prove the point. Another example of a foreseen disruption is a change in legislation or policy. Those opposing this view argued that if an event is planned, it is possible to prepare a response in advance and mitigate effects to some extent. They preferred to term these planned events as operational challenges or irregularities, instead of disruptions.

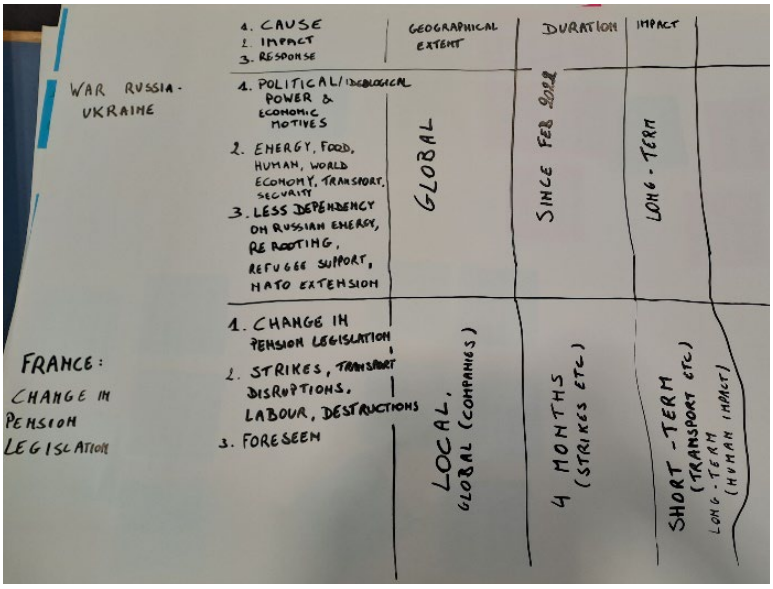


Figure 6: Example of unforeseen and foreseen disruptions

The consensus from this discussion was that both unplanned disruptions and planned operational challenges have the potential to negatively impact the transport networks. While the definition for disruption may be disputed, the notion that supply chains and transport networks are regularly challenged and impacted by both planned and unplanned events is undisputed.

4. Root-cause analysis of some disruptive events

When a disruption occurs, often the immediate focus is on limiting the impact and planning the response (Kulkarni et al., 2023). A qualitative study involving various stakeholders in the EU multimodal transport network conducted under the ReMuNet project saw that 100% of the respondents prioritized response and impact, over the cause of the disruption. While intuitively this seems to be a logical approach, through this section we highlight the necessity of studying the underlying causes in detail. Unless the main causes are identified and addressed satisfactorily, the risk of a recurrence of the disruption remains. Building a safe and sustainable transport network requires a thorough risk assessment, with sufficient methods of risk mitigation identified and implemented. The predictability of disruptive events also depends on the causes of the event.

In this section, 5 recent transport disruptions in Europe are analysed. Master's students of the course of "Supply Chain Strategy for Sustainability" at Hanken School of Economics were invited to analyse these events in detail. The insights from these analyses are included in the following discussions. An important aspect common to all these disruptive events is that *the immediate reason for the disruption is not the root cause of the problem.* All these disruptions *have a high risk of recurrence* since the underlying root causes are only worsening. The discussion on root-causes of the disruptions is structured as follows: 1) the disruptive scenario is described, including its coverage in the media 2) a summary of the consequences and impact on the transport network is presented 3) root-cause analysis is performed using the 5-why method and finally, 4) some recommendations on addressing the situation are presented.

4.1 Rhine river droughts

The next disruption that has significant impact on the EU transport network is the increasing frequency of droughts and declining water levels in the Rhine River (Ahr, 2023). The Rhine River is a critical waterway connecting multiple central European countries, including Switzerland, Germany, France, the Netherlands, and Belgium. It is therefore also referred to as the primary artery of the region (Leuven et al., 2009). In the last 5 years, declining water levels leading to transport disruptions have been experienced in 2018, 2022 and more recently 2023. The severity of the reduced water levels resulted in limitations on cargo loaded in the vessels (Steitz & Flasseur, 2023). For example, when the water level in the river drops below 135 cm, cargo must be reduced, sometimes by half, to ensure safe navigation (‘Rhein’, 2023).

Historically, the Rhine has been significant, not just as a political border, but also a crucial economic lifeline, as highlighted by (Levainville, 1924), as early as 1924. German inland shipping currently accounts for nearly 7% of the total national transport, although there is a trend of steady decline from the previous years (Nicolai, 2022). There are several big corporates and industries strategically situated along the Rhine to reduce transport costs, such as BASF and Covestro. The river is still the primary shipping route for grains, chemicals, minerals, coal, and oil products (‘Rhein’, 2023). In 2022, 182 metric tons of material were transported on the Rhine, which is significant, even though these were the lowest numbers since the Reunification and 6.4 percent less than in 2021.

Covestro, which produces chemicals, ships more than 30% of their finished goods on the Rhine, while also receiving most of its raw materials via the waterway. The river offers a safer alternative over road transport for hazardous materials (Steitz & Flasseur, 2023). Further, the inland waterway is an environmentally friendlier alternative, since one vessel may replace nearly 150 freight truck trips.

European commerce suffers as Rhine River drought persists

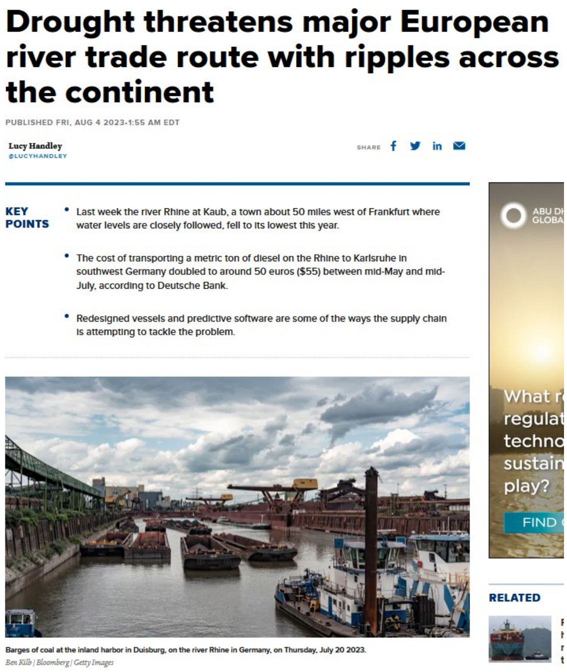
August 2, 2023

By Rakin Rahman

TWITTER FACEBOOK LINKEDIN EMAIL

Companies are adapting to the receding water levels in one of Europe's most important trade routes, Rhine River, which has impeded shipping since the beginning of summer.

Chemical producer, BASF SE, loads and unloads approximately 15 barges a day, accounting for about 40 per cent of its transport volume, and it is set to re-route its logistics to trains and trucks, Bloomberg reported.



Drought threatens major European river trade route with ripples across the continent

PUBLISHED FRI, AUG 4 2023·1:55 AM EDT

Lucy Handley
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KEY POINTS

- Last week the river Rhine at Kaub, a town about 50 miles west of Frankfurt where water levels are closely followed, fell to its lowest this year.
- The cost of transporting a metric ton of diesel on the Rhine to Karlsruhe in southwest Germany doubled to around 50 euros ($55) between mid-May and mid-July, according to Deutsche Bank.
- Redesigned vessels and predictive software are some of the ways the supply chain is attempting to tackle the problem.

Barges of coal at the inland harbor in Duisburg, on the river Rhine in Germany, on Thursday, July 20 2023.

Ben Kilb | Bloomberg | Getty Images

RELATED

(Rahman, 2023) and (Handley, 2023)

Consequences and impact

Since the transport networks depending on the Rhine are so close-knit, the effects of disruptions percolate both downstream and upstream in the related supply chains (Meuchelböck & Jannsen, 2023). There are industries which rely on the river for their raw materials as well as finished goods. A disruption in supply of raw materials leads to delays and increased costs (Schattenberg, 2023). Reduced water levels can result in higher shipping costs since ships that are operational are required to operate with reduced capacities. The cargo then needs to be distributed across several ships. Companies such as BASF receive nearly 40% of their raw materials from the river and use the water from the river for their cooling systems. There is a strong need now, to find alternatives to the Rhine (Spiegel, 2023) and this necessitates additional investments. There is now a greater demand for special low-water barges, catering to the lower water levels. Investment in a new fleet of vessels, however, is a huge financial commitment, estimated to be around 5 million euros per vessel Nicolai (2022). These increased costs are likely to be passed down to the end-consumers and influence private household expenses.

The threat of increased expenses and longer lead times is also driving companies to consider shifting in part from water transportation to road transportation. However, this transition is not straightforward, as the demand for professional truck drivers is already greater than the availability and freight forwarders are often fully booked. An instance of a situation where the public was at the direct receiving end of the consequences, was in 2018. The low water levels affected the restocking of petrol and diesel, leading to the closure of petrol stations in certain regions (Nicolai, 2022).

4.1.1 *Root-cause using 5-why method.*

The root-cause analysis of this disruption begins with the question: "why is there less water in the Rhine?" The reason for this is insufficient rains. The second question is "why is there insufficient rain?", and the answer is that there are frequent drought events. The third question investigates why droughts are more frequent and the answer is due to increased hot events and high-pressure areas along the waterways. The reason behind the increased hot events is the climate change. The major reason behind climate change, as discussed in the previous disruption as well, are human activities that have led to increase in GHG emissions.

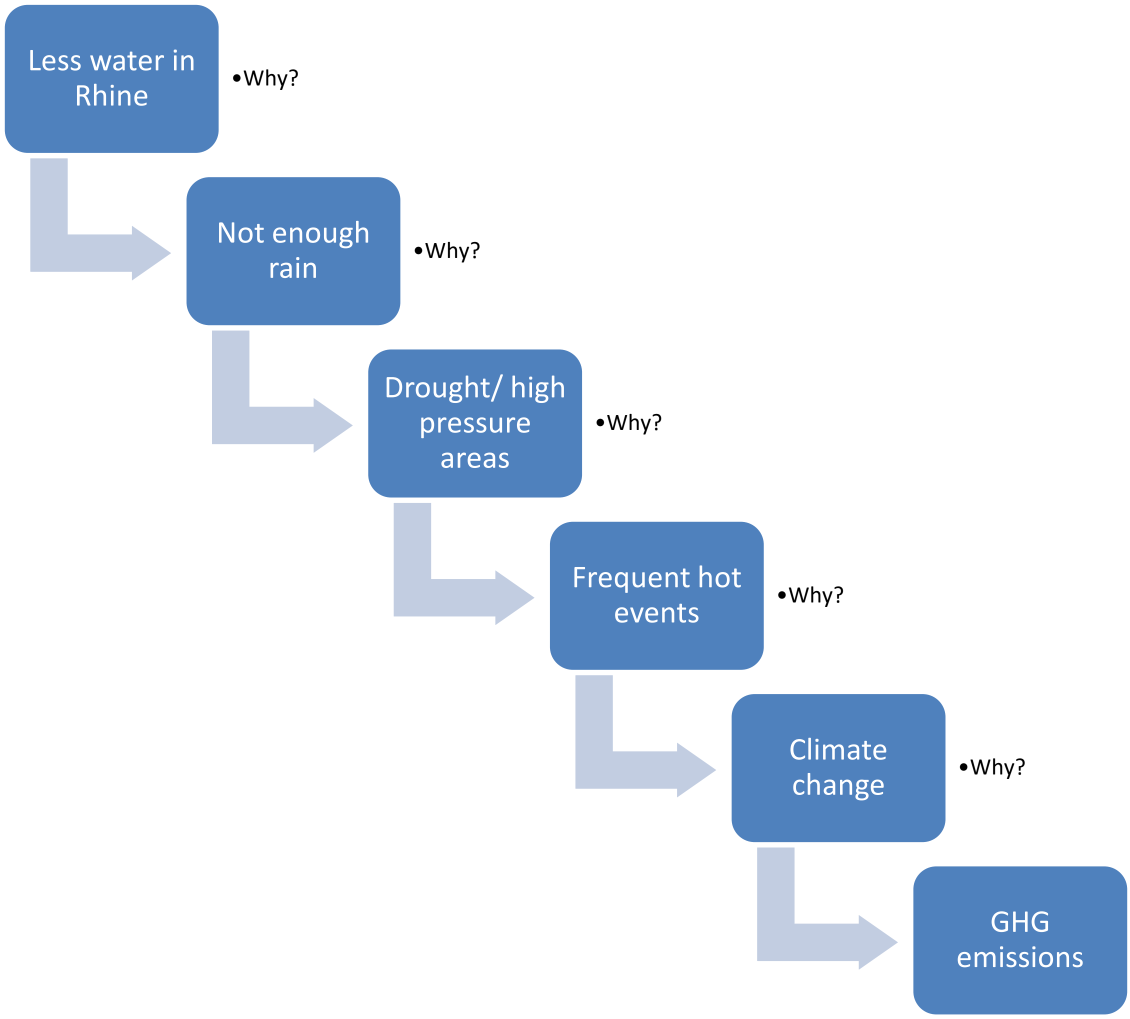
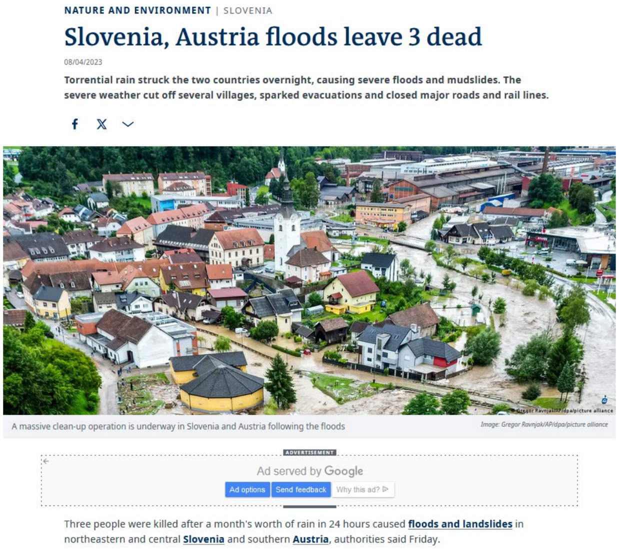


Figure 7: Root-cause analysis of the low water levels in Rhine

4.2 Floods in Slovenia

In August 2023, heavy rains caused major flooding in Slovenia, which also affected the neighbouring countries of Austria and Croatia (Karlsson, 2023). Along with flooding, landslides were also observed due to severe weather (Davies, 2023). The disruption led to major infrastructural damages, including destruction of buildings, roads, bridges, and flooded land masses. Some areas were rendered inaccessible. There was also a loss of 6 lives. Supplies of essential commodities such as water and electricity supply were disrupted.

The challenging situation made it difficult for humanitarian agencies to provide assistance (IFRC 2023).


NATURE AND ENVIRONMENT | SLOVENIA

Slovenia, Austria floods leave 3 dead

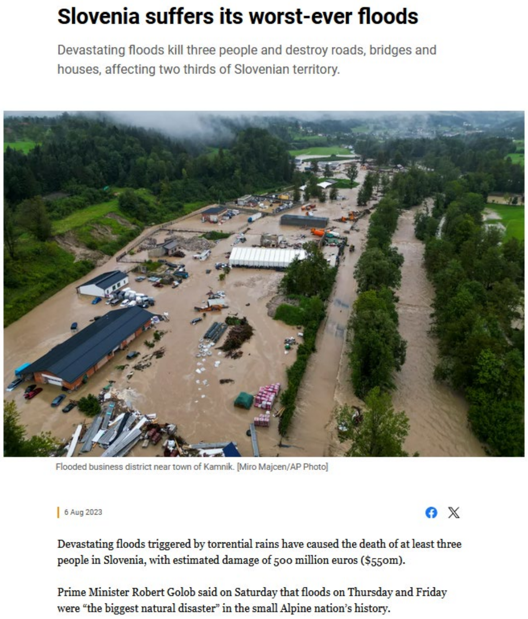
08/04/2023

Torrential rain struck the two countries overnight, causing severe floods and mudslides. The severe weather cut off several villages, sparked evacuations and closed major roads and rail lines.

A massive clean-up operation is underway in Slovenia and Austria following the floods

Image: Gregor Ravnjak/APAfpa/picture alliance

Three people were killed after a month's worth of rain in 24 hours caused floods and landslides in northeastern and central Slovenia and southern Austria, authorities said Friday.


Slovenia suffers its worst-ever floods

Devastating floods kill three people and destroy roads, bridges and houses, affecting two thirds of Slovenian territory.

Flooded business district near town of Kamnik. [Miro Majcen/AP Photo]

6 Aug 2023

Devastating floods triggered by torrential rains have caused the death of at least three people in Slovenia, with estimated damage of 500 million euros ($550m).

Prime Minister Robert Golob said on Saturday that floods on Thursday and Friday were "the biggest natural disaster" in the small Alpine nation's history.

(*Slovenia, Austria Floods Leave 3 Dead – DW – 08/04/2023*, n.d.) (*Slovenia Suffers Its Worst-Ever Floods | Floods News | Al Jazeera*, n.d.)

4.2.1 *Consequences and impact*

The damage to infrastructure and inaccessibility to areas resulted in significant disruption of the transport networks along with severe damages to some manufacturing. The affected area was an important zone for component manufacturing for the automobile industry. Due to the damages to the manufacturing facilities and destruction of certain warehouses, automobile production was slowed down. The destruction and flooding of roads made transportation nearly impossible through these areas. Several people faced extreme material and financial losses which also affected the availability of workforce. The event in August 2023 was not the first. The region had already experienced a similar, though less severe flooding event in recent years. Due to this, the area and its residents were already grappling with socioeconomic challenges before this flooding. This disruption further accentuated the economic crisis by increasing loss of assets and livelihoods such as livestock and crops, and damages to infrastructure and businesses (IFRC 2023). The disaster affected both privately owned business and public sector alike, and highlighted the impact government actions and responsibility have on supply chain mitigation.

4.2.2 *Root-cause using 5-why method.*

Although the main cause of the economic crisis and loss of life appears to be the weather-related events, it is worth investigating whether there was any other reason behind the extent of the damage caused by the disruption. The first question in the root cause analysis is why there were floods in Slovenia. The answer is the occurrence of flash floods that overpowered the area's drainage systems. The next question is "why did the flash floods overpower the drainage system?". The answer is that the riverbed infrastructure was outdated and not maintained to handle the extent of the 2023 floods. There was continued construction in the riverbed, despite flood warnings (*Floods in Slovenia*, n.d.). The next question investigates why the infrastructure is not updated, and the answer is that there was a lack of investments in the maintenance of this infrastructure. We then ask the question why there was a lack of investment. The answer to this is that the risks of flooding were grossly underestimated, despite multiple incidents of similar nature in recent past. As to why there was an inadequate risk assessment, this appears to be a failure of policymaking and governance, which needs detailed investigation.

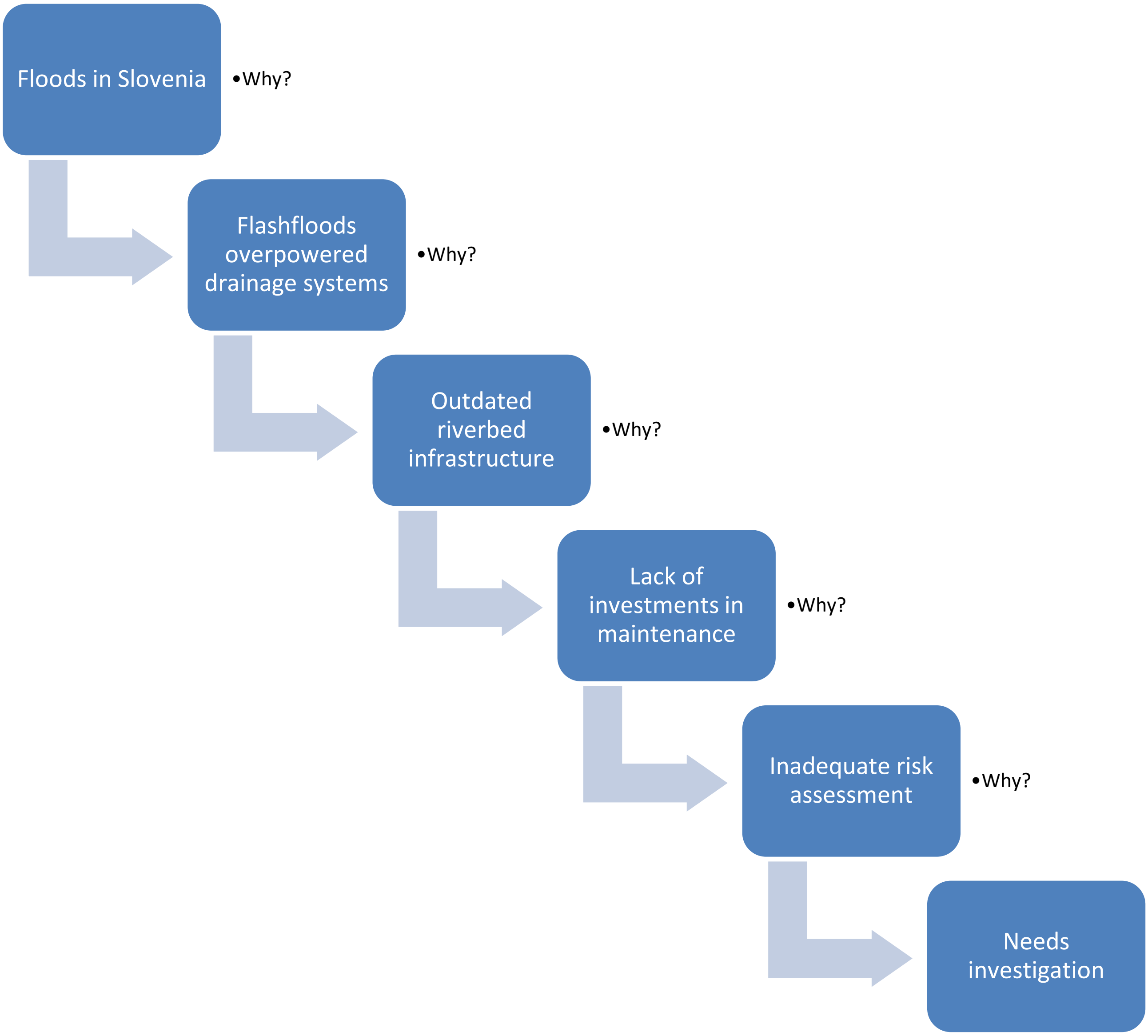


Figure 8: Root-cause analysis of the floods in Slovenia

The EU recently granted the country additional funding to deal with the aftermath of the floods (*Inforegio - EU Solidarity Fund Grants €100 Million of Advance Payment to Slovenia Following the Summer Floods*, n.d.).

4.3 Gotthard rail tunnel

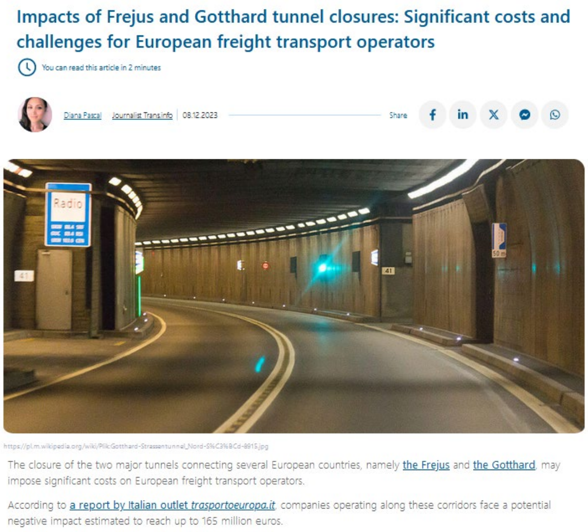
The Gotthard rail tunnel is the world's longest rail tunnel, running for 57km. The tunnel opened to both freight and passenger traffic in 2016, reducing the previous commuting route by 30km and the transport time by nearly 60 min. The tunnel also increased the capacity of freight trains from 180 to 250 every day (*New Gotthard Railway Tunnel - DETEC*, n.d.). The disruption discussed in this section is about a freight train derailment accident in the tunnel on August 10th, 2023 (Chamoux, 2023). The accident caused 16 freight wagons to go off track, approximately 17km after entering the tunnel. The derailed train was carrying cargo, which was destroyed, along with damage to at least 8km of track, resulting in a traffic shutdown. Although the actual damage was restricted to a single tube (the eastern tube remained intact), there was an immediate and complete halt of all train traffic for multiple days (*Intermediate Report from the STSB*, 2023). Partial freight traffic could only resume by August 23rd and passenger traffic restoration was delayed all the way until September 30th. As of December 2023, both freight and passenger traffic had not yet been restored to full capacity, operating only smaller, lighter, and fewer trains than usual and at reduced speed.


Gotthard rail tunnel, world's longest, closes for months after Swiss derailment

Sixteen freight carriages run off rails, tearing up eight kilometres of train track and leaving engineering marvel inaugurated in 2016 unable to take passengers

The first train comes out of the Gotthard base tunnel's north portal accompanied by a pyrotechnic show on its opening day, Wednesday 1 June 2016, near Erstfeld, Switzerland. Passenger services have been halted by a serious derailment. Photograph: Laurent Gilliéron/AP

Train passengers between north and southernmost Switzerland will have to skip the world's longest train tunnel and go back to the longer scenic route for months, rail authorities have said, after a freight service derailed and tore up the track.


Impacts of Frejus and Gotthard tunnel closures: Significant costs and challenges for European freight transport operators

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Diana Pascal Journalist Trans.info | 08.12.2023 Share

https://pl.m.wikipedia.org/wiki/Plik:Gotthard-Strassentunnel_Nord-S%C3%BCd-8915.jpg

The closure of the two major tunnels connecting several European countries, namely the Frejus and the Gotthard, may impose significant costs on European freight transport operators.

According to a report by Italian outlet *trasportoeuropa.it*, companies operating along these corridors face a potential negative impact estimated to reach up to 165 million euros.

('Gotthard Rail Tunnel, World's Longest, Closes for Months after Swiss Derailment', 2023)

(*Impact of Frejus and Gotthard Tunnel Closures*, n.d.)

4.3.1 *Consequences and impact*

The Gotthard rail tunnel is a critical component of the Rhine-Alpine Corridor connecting Rotterdam to Geneva, facilitating an important trade route through the Alps (*New Gotthard Railway Tunnel - DETEC*, n.d.). Multiple European companies, many of them German and Italian, were reliant on this trade route and had to look for alternatives overnight, to prevent production and delivery delays. To mitigate some of the effects of this disruption, few trains were rerouted via the Lötschberg/Simon route and the Gotthard panorama route, which was the original route that the Gotthard rail tunnel was built to replace (*Après le déraillement d'un* *train, le tunnel de base du Gothard restera fermé jusqu'à mercredi - Le Temps*, 2023). Even though the accident involved a single train on a single tube, the impact of this derailment is much longer term than expected, since the date for a complete reopening of the tunnel at full capacity is now estimated to be the end of 2024. Along with restoration of the damaged 8km track, there are also nearly 20,000 concrete railroad ties that need to be replaced. This accident is estimated to cost the infrastructure managers between CHF100-130 million (106-138 million €) in repair work alone, not including the increased logistical costs to the users.

4.3.2 *Root-cause using 5-why method.*

Although this disruption is an accident (unlike the previous disruptions, which were nature related), it is important to identify the root-cause of this event and see if there are ways to prevent similar events from recurring. The first question in the root-cause analysis is why the train derailment occurred. The answer is due to a broken wheel on the concerned train. The next question is: "why did the wheel break?". The answer, as per sources (Keystone-SDA, 2023), is that the wheel was worn out and not replaced. The next question is: "why was the wheel not replaced?". A preliminary investigation has revealed that the current control protocols are incapable of detecting such faults. It was, therefore, not possible to detect this issue and prevent this accident, given the current protocols in place. As to why the protocols could not detect this fault, the answer is that the protocols have not been updated to include all possible current scenarios and require a careful, thorough upgrade.

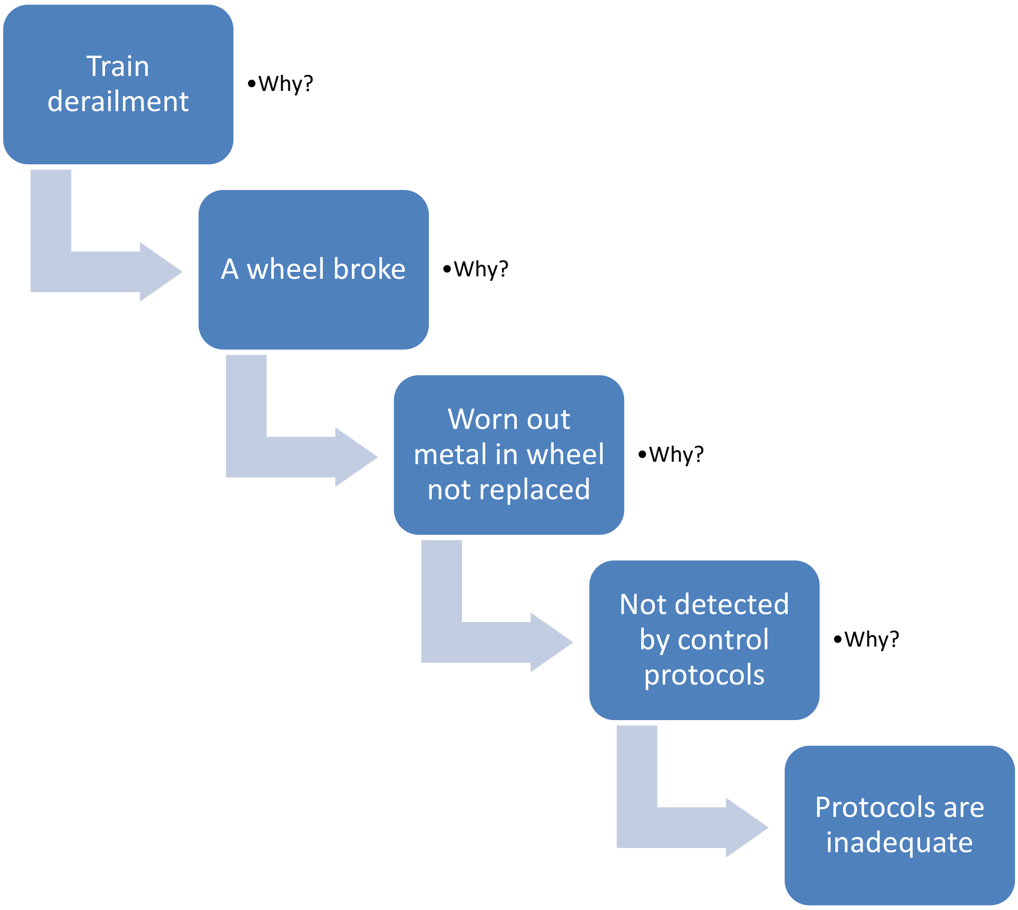
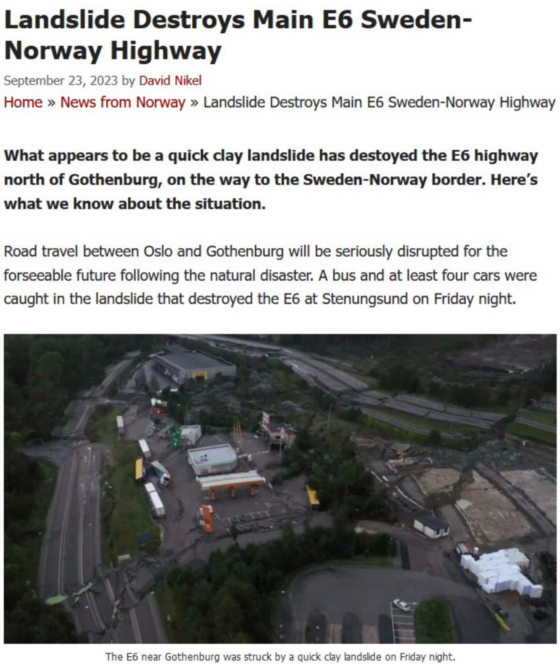


Figure 9: Root-cause analysis of Gotthard tunnel accident

4.4 Landslide in Sweden

This disruptive event describes a landslide that occurred in Sweden and resulted in the closure of a critical highway on the E6 route. The event occurred on September 23rd, 2023 in Stenungsund, Sweden (Kulmala, 2023). A landslide caused the collapsing and caving in of the road for nearly 50m (Nyheter & Wickström, 2023). Although there was no loss of life, three people were injured and several vehicles drove off the highway. The E6, which is an important route connecting Sweden and Norway, was completely closed between Stenungsund and Ljungskile. As an immediate resolution, traffic was redirected via lengthy detours. It is estimated that the repairs will take months. The authorities are concerned that there is still a risk of further landslides in the region. As a result, an advisory has been issued for the public to stay away from the area (Nyheter & Degerström, 2023). The state accident commission has swung into action and investigations are still ongoing to understand all possible causes of the disruption (Wickström 2023), including any connection with blasting work on a nearby building site (Nyheter & Degerström, 2023).


Landslide Destroys Main E6 Sweden-Norway Highway

September 23, 2023 by David Nikel

Home » News from Norway » Landslide Destroys Main E6 Sweden-Norway Highway

What appears to be a quick clay landslide has destoyed the E6 highway north of Gothenburg, on the way to the Sweden-Norway border. Here's what we know about the situation.

Road travel between Oslo and Gothenburg will be seriously disrupted for the forseeable future following the natural disaster. A bus and at least four cars were caught in the landslide that destroyed the E6 at Stenungsund on Friday night.

The E6 near Gothenburg was struck by a quick clay landslide on Friday night.


Landfill may have triggered damaging landslide in Sweden, experts say

29 SEPTEMBER, 2023 | BY THAMES MENTETH

Photo: Anders Rudäng / Vastra Gotaland County Administration

A significant landslide that destroyed part of a highway in south west Sweden may have been caused by excavated material placed on a site at the top of the slope, some landslide experts have said.

The major incident at Stenungsund last Saturday (23 September) destroyed large parts of the E6 motorway, which connects Gothenburg in Sweden to Oslo in Norway.

(Nikel, 2023) (Menteth, 2023)

4.4.1 *Consequences and impact*

As mentioned earlier, the E6 is a critical route connecting Norway and Sweden. The E6 is considered to be one of Sweden's busiest motorways, used heavily by freight and public transport and regional work commuting. It is estimated that the E6 is used by nearly 50,000 vehicles per day and traffic volumes have doubled in the last 15 years on certain parts of the route (Trafikverket, 2023).

The relevant stakeholders directly impacted by the landslide include private persons, businesses and logistics operators in Scandinavia, public transport operators and the community of Stenungsund. Indirectly affected stakeholders include Swedish society at large, for instance its officials and public bodies such as police, state accident commission, county administration, hospital, fire fighters and safety officials, and Swedish Transport Administration.

4.4.2 *Root-cause using 5-why method.*

The investigation of all causes for this event is still underway since it is quite recent. The root-cause analysis presented in this section is based on available reports until November 2023. The first question is: “why was there a landslide on the E6?”. The reason behind this is the presence of large amounts of quick clay in the nearby areas. Quick clay is highly mobile and can cause landslides when triggered into motion. The next question is: “what are the triggers for quick clay, that set it into motion?”. As per studies (*What Is a Landslide and What Causes One? | U.S. Geological Survey*, n.d.), heavy rains, vibrations, stream erosions, and water level changes can all cause quick clay to mobilize. So, the next question in the analysis is: “what causes these triggering events?”. There are, of course, some environmental factors, beyond human control, which cause these triggering events. However, it is now being investigated whether some human activities increased the severity of the environmental events. For example, it is being studied whether the blasting work at nearby building sites or the landfill work in the vicinity had any impact on the landslide. Since the area has a high presence of quick clay, it is critically important to understand the triggers that mobilize it and minimize human activities in the area that aggravate the situation. Better risk assessment of natural events can also be helpful.

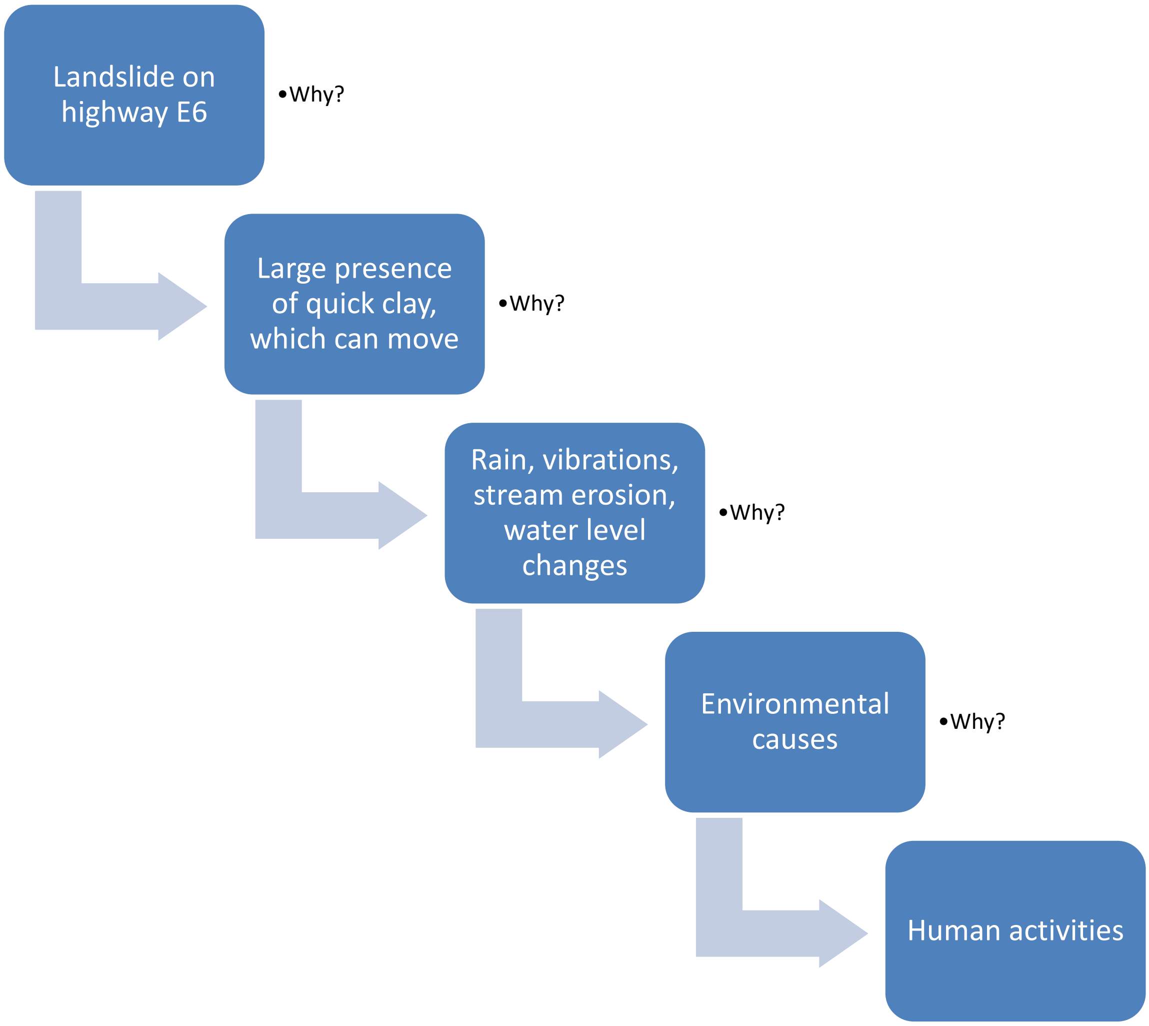


Figure 10: Root-cause analysis of landslide on E6

4.5 The Panama Canal congestion

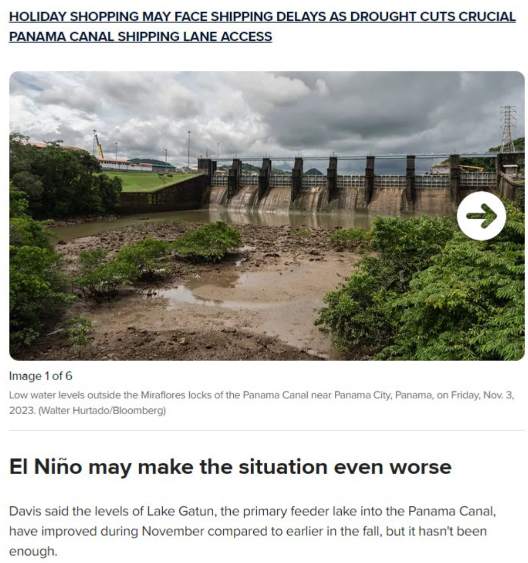
The Panama Canal was first operational in 1914, drastically reducing the maritime transit times between the Americas and Asia (*End Of The Construction*, n.d.). It is a maritime shortcut, that provided an alternative to traveling all the way around the southern tip of Central America, thereby saving time and cost of transporting goods. In recent times, the canal, operated by the Panama Canal Authority (ACP), is facing issues in managing consumer ship traffic going through the canal, largely due to the frequent droughts in Central America (Backas, 2023), (Jalanko, 2023). These droughts are leading to regular, lengthy queues of vessels waiting for passage through the canal (Partridge, 2023).

The canal operates through a series of water locks that transfer a vessel from one side to another. The water in these locks is sourced from the Gatun Lake, which has unfortunately seen a drastic fall in the water levels in recent years (Berman, 2023). To ensure safety, the ACP limits the number of vessels allowed to pass per day. When water levels are low, these numbers are reduced. As of December 2023, 24 vessels are being allowed per day, which might be reduced to 18 by February 2024 (Berman, 2023). Before the drought, up to 36 vessels could transit through the canal per day (Moreno et al., 2023).

Long delays at Panama Canal after drought hits global shipping route

Number of vessels able to pass through each day limited because lower availability of water

The canal is favoured by many shippers as it usually reduces cost and transit times. Photograph: Luis Acosta/AFP/Getty Images



HOLIDAY SHOPPING MAY FACE SHIPPING DELAYS AS DROUGHT CUTS CRUCIAL PANAMA CANAL SHIPPING LANE ACCESS

Image 1 of 6

Low water levels outside the Miraflores locks of the Panama Canal near Panama City, Panama, on Friday, Nov. 3, 2023. (Walter Hurtado/Bloomberg)

El Niño may make the situation even worse

Davis said the levels of Lake Gatun, the primary feeder lake into the Panama Canal, have improved during November compared to earlier in the fall, but it hasn't been enough.

(Partridge, 2023) (*Shipping Companies Bid Millions to Jump Lines for Drought-Stricken Panama Canal*, n.d.)

4.5.1 *Consequences and impact*

The droughts affecting Lake Gatun and the Panama Canal are expected to have significant implications on global supply chains. The canal is responsible for a sizeable portion of the global trade, with over 40 million tons, or nearly 5% of global maritime trade volumes passing through it per month (*Climate Change Is Disrupting Global Trade*, 2023). This situation can cause delays for vessels at the canal anywhere from one to two weeks (Berman, 2023). This has already resulted in increased lead time for shipments, such as those from China to the US east coast, with the median average lead time being 4 days longer (Berman, 2023). Although there may be some reduction in lead times after the holiday season, this issue is of rising concern for global transport networks. The impact of reduced slots in the canal is most severely felt by wet bulk vessels and dry vessels, as containerships have priority and have booked slots in advance (LaRocco, 2023). Further, some vessels are required to travel with a reduced load, even up to 40% of the maximum allowed load. These ships are then asked to unload part of their cargo, which is then transported either by rail or road to the other side of the Panama Canal (LaRocco, 2023). The Panama Canal is a great example of how a disruption in another part of the world can deeply impact the EU transport network. The Panama Canal is an important link that connects parts of EU to the Americas on the maritime shipping routes. The increased costs and delays would affect businesses in EU that have trade relations with the US and parts of South America.

4.5.2 *Root-cause using 5-why method.*

The first question to answer is why there is congestion at the canal. The reason is the reduced number of vessels allowed to transit (reduced reservations) by the ACP. The second question then follows, as to why the ACP has reduced the reservations. This is because of insufficient water levels in the locks, due to a water shortage in Lake Gatun.

Next, we ask why the lake has a water shortage. The answer to this is the phenomenon called El Nino, which has increased in frequency and intensity in recent years. This phenomenon occurs when the sea surface temperatures in the tropical eastern Pacific Sea increase by 0.5 degrees Celsius above the long-term average (Stallard & Poynting, 2023). The natural El Nino effect is increasing in frequency and intensity as result of climate change and global warming (Wilcox et al., 2023), which are caused by Greenhouse gas (GHG) emissions from burning of fossil fuels, farming, and other human activities.

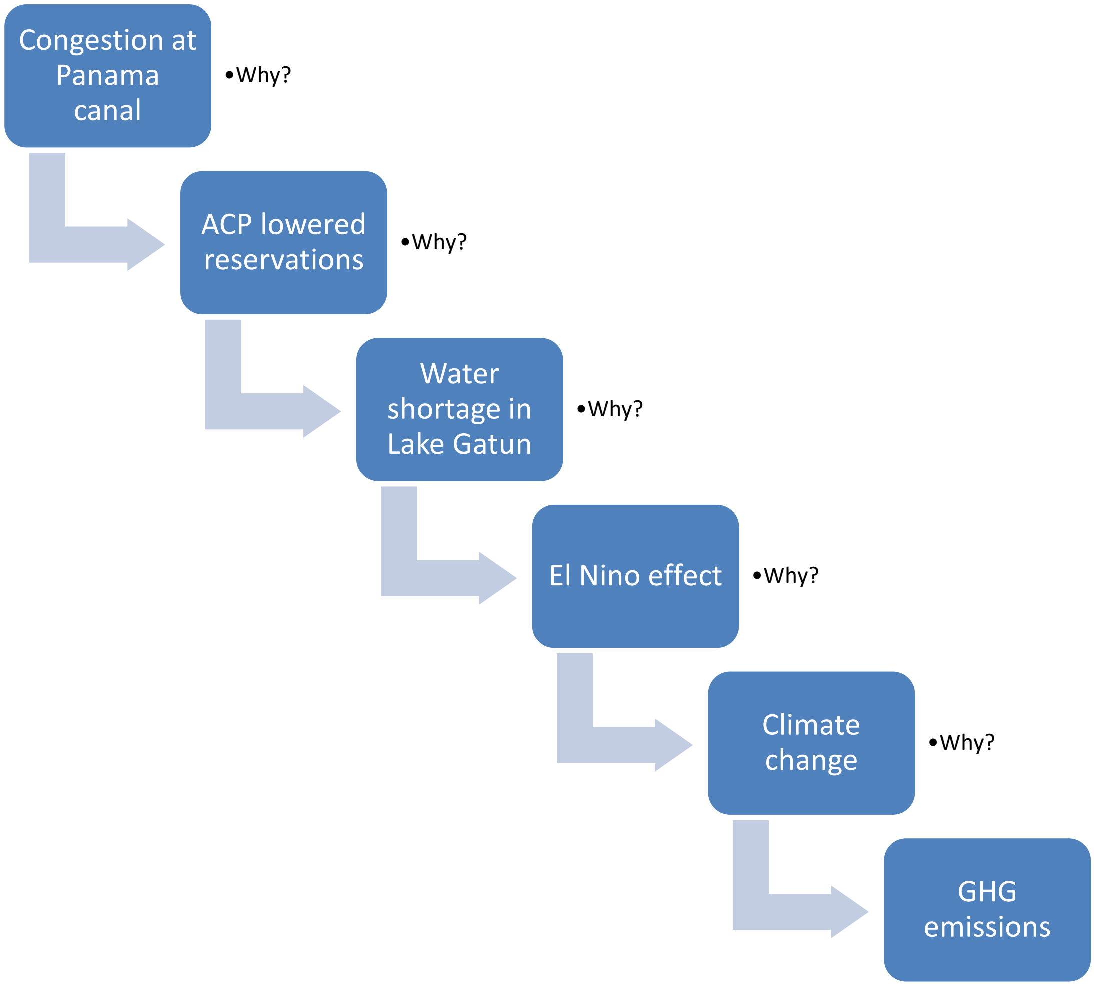


Figure 11: Root-cause analysis of congestion at the Panama Canal

5. Discussion

This report has presented different ways to analyse disruptive events, their (root) causes, consequences, and impacts. In Section 3, a broader level analysis is presented, that studies how seemingly different and distinct events might be correlated and cause further disruptions in the network. In Section 4, five recent disruptions affecting the EU transport network are chosen and analysed for their root-causes. The 5-why method is chosen due to its simple, easy-to-follow structure and wide applicability. The aim of these analyses was to highlight to the readers on how deep the actual cause of an event could be. The disruption may appear to have occurred due to a preliminary or direct cause (such as a landslide or a broken wheel), however, its effects could have been mitigated if the root-cause was understood or considered during risk assessment. While not all disruptions are preventable, all these events provide great learning potential on how to improve resilience and safety of our transport networks. An analysis of all related factors and causes of events that have happened can help prepare for the future and reduce losses to human life and materials.

The results highlight the need to bring all stakeholders and users of the system on the same page. This is crucial in correctly identifying the risks, assessing them, and designing mitigation strategies. An inadequate risk assessment can lead to recurring disruptions, such as the flooding in Slovenia. Similarly, for designing effective control protocols and regulations, stakeholders need to agree on perceived risks and possible challenges or disruptions. The accident in the Gotthard tunnel is an example of the severe consequences of not having up-to-date protocols.

The analysis in Section 3 shows that disruptions have interactive effects and can affect networks differently, depending on how they are connected. This raises some important issues with the EU network. As highlighted by interviewee 14, although we speak of the EU transport as a network, in reality, the sector is highly fragmented, with stakeholders deeply focussed on individual corridors and segments (Kulkarni et al., 2023). To complicate matters, stakeholders often benefit from disruptions in other modes. For example, disruption in rail due to electricity pricing or maintenance benefits road freight. Due to this structure, there is a need to incentivize stakeholders to look at the bigger picture and consider the implications of their actions and strategies on the wider network. When performing a risk assessment, it is essential to not just gauge the impact on one’s own business, but on how it can percolate across the network. One example of this, as pointed out by interviewee 1, is the lack of communication standards in the railway (Kulkarni et al., 2023). The EU is a region of multiple languages and cultures. When railways operate across countries, the drivers are required to be aware of local languages and operating procedures of that region. This limits the availability of personnel, who can take on such jobs. A standardized communication framework which is resilient to local cultural and language influences, similar to the one in place for air transport, can increase the reliance of the railways as a whole.

The disruptions events in Panama, the Rhine, Slovenia, and Sweden analysed in Section 4 clearly highlight that unless the root-cause is understood and addressed, there is a risk of recurrence of the event, sometimes with greater intensity, as evident in the case of the flooding in Slovenia. While some root causes are very fundamental, such as climate change for the low water levels of the Rhine and may not be possible to address at the level of a single stakeholder or even the whole network, their mitigation, for example through improved riverbed infrastructure, is still important to increase the resilience of the European transport network. However, when asked about the important factors in analysing disruptions, 100% of interviewees claimed impact and response is more important than cause. The emphasis was strongly on restoring normal operations of the transport network as soon as possible, with as little downtime as possible. While some of the interviewees added that the reporting of the events included some form of analysis of causes, it was not a priority (Kulkarni et al., 2023). This situation was well formulated as a question by an interviewee 15 who asked: “Are they economically incentivized to tackle the root cause?” (Kulkarni et al., 2023). The point raised here was that businesses and transport networks operate for profit. The issues that receive priorities are those that cost the businesses money.

5.1 Mega Root Causes

Root cause analysis has been used to further explore the causes of disruptions that formed part of the typology of disruptive events developed in WP 1.3. Based on the analysis of the cases presented in this report, as well as the wider analysis of disruptive events, five “mega root causes” emerged that are the underlying causes of the majority of disruptive events for the European transport network:

Climate Change and Biodiversity Loss: This root cause refers to the long-term changes in temperature, precipitation, and other climatic conditions often attributed to human activities (O’Brien, 2023). It also encompasses the loss of biodiversity, which is the variety and variability of life on Earth, as ecosystems are disrupted, and species become extinct. Both factors can lead to more frequent and severe weather events, disruptions in food chains, and increased vulnerability of infrastructure.

Social and Economic Changes: These changes include shifts in population demographics, economic growth or decline, changes in consumer behaviour, and societal values. Social changes can reflect alterations in demographics which could affect availability of truck drivers and other transport workers, while economic changes can involve fluctuations in markets, employment rates, and economic policies. Together, they influence demand and supply for transportation services and the regulatory environment.

Infrastructure and Maintenance: This root cause deals with the physical assets used in transportation networks and their upkeep. It covers the design, construction, operation, and maintenance of infrastructure components such as roads, bridges, ports, and railways. Adequate and proactive maintenance is crucial to prevent disruptions and extend the service life of these assets.

Human Behaviour: Human behaviour encompasses the actions, decisions, and practices of individuals and groups. In the context of transportation networks, it can include the operational decisions made by managers, compliance with safety protocols by workers, human error of operators, and the public's adherence to regulations. Human behaviour can significantly impact the efficiency and safety of transport systems.

Geopolitical Conflict: This cause involves the political and economic relations between countries that can impact global and regional stability. Geopolitical conflict can lead to war, sanctions, trade disputes, and political tensions that can disrupt transportation networks by closing routes, causing resource shortages, and shifting trade patterns.

More than one of the mega root causes can be applicable for a single disruptive event. They are not mutually exclusive. However, identifying these highlights the global challenges that underpin much of the disruption experienced by transport networks and an understanding of which is thus essential to enhancing resilience.

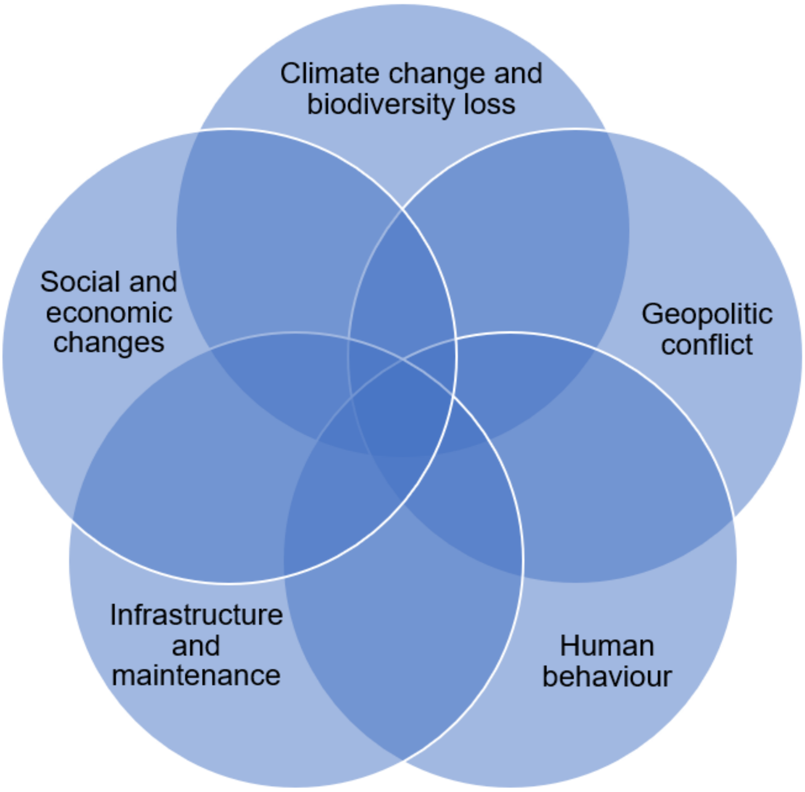


Figure 12: Mega root causes

While the mega root causes involved will differ for each disruptive event, there are certain mega root causes that are particularly strongly associated with certain causes as identified in the typology of disruptive events in ReMuNet WP 1.3. These links are highlighted in Table 2. Each written explanation explores a significant link between a mega root cause and a cause of disruptive events. Where there is no written explanation, the link is less significant for the majority of disruptive events with this cause.

Table 2: Causes of disruptive events and mega root causes

	Climate Change and Biodiversity Loss	Social and Economic Changes	Infrastructure and Maintenance	Human Behaviour	Geopolitical Conflict
Natural disasters	Climate change increases the frequency and severity of such events, impacting ecosystems.		Poorly maintained infrastructure can exacerbate the impact of natural disasters.		
Technological failures		Changes in economic	Failures often result from	Failure to update	

		conditions can affect investment in technology.	neglected maintenance or outdated systems.	systems or adhere to protocols can cause technological breakdowns.	
Regulatory changes	Environmental regulations have a major impact on transport.	Economic and social pressures can drive regulatory reform.		Changes in legislation can reflect shifts in public opinion and societal values.	International policies and treaties can bring about regulatory changes.
Security incidents				Security incidents are often the direct result of intentional malicious actions.	Geopolitical tensions can manifest as security threats to transport networks.
Accidents		Societal attitudes towards risk can influence the prevalence of accidents.	Accidents may stem from inadequate infrastructure or poor maintenance.	Human error is a significant contributor to accidents.	
Health emergencies	Altered ecosystems may influence the spread of diseases.	Public health policies and social behaviour greatly affect the spread and impact.		Individual and collective behaviours impact the spread and response to health crises.	
Capacity shortage		Economic growth can lead to increased demand, outpacing available capacity.	Shortages often due to lack of investment in maintaining and expanding infrastructure.	Operators may not scale up in time due to misjudgement of market signals.	
Geopolitical crisis					Crises can arise from resource-based conflicts aggravated by

					geopolitical tensions.
Extreme weather	Direct result of climate change, altering weather patterns.		Lack of resilient infrastructure can lead to susceptibility to weather events.		
Economic slowdown		Economic fluctuations can lead to a reduced demand for transport services.		Consumer confidence and spending habits can lead to economic downturns.	

5.2 Impact of Disruptive Events

This section builds on the typology for disruptive events developed in ReMuNet Task 1.3, especially its impact section, as well as findings from the primary data. It is crucial to acknowledge that disruptive events have cascading effects (Pescaroli & Alexander, 2015) that can have an impact far beyond individual nodes and links or even the transport network as a whole, impacting supply chains and society as a whole. Such cascading effects have been particularly evident during the COVID-19 pandemic and its aftermath, both regarding supply chains (Permal, 2022) and critical infrastructure (Barquet et al., 2023), but are also discussed in connection to the impact of climate change on transport (Vinke et al., 2022). Table 3 gives examples of impacts for the Rhine River droughts discussed earlier.

Table 3: Impacts of Rhine River droughts

Impact on individual actor	More challenging navigation for crew of river ships Rescheduling or cancelling shipments for freight forwarders Reduced income for barge operators due to inability to carry full loads
Impact on node/link	Decreased throughput for ports like Duisburg or Basel Congestion at inland terminals as goods cannot be shipped onwards Key sections of the Rhine (e.g. around Kaub) become impassable or have severe traffic restrictions Locks and docks must close temporarily or alter their operations

Impact for entire transport network	Pressure on alternative transport corridors (e.g. on rail and roads along the river) Efficiency of inland waterways as a sustainable major transport artery is questioned Need for robust contingency planning and investment in infrastructure capable of handling extreme weather events
Impact for supply chains	Gas and coal transports hampered at a crucial time of establishing independence from Russian imports Raw material shortages for key industries along the river (e.g. chemicals, steel) Global maritime transport affected as shipments do not arrive in Rotterdam or Antwerp as planned
Impact for society	Rising fuel prices as petrol moves most effectively along the river Exacerbated environmental concerns for communities along the river Wider political debate around maintaining transport infrastructure and enhancing resilience

Disruptive events can have profound effects on **individual actors** within the freight transport sector. Freight forwarders may face challenges in meeting delivery deadlines, leading to financial penalties and loss of reputation. Drivers can experience increased stress due to extended hours, delays, and rerouting (Chandiran et al., 2023). These disruptions can also lead to loss of income and job insecurity for individual's dependent on the efficiency and reliability of the transport network.

Ports, airports, distribution centres etc. serve as critical **nodes** in the European transport network. Disruptive events can lead to congestion at these nodes, with goods not being offloaded in time, resulting in storage challenges and increased dwell times (Verschuur et al., 2020). This inefficiency can ripple through the network, affecting scheduling and the overall throughput of the node. The resilience and flexibility of these nodes are tested during such times, often requiring additional resources to manage the disruption (Kim et al., 2015).

Transport **links** like roads, inland waterways, and railway lines are the arteries of the transport network. Disruptions can cause immediate bottlenecks, forcing freight to be rerouted, which in turn can lead to increased traffic on alternative routes and potentially overextend other parts of the network (Gedik et al., 2014). Maintenance and repair to restore these links can also be costly and time-consuming, leading to prolonged inefficiencies.

The European **transport network** is an interconnected system; thus, disruptions can have systemic effects. A localized issue can escalate into a network-wide problem, diminishing the overall capacity and fluidity of the transport system. Especially within intermodal transport, disruption within one transport mode has knock-on effects on others (Burgholzer et al., 2013), with respondents for example highlighting late arrival of trucks influencing port operations. Another cascading effect on the wider transport network occurs when freight is being shifted from one (disrupted) transport mode onto another. This can result in increased lead times, reduced reliability, and higher costs for shippers, which may impact the competitiveness of the European market.

Transport is a derived demand which relies on economic activity across **supply chains**. As such, supply chains are especially vulnerable to disruptions in the transport network. Just-in-time delivery models can collapse, leading to production delays and stockouts (Pujawan & Bah, 2022). The lack of goods movement can interrupt manufacturing processes and retail operations, causing financial losses and strained business relationships (Dolgui & Ivanov, 2021). Long-term disruptions can force businesses to rethink and redesign their supply chain strategies for greater resilience.

The **societal** impacts of disruptions in the transport network are broad and significant (Aldrighetti et al., 2021). They can lead to shortages of essential goods, increased prices for commodities, and even affect public welfare if medical supplies or food distribution are hindered. Several respondents shared anecdotes of their experiences during the COVID-19 pandemic when many members of the public realized the importance of transport to their daily lives. On a larger scale, persistent disruptions can impact economic growth and employment, as well as public confidence in the transport system and the authorities managing it. An example highlighted in multiple interviews was the perception of a bad state of repair in the German railway infrastructure resulting in wide-spread public opinions of rail transport as unreliable. In the long run, such events can shape policy discussions and influence public investment in infrastructure resilience.

5.3 Recommendations and Conclusions

This report presents the insights garnered from a literature review and qualitative analysis conducted by the team at Hanken School of Economics. This analysis delves into the multi-layered nature of disruptive events within the European transport network, focusing on both the immediate and underlying root causes, as well as the impacts of disruptive events. Drawing upon a data collection process comprising 17 interviews, two focus group discussions, and evaluations of 53 postgraduate students' assignments, the study illuminated the factors that precipitate disruptive events.

Central to this study was the application of the 5-whys method, a root cause analysis technique designed to get to the core of problems. Through this systematic approach, the complexities that lie beneath the surface of transport network disruptions were highlighted, represented in this report by a series of examples of recent disruptive events. The findings underscore not just the depth and interconnectivity of these causes but also their propensity to induce cascading effects across the network.

Based on this research, it is crucial to emphasize the interconnectedness of various stakeholders within the transport network. They are not merely independent units but integral components of a larger, interconnected system. Disruptions, therefore, should not be viewed solely through the lens of individual business impact but must be analyzed in the context of the entire supply chain and society. This big picture view is essential for developing strategies that address the cascading effects of disruptions across the transportation network. However, in the interviews conducted for this study, many respondents were focused solely on their own business interests with limited interest in or concern about the wider system.

Further work in this area should explore mechanisms to promote and incentivize a more systemic viewpoint. Such incentives would not only foster a deeper understanding of underlying issues but also motivate stakeholders to invest in long-term solutions. These measures could take various forms, including tax breaks, grants, or subsidies for businesses that invest in resilience planning and root cause analysis.

The report identifies five mega root causes that underpin the disruptive events observed. These are climate change and biodiversity loss, social and economic changes, infrastructure and maintenance, human behaviour, and geopolitical conflict. Each of these mega root causes has broad implications. Understanding these root causes of disruptive events is crucial to resilience planning and risk mitigation. This study has revealed that the immediate causes of transport network disruptive events are often just surface-level symptoms of deeper, more systemic issues. By identifying and documenting these mega root causes, stakeholders can move beyond quick fixes and reactive actions to implement more effective mitigation and adaptation strategies. While some disruptive events might be challenging to predict due to their complex nature, others, once their root causes are understood, can be anticipated, and managed more effectively.

By integrating the typology for disruptive events established in ReMuNet Task 1.3, the analysis presented in this report also shows the impact of disruptive events on different levels; individual actor, node/link, the entire transport network, supply chains, and societal level.

In conclusion, the integration of a systemic perspective in understanding and addressing transport disruptions, coupled with supportive economic policies, can significantly enhance the resilience and efficiency of the European transport network. The insights of this study are important l to the creation of a stakeholder-wide collaborative platform and an Artificial Intelligence (AI)-based self-learning transport network. Identifying the root causes and impacts of disruptive events will inform the mathematical models that will underpin subsequent work packages.

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7. Appendix

7.1 Individual assignment: root-cause analysis of disruptive events in logistics

This assignment accounts for 60% of the grade.
Deadline: 22nd November 2023
Word limit: 2500 words (excluding images, tables, and references).

Your task is to write an essay of root-cause analysis of disruptive events in EU transport supply chains, encompassing a literature review, and an analysis of specific scenarios. The aim is to provide a nuanced understanding of the multiple cause and effect relations in disruptions, both in terms of immediate consequences and their broader impact on the sustainability of European supply chains.

Answer the following questions in comprehensively:

1. Conduct a literature review of disruptive events in supply chains. Define disruptive events in supply chains and elaborate on potential causes.
2. Root- cause analyses of scenarios: Select any one scenario from the given six for in-depth investigation, including the following:
    a. Provide a concise overview of the disruption and its significance. Analyse the chosen scenario, considering its impacts on the supply chains. Include both the nodes and links of the underlying supply chain into your analyses.
    b. Perform a root-cause analysis using the "5 Why" method.
    c. Assess the consequences of the selected scenario and evaluate the broader impact of these disruptions on the European transport network. Examine how these disruptions affect the sustainability of supply chains? Include an analysis of stakeholder perspectives, emphasizing how different stakeholders are impacted.
    d. Provide recommendations on how the EU can prepare for future similar disruptive events.
3. Ensure a thorough and properly formatted list of references, including scholarly articles, books, and authoritative reports that informed your analysis.

Scenarios:

Scenario 1: https://www.theguardian.com/world/2023/aug/17/gotthard-base-tunnel-railway-train-closed-for-months-switzerland-derailment


Gotthard rail tunnel, world's longest, closes for months after Swiss derailmen

Sixteen freight carriages run off rails, tearing up eight kilometres of train track and leaving engineering marvel inaugurated in 2016 unable to take passengers

Scenario 2: https://yle.fi/a/74-20051595

A huge landslide destroyed a busy highway in Sweden

The cause of the accident is not yet known. According to the authorities, the rehabilitation of the road will take a long time.

Scenario 3: https://yle.fi/a/3-5087906

Scores of Ships Iced In

High winds creating pack ice out of ice floes have roadblocked shipping traffic in the northernmost and narrowest parts of the Gulf of Bothnia, which lies between Finland and Sweden.

Scenario 4: https://www.theguardian.com/business/2023/aug/14/drought-causes-queues-and-delays-for-ships-passing-through-panama-canal

Long delays at Panama Canal after drought hits global shipping route

Number of vessels able to pass through each day limited because lower availability of water

Scenario 5: https://www.reuters.com/markets/europe/german-industry-changes-tack-river-rhine-runs-drier-2023-07-26/

German industry changes tack as river Rhine runs drier

Scenario 6: https://www.dw.com/en/slovenia-austria-floods-leave-3-dead/a-66443381

Slovenia, Austria floods leave 3 dead

08/04/2023

Torrential rain struck the two countries overnight, causing severe floods and mudslides. The severe weather cut off several villages, sparked evacuations and closed major roads and rail lines.

The project

ReMuNet identifies and signals disruptive events and assesses their impact on multimodal transport corridors. It reacts quickly and seamlessly upon disruptive events in real-time. It supports TMS providers to improve route planning resilience. ReMuNet communicates alternative, pre-defined, multimodal transport routes to logistics operators and subsequently to truck drivers, locomotive drivers and barge captains. Through this, it enables a faster and adaptive multimodal network response. ReMuNet orchestrates route utilization, suggests transshipment points and optimizes capacity allocation, minimizing damage and shortening the recovery time. What is ReMuNet's core objective? As trailblazer for the Physical Internet, ReMuNet pursues the vision to enable and incentivize synchro-modal relay transport on European rail, road, and inland waterways to increase the holistic network resilience. It significantly reduces emissions and boosts freight transport corridor efficiency in case of disruptive events. stakeholders to ensure Europe-wide practicability and acceptance.

Coordinator: FORSCHUNGSINSTITUT FUER RATIONALISIERUNG (FIR)

PARTNER		SHORT NAME
fir RWTH Aachen University	FORSCHUNGSINSTITUT FUER RATIONALISIERUNG	FIR
HANKEN	SVENSKA HANDELSHOGSKOLAN	HANKEN
PTV GROUP	PTV PLANUNG TRANSPORT VERKEHR GmbH	PTV
4PL Intermodal	4PL INTERMODAL GMBH	INT
MANSIO truck meets truck	MANSIO GMBH	MAN
Fraunhofer AUSTRIA	FRAUNHOFER AUSTRIA RESEARCH GMBH	FHA
HAFEN WIEN ein unternehmen der wienholding	HAFEN WIEN GMBH	HWI
WHITE	WHITE RESEARCH SRL	WRE
UIRR UNION INTERNATIONALE POUR LE TRANSPORT COMBINE RAIL-ROUTE	UNION INTERNATIONALE DES SOCIETES DE TRANSPORT COMBINE RAIL-ROUTE SCRL	UIR
CONTARGO® trimodal network	CONTARGO GMBH & CO KG	CON

	VEDIAFI OY	VED
	DANSK RODE KORS (DANISH RED CROSS)	DRC
	ILMATIETEEN LAITOS	FMI
	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE	ETP-ALICE
	SCHACHINGER IMMOBILIEN UND DIENSTLEISTUNGS GMBH & CO OG	SCH