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Ripple effects of disruptive events in the European freight transport network

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Abstract

Purpose – This paper aims to advance understanding of freight transport network disruptions by reconceptualising them as systemic, multi-level phenomena. It examines how disruptive events originating in European freight transport networks generate ripple effects across transport networks, supply chains and society, and how resilience is expressed across these interconnected levels.

Design/methodology/approach – The qualitative, multi-stage research design combines focus group discussions, semi-structured interviews and document analysis. Data on four disruptive events is analysed using an analytical framework capturing ripple effects, intersectionality and resilience across transport network, supply chain and societal levels.

Findings – Disruptions generate ripple effects that propagate into supply chains and society. They vary in scale, scope and intensity, and intersect with existing vulnerabilities. Ripple effects are not linear but unfold through interacting and co-occurring dynamics across levels, highlighting the systemic nature of transport disruptions.

Research limitations/implications – The study is based on a limited number of qualitative cases and does not aim for statistical generalisation. It opens avenues for further research on multi-level disruption dynamics, ripple effects and transport network resilience.

Practical implications – The findings highlight the need for resilient transport infrastructure, improved coordination, and enhanced stakeholder communication to mitigate ripple effects.

Social implications – Freight transport disruptions have far-reaching societal consequences, emphasising the importance of preparedness, communication and disruption management.

Originality/value – The paper contributes to disruption and resilience literature by shifting analytical focus from individual firms and supply chains to freight transport networks and their societal embeddedness. By examining multiple disruptive events, it reveals shared vulnerabilities and recurring patterns of propagation.

Keywords Disruptive events, Resilience, Ripple effects, Transport networks

Paper type Research article

1. Introduction

Freight transport systems have experienced repeated, highly visible disruptions in recent years, arising from events such as the COVID-19 pandemic, the blockage of the Suez Canal, and prolonged droughts affecting the Panama Canal (Tran *et al.*, 2024; Singh *et al.*, 2021). These events highlight the vulnerability of freight transport networks. Yet, despite their centrality to the functioning of supply chains, transport networks themselves remain comparatively underexplored in the disruption literature (Albertzeth *et al.*, 2019; Cao *et al.*, 2025b), which has focused on supply chains rather than the transport infrastructures and services that enable them. Research on supply chain disruptions spans many industries and geographic contexts (cf. Pettit *et al.*, 2019; Scholten and Schilder, 2015), and has generated substantial insights into risk, resilience, and recovery (cf. Ambulkar *et al.*, 2015; Wang *et al.*,

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2024; Carnovale *et al.*, 2025). Studies examining freight transport networks, despite their critical role in sustaining economic activity and societal functioning, have received less systematic attention, particularly regarding how disruptions propagate beyond the transport system itself.

Disruptive events affecting freight transport networks can generate far-reaching effects (Cao *et al.*, 2025b). The COVID-19 pandemic illustrated how transport disruptions may coincide with, reinforce, or exacerbate disruptions in supply chains and be associated with broader societal impacts (Kovács and Falagara Sigala, 2021). While the concept of ripple effects has been examined within supply chains (Dolgui *et al.*, 2020; Ivanov and Dolgui, 2021; Moreno-Baca *et al.*, 2025), existing research has largely confined such analyses to intra-supply-chain dynamics. Less is known about how disruptive events in freight transport networks are linked to effects across transport systems, supply chains, and society, particularly when multiple disruptions overlap in time and context.

This paper aims to advance understanding of freight transport network disruptions by reconceptualising them as systemic, multi-level phenomena. It examines how disruptive events originating in European freight transport networks generate ripple effects across transport networks, supply chains, and society, and how resilience is expressed across these interconnected levels. To do so, the study adopts a perspective that recognises that disruptive events may generate interrelated effects that co-occur, reinforce one another, or manifest unevenly across different levels, without assuming simple linear causality.

Empirically, the article examines four disruptive events affecting European freight transport networks: flooding in the Rhine–Danube corridor in December 2023; droughts along the Rhine in July–August 2022; port strikes in Finland in March–April 2024; and the war in Ukraine since February 2022. These cases were selected to represent contrasting disruption contexts rather than to provide an exhaustive account of freight transport disruptions, and to open up a broader research agenda on freight transport network disruptions and their wider implications. The study addresses the following research questions:

RQ1. How do disruptive events in the European freight transport network affect the freight transport network, supply chains, and societal levels?

RQ2. How is resilience expressed across transport network, supply chain, and societal levels in relation to disruptive events in the European freight transport network?

The remainder of this paper is structured as follows. Section 2 reviews relevant literature on disruptions in transport networks and supply chains, with particular attention to ripple effects and interdependencies across levels, as well as resilience. Section 3 outlines the data collection and analysis approach. Section 4 presents the findings, and Section 5 discusses implications for research, practice, and policy, as well as directions for future research.

2. Literature review

This literature review is intended as a critical, theory-driven synthesis rather than a systematic or exhaustive review. It positions the study theoretically and identified key conceptual limitations and research gaps relevant to the paper's contribution. The reviewed literature was identified through an iterative process combining targeted searches in major academic databases (e.g. Scopus and Web of Science), backward and forward citation tracking, and snowballing within the transport disruption, ripple effect, and supply chain resilience literature. Literature was selected and organised based on its relevance for developing the study's analytical framework and theoretical positioning.

2.1 Freight transport network disruptions

A disruptive event is commonly defined as an unplanned and unexpected occurrence that interferes with the usual operations of organisations (Ivanovic *et al.*, 2025). In the context of freight transport, such events challenge the stability of transport networks and the continuity of freight flows, often generating cascading consequences that extend beyond the immediate disruption (Cao *et al.*, 2025a; Albertzeth *et al.*, 2019). Disruptions within freight transport networks can arise from internal events, such as traffic accidents, blockages, and infrastructure failures (Cao *et al.*, 2025a; Tran *et al.*, 2024), as well as from external events, including natural hazards such as floods, landslides, heavy snowfall, storms, wildfires, and earthquakes (Rahimitouranposhti *et al.*, 2025; Woodburn, 2019). Human-induced crises, including strikes, pandemics, and geopolitical conflicts, further contribute to transport network instability, resulting often in widespread shutdowns, port closures, labour shortages, and reduced freight capacity (Fu *et al.*, 2022; Dirzka and Acciaro, 2021; Rahimitouranposhti *et al.*, 2025). In the context of this research, we consider human-induced crises to be those directly caused by human activity (e.g. terror attacks), as well as those spread by human behaviour (e.g. pandemics). We acknowledge that the categorisation by causes is not always clear as for example wildfires may also have a human cause but are commonly understood as natural disasters while pandemics have a natural cause but unfold their full destructive potential because of human actions.

Empirical studies in this stream largely focus on immediate performance impacts, such as delays, reduced reliability, capacity losses, and cost increases (cf. Tran *et al.*, 2024; Woodburn, 2019). These studies show that even the loss or impairment of a small number of critical nodes or links can disproportionately reduce network capacity and freight throughput, particularly when disruptions occur at central or heavily utilised network links or nodes (Rahimitouranposhti *et al.*, 2025), as illustrated by the Suez Canal blockage (Tran *et al.*, 2024) and the Baltimore bridge collapse (Zahedian *et al.*, 2025). At the same time, the scope and scale of transport disruptions vary considerably by disruption type, for instance, while accidents and technical failures are often localised and affect specific routes or modes, disruptions caused by natural hazards tend to cover larger geographical areas and may persist over longer periods (Cao *et al.*, 2025a; Rahimitouranposhti *et al.*, 2025).

Despite growing evidence of large-scale and prolonged transport disruptions, much of the literature continues to frame them as discrete events, overlooking their overlapping and systemic nature as observed during the COVID-19 pandemic, climate-related disruptions, and geopolitical conflicts (Dirzka and Acciaro, 2021; Cao *et al.*, 2025a; Dolgui *et al.*, 2020). Moreover, research remains fragmented, with most studies focusing on individual disruption types or isolated events. Table 1 provides an overview of key examples of disruption types and impacts from the literature. While such event-specific analyses provide valuable insights into particular disruption mechanisms, they offer limited insight into how disruptions interact, accumulate, or reinforce one another within freight transport networks and across interconnected systems.

2.2 Ripple effects and intersectionality of disruptive events

Ripple effects are the chain of indirect, often unanticipated outcomes that arise from an initial disruptive event and extend beyond its immediate operational consequences (Ivanov and Dolgui, 2021). These effects may be positive or negative and typically influence broader systems and stakeholders across time and space. In a supply chain context, ripple effects refer to the cascading propagation of disruptions from one node or firm to others, often resulting in widespread operational, financial, and reputational impacts across interconnected networks (Ivanov and Dolgui, 2021; Moreno-Baca *et al.*, 2025). Dolgui *et al.* (2020, p. 1286) define the ripple effect as the "downstream propagation of the downscaling in demand fulfilment in the supply chain as a result of a severe disruption," emphasising the role of multi-stage network structures and domino-like failures among interdependent elements (cf. Ivanov and Dolgui, 2021).

The literature suggests that ripple effects materialise through different types of impacts, which can be distinguished by the clarity of their relationship to the initial disruption and the

Table 1. Summary of disruption types, impacts, and literature examples in freight transport networks

Type of disruption	Description of impact	Examples from literature	Citations
Natural disasters	Sudden events (e.g. floods, earthquakes, extreme weather) causing infrastructure damage, delays, or network paralysis. Tend to cover larger geographical areas and may persist over longer periods	Climate-induced disruptions, particularly heatwaves, are likely to become persistent rather than episodic, posing long-term threats to transport network resilience and freight capacity. Extreme weather events causing rail line closures, leading to fewer trains, longer journeys, and supply chain delays	Woodburn (2019), Rahimitouranposhti *et al.* (2025), Hrušovský *et al.* (2021)
Infrastructure failure	Breakdown or loss of key nodes/links (e.g. bridge collapse, tunnel closure) disrupting connectivity	Closure of Lamington Viaduct in the UK rail network; node removal reducing network tonnage capacity by up to 80% The collapse of the Francis Scott Key Bridge in Baltimore resulted in significant increases in travel time for all alternative routes, increased congestion, diminished reliability, and more accidents	Woodburn (2019), Rahimitouranposhti *et al.* (2025), Zahedian *et al.* (2025)
Accidents and incidents	Unexpected link closures or severe delays; missed time windows; hazardous material spills; higher costs and CO_2; need for rapid re-planning and rerouting. Often localised and affect specific routes or modes, depending on the criticality of the node	Accidents temporarily block transport links, causing delays and service infeasibility that require operational re-planning. The Suez Canal blockage triggered extensive vessel delays and rerouting, resulting in significant ship, inventory, and environmental costs across global maritime supply chains	Hrušovský *et al.* (2021), Tran *et al.* (2024)
Capacity degradation	Partial loss of network capacity due to congestion, maintenance, or weather, increasing travel times	Unexpected link disruptions reduce effective network capacity through delays and missed connections, necessitating real-time re-planning. Capacity degradation occurs when port failures trigger load redistribution, causing congestion and cascading declines in network connectivity and efficiency	Hrušovský *et al.* (2021), Cao *et al.* (2025b), Gu *et al.* (2023)

(*continued*)

Table 1. Continued

Type of disruption	Description of impact	Examples from literature	Citations
Human-induced crisis	Events like pandemics, financial crises, strikes or geopolitical turmoil causing widespread disruption	Targeted attacks that intentionally affect the most critical nodes or links in a transport network, resulting in disproportionately large system-wide impacts compared with random failures. Strikes of transport workers such as truck drivers can effectively blockade a national economy and harm key sectors. The war in Ukraine has resulted in extensive rerouting of flights between Europe and Asia and disrupted Danube and Black Sea shipping, as well as energy and grain flows and European rail and road freight corridors, generating prolonged capacity constraints and cascading impacts across transport networks and supply chains	Fu *et al.* (2022), Dirzka and Acciaro (2021), Rahimitouranposhti *et al.* (2025), Singh *et al.* (2021), Zhao *et al.* (2024), Nowak (2022), Ivannikova *et al.* (2024), Cao *et al.* (2025a)

Source(s): Authors' own work

system level at which they occur. *Direct ripple effects* arise from the immediate operational consequences of disruptions at the transport network level, such as capacity reductions, delays, blank sailings, and reduced reliability. These effects propagate into supply chains, resulting in inventory shortages, missed deliveries, lost sales, reduced profits, and declining service performance (Albertzeth *et al.*, 2019; Dolgui *et al.*, 2018; Ghadge *et al.*, 2021). Importantly, Albertzeth *et al.* (2019) show that even when production facilities remain unaffected, transport-induced capacity degradation alone can generate substantial downstream performance losses, highlighting transport networks as active sources of ripple effects rather than passive conduits. Large-scale disruptions such as the COVID-19 pandemic and the Suez Canal blockage provide clear examples of direct impacts, as disturbances at critical transport nodes rapidly translated into delays and operational breakdowns across global logistics and distribution networks (Tran *et al.*, 2024; Dirzka and Acciaro, 2021; Notteboom *et al.*, 2021).

Beyond these immediate effects, prior literature demonstrates *indirect or interactive effects* in which disruptions interact with concurrent shocks and structural vulnerabilities. Due to the high interconnectedness of global supply chains, a disruption originating within the transport network can propagate across multiple tiers of suppliers and customers, amplifying risks and compounding negative outcomes (Hosseini *et al.*, 2019; Ghadge *et al.*, 2021; Dolgui *et al.*, 2018; Albertzeth *et al.*, 2019). Empirical evidence from the COVID-19 pandemic illustrates how transport constraints interacted with production shutdowns and demand volatility, leading to substantial declines in freight volumes, reduced industrial output, and spillover effects affecting non-transport sectors and the wider economy (Cui *et al.*, 2021; Fu *et al.*, 2022). However, much of the ripple-effect literature remains rooted in supply chain-centric modelling approaches, often treating transport networks as exogenous or simplified inputs, thereby limiting insight into how transport network characteristics shape the emergence, propagation, and severity of ripple effects.

A third category comprises *co-occurring effects* that arise within the same temporal window as a disruption but for which a clear causal link cannot be established. These effects are most evident at the societal level, where transport and supply chain disruptions coincide with broader socio-economic changes. For example, periods of large-scale transport disruption have been associated with temporary reductions in emissions and noise due to decreased mobility, while simultaneously coinciding with reduced access to essential goods, healthcare services, and emergency response capabilities (Dolgui *et al.*, 2018; Kovács and Falagara Sigala, 2021; Wassmer *et al.*, 2024). Although such effects cannot always be directly attributed to transport disruptions alone, their concurrence highlights the broader systemic context within which ripple effects unfold and affect societal well-being.

The literature, thus, indicates that ripple effects propagate across interconnected transport, supply chain, and societal systems, with impacts spreading both downstream toward customers and upstream toward suppliers (Dolgui *et al.*, 2018; Ghadge *et al.*, 2021; Hosseini *et al.*, 2019). The severity of these effects is shaped by node-level vulnerability and risk absorption capacity, as more resilient actors are better positioned to absorb shocks and prevent escalation across system levels (Li *et al.*, 2020; Li and Zobel, 2020).

Transport disruptions operate across multiple, interconnected levels. At the transport network level, disruptions reduce infrastructure availability and capacity, leading to delays, congestion, and rerouting. These effects propagate to the supply chain level, where impaired transport performance disrupts material flows, increases inventory and delivery risks, and undermines service reliability (cf. Albertzeth *et al.*, 2019). In prolonged or large-scale events, impacts extend further into the societal domain, manifesting as shortages, price pressures, and heightened public and policy attention (Notteboom *et al.*, 2021; Cui *et al.*, 2021). This multi-level perspective highlights that transport disruptions are not confined to operational failures but evolve into broader systemic challenges (Li *et al.*, 2020; Li and Zobel, 2020; Ivanov and Dolgui, 2021). Despite increasing recognition of societal consequences, these impacts are often treated as secondary or residual outcomes rather than integral components of disruption dynamics. Citizens and public institutions are therefore rarely conceptualised as active stakeholders in ripple-effect processes, even though they are significantly affected by large-scale, prolonged transport disruptions.

Intersectionality of transport disruptions refers to the overlap or convergence of multiple factors or events affecting transportation systems simultaneously (Steinfield *et al.*, 2021). This intersectionality can involve various types of disruptions, such as natural hazards, geopolitical conflicts, infrastructure failures, or technological breakdowns, occurring concurrently or sequentially within the transport network. Unlike ripple effects, which focus on the spread of disruptions within a specific system (e.g. supply chain) (c.f. Dolgui *et al.*, 2020), the intersectionality of transport network disruptions emphasizes the multifaceted nature of disruptions affecting transportation infrastructure, services, operations, and society at large. These disruptions may interact and compound, creating complex challenges for transportation stakeholders and users. For instance, the intersectionality of the economic, climate and digital crises along with the war in Ukraine and the lingering effects of COVID-19 has significantly impacted the transport sector.

2.3 Resilience in transport networks and supply chains

Effective disruption management and resilience across different system levels are essential for mitigating the negative impacts of transport network disruptions and maintaining supply chain continuity. Accordingly, supply chain resilience has received growing attention in the academic literature (cf. Pettit *et al.*, 2019; Scholten and Schilder, 2015), with research predominantly focusing on firm- and network-level vulnerabilities, as well as mitigation and recovery strategies (cf. Ambulkar *et al.*, 2015; Wang *et al.*, 2024; Carnovale *et al.*, 2025).

Supply chain resilience can be defined as the adaptive capability to prepare for, respond to, and recover from disruptions while maintaining operational continuity (Scholten *et al.*, 2025) and it entails the ability to return to normal performance levels following a supply chain disruption (Behzadi *et al.*, 2020). Resilience can be divided into two categories (Wei *et al.*, 2022). Static resilience refers to the ability to maintain a high level of functionality in a system impacted by external shocks. Static economic resilience specifically refers to the capability to use remaining resources efficiently at a specific point in time, essentially measuring how well a system can continue operating despite disruption. Dynamic resilience refers to the capability and speed by which a system recovers from external shocks. Dynamic resilience focuses on how resources can be utilized efficiently for repair and reconstruction throughout the recovery period. Supply chains frequently face multiple disruptions that occur simultaneously, creating significant challenges for maintaining operational continuity (Ivanovic *et al.*, 2025). These underscore the need for supply chains to rebuild with resilience to effectively respond to challenges posed by systemwide disruption. Transport network resilience is conceptually related to supply chain resilience, as both are concerned with how organizations must deal with disruptions. At transport network level, resilience refers to the ability of a transportation system to absorb, adapt to, and recover from disruptions while maintaining its essential functions and services (Cao *et al.*, 2025b). A resilient transport network can withstand various shocks and stresses, such as natural hazards, accidents, infrastructure failures, or other disruptive events, without experiencing significant downtime (Albertzeth *et al.*, 2019). At a societal level, resilience refers to ability of the society or social entities (not just individuals or organizations) to reach an equilibrium after a shock and to renew itself while going back to normal functioning after the disruption (Anholt *et al.*, 2021). These approaches emphasize the collective ability of various stakeholders, including individuals, institutions, communities, societies, and social systems to withstand, adapt to, and recover from disruptions while maintaining essential functions and services.

Figure 1 summarises the analytical framework of this study linking transport network disruptions to ripple effects, intersectionality, and multi-level resilience.

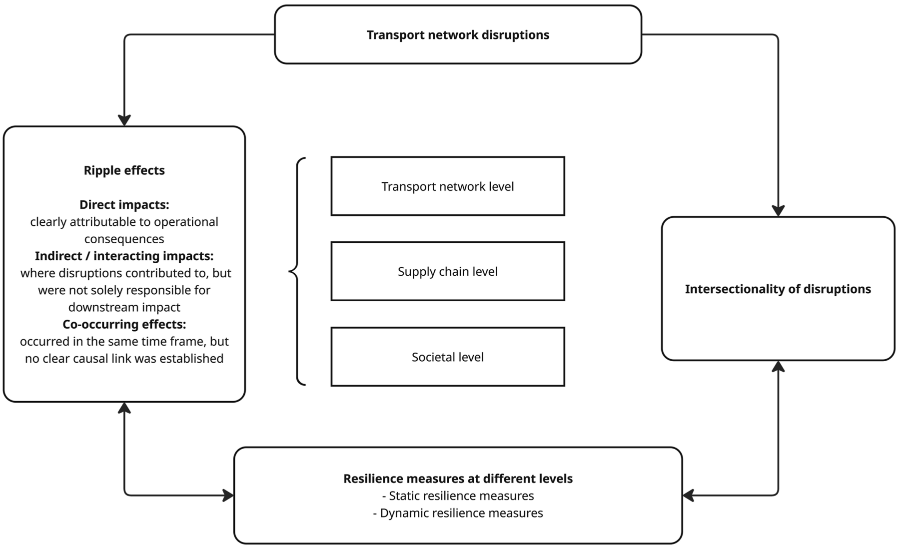

Figure 1. Analytical framework of this study. Source: Authors' own work

3. Methodology

This study draws on data from focus groups, interviews, and document analysis. A multi-stage qualitative design is employed, with each stage informing the next (Bingham, 2023). The research process (Figure 2) involved four sequential steps. First, focus group discussions with practitioners and academics familiar with the European freight transport network resulted in an overview of recent disruptive events and their characteristics. Four events were selected for further study. In a second round of focus group discussions, impacts of these four events were mapped and intersectionality and ripple effects discussed. Then, more data was collected on each of the four events, their effects, and resilience measures through semi-structured expert interviews and the gathering of relevant documents. Based on this data, descriptions of the disruptive events were produced, and ripple effects, intersectionality, and resilience were analysed across the events, as well as the transport network, supply chain, and societal level (see analytical framework in Figure 1). Portions of the manuscript were copy-edited using the generative AI tool ChatGPT (version 5.2) to improve clarity, grammar, and readability. The authors retain full responsibility for the accuracy, integrity, and originality of the content.

3.1 Initial focus group discussion: identification of events, causes, and characteristics

The first round of focus group discussions consisted of 22 participants organized into three groups of 6–8 people (Sim and Waterfield, 2019). Participants were European freight transport experts, including infrastructure managers, logistics operators, members of government agencies, and policymakers. All participants had professional experience with multimodal freight operations and had been affected by at least one major transport disruption in the past five years. During the session, they collaboratively identified prominent recent disruptive events and categorised them by cause, scope, and scale. The participants were then asked to deepen the analysis by reflecting on what factors would be most useful for comparing these events. Instead of being provided with predefined categories, the participants generated an initial set of characteristics of disruptive events. During the subsequent discussion session, each group presented their proposed characteristics, which helped with clarification of meanings, and consolidation of overlapping ideas. Through this iterative group deliberation, the characteristics of cause, time duration, geographical extent, predictability, recurrence, probability, and criticality were agreed upon as characteristics for differentiating disruptive events. This consensus-building process ensured that the selected characteristics reflected the shared understanding of the participants rather than the research team's prior assumptions.

Based on these characteristics, the groups then discussed various disruptive events based on their experience. To ensure that participants could provide accurate and detailed recollections of the events, their operational responses, and the consequences, the discussion was limited to

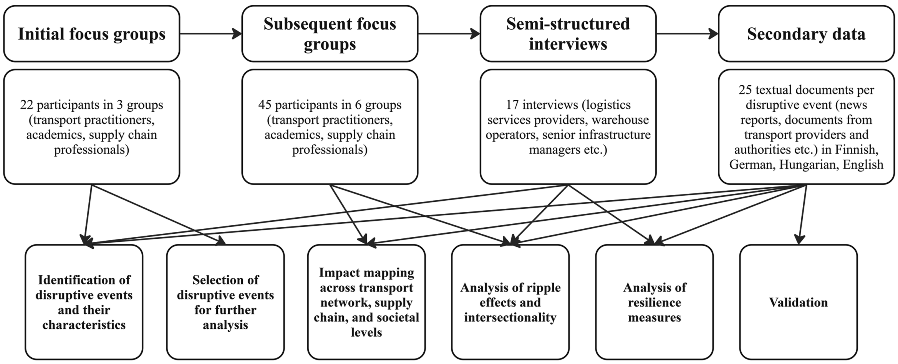

Figure 2. Research process. Source: Authors' own work

events from 2020 onward. This temporal focus also enhanced cross-case comparability across the three data sources used in this study (focus groups, expert interviews, and media analysis), as it captures a period characterised by a dense sequence of highly visible and well-documented disruptions. This ensured both the relevance and traceability of the examined events. From the discussed events, four disruptive events were selected (see Table 2) to encompass diverse characteristics. Additionally, the selection of events was guided by participants anticipating meaningful intersectionality patterns and ripple effects, thereby ensuring the selected events would provide sufficient analytical depth for examining these complex phenomena.

3.2 Second focus group: deepening the analysis

The second focus group discussion session included 45 participants all based in Finland, but with practical exposure to European freight transport and supply chain operations. Most participants also held advanced degrees in supply chain management. The participants were divided into six groups of 6–8 people. In this session, participants concentrated on the four selected disruptive events (Table 2) and developed a detailed analysis of the impacts across the transport network, supply chain, and societal levels, utilising flipcharts and sticky notes to support their discussion. Their task was to analyse the chain of operational consequences, broader ripple effects and intersectionality, as well as the resilience measures expressed.

3.3 Semi-structured interviews

A total of 17 semi-structured interviews were conducted to gain insight into the effects of each disruptive event. Interviewees included infrastructure managers, logistics operators, members of government agencies, and other stakeholders in the European freight transport network (see Table 3). The interviews covered the background and role of the participants, their experience with recent disruptive events, ripple effects emanating from them, the resilience measures, and their perspectives on future risks. A careful effort was made to include respondents representing different modes of transport and ensure multimodal coverage. The semi-structured interviews allowed for systematic coverage of key themes while retaining the flexibility to explore event-specific dynamics, cross-level ripple effects, and resilience measures as they emerged from participants' accounts.

The sampling strategy followed the geographical scope of the four selected events, which concentrated on two Trans-European Transport Network (TEN-T) corridors: the North Sea–Baltic Corridor and the Rhine–Danube Corridor (Öberg *et al.*, 2018). These corridors represent

Table 2. Characteristics of disruptive events

Characteristics	Rhine-Danube floods 2023	War in Ukraine from 2022	Rhine droughts 2022	Port strikes Finland 2024
Cause	Climate change	Complex social, economic, historical, ideological	Climate change	Human factors
Time duration/ scope	17 days	Ongoing since February 2022	~6 months	Four weeks
Geographical extent/scale	Multiple neighbouring countries	Europe-wide, potentially global	Stretches of the river mainly in Germany	All main ports in Finland and railways
Predictability	High	Low	Medium	Medium
Recurrence probability	High	Medium	Medium	Medium
Criticality	Medium	High	Medium	High

Source(s): Authors' own work

Table 3. Interviewee details

Identifier	Role	Sector	Transport mode	Country
#1	Technical director	Combined transport	Rail, road	Belgium
#2	Member of management board	Terminal operator	Rail, road, shipping, warehouse	Estonia
#3	Founder	Road freight relay	Road	Germany
#4	Manager	Network planning	Rail, road	Germany
#5	Head, digitalization	Air freight	Air, road	Switzerland
#6	Managing director	Terminal operator	Rail, road, inland shipping	Austria
#7	Transport consultant	Combined transport	Rail, road, terminal	Lithuania
#8	Head of sales	Network planning	Rail, road, inland shipping	Germany
#9	Senior project manager	Combined transport	Rail, road, inland shipping	Germany
#10	Managing director	Combined transport	Rail, road	Germany
#11	Logistics development manager	Government transport agency	Road, inland waterway	Finland
#12	Sales manager, specialist	Terminal operator	Rail, road	Finland
#13	Consultant	Humanitarian logistics	Air, rail, road, inland shipping	Denmark
#14	Founder	Combined transport	Rail, road, inland shipping	Germany
#15	Consultant	Maritime shipping	Shipping	Estonia
#16	Data manager	Terminal operator	Port	Finland
#17	Project manager	Combined transport	Rail, road, inland shipping	Germany

Source(s): Authors' own work

critical multimodal freight routes in Europe. Interviewees were accordingly selected from countries along these corridors and from organisations operationally linked to them, ensuring direct experience of the disruptive events and the ability to provide context-rich, corridor-specific insights relevant to the research questions (Robinson, 2014). The focus in the interviews lay on the analysis of ripple effects and intersectionality, as well as resilience measures.

3.4 Secondary data analysis

Along with focus group discussions and interviews, we conducted a systematic news media data analysis following Altheide and Schneider (2013). A purposeful media sampling strategy was applied (Newbold *et al.*, 2002), selecting news according to their relevance to the four disruptive events. The full list of 100 media articles is provided in Appendix. The articles are sectioned in four groups: Rhine droughts 2022 (D), Rhine-Danube floods 2023 (F), War in Ukraine from 2022 (W) and Port strikes Finland 2024 (S) and article identifiers (such as D1, or W7) will be used throughout the Findings section.

The data sources included national news agencies (such as Yle-Finland, DR-Denmark, and NRK-Norway), international news aggregators (such as Reuters and AFP) and official documents of transport authorities (such as Deutsche Bahn, DSB, and VR). A manual web search was conducted using keywords derived from the disruptive events along with the time frame. Multiple sources were cross-referenced to confirm findings. Ambiguous news reports without clear dates, locations or impact descriptions were excluded from the sample. 25 articles per event were included after screening. Consistent with the principle of theoretical saturation (Glaser and Strauss, 1967), sampling was discontinued once additional articles did not reveal new empirical properties of the disruption categories or further insights into ripple effects across transport networks, supply chains, and societal levels. News coverage for each event converged rapidly, with the main disruption mechanisms, ripple effects across transport networks, supply chains, and societal levels, and key timelines already fully articulated within the first 10–12 articles. Additional articles largely reiterated these established patterns without introducing substantively new insights. Given the high visibility and extensive documentation of the four events, a larger media sample would have increased volume rather than analytical depth. Accordingly, approximately 25 articles per case provided an adequate and robust empirical basis for tracing ripple effects while maintaining a manageable and focused dataset.

3.5 Analyses of ripple-effect, intersectionality and resilience measures

Our analysis integrated data from focus groups, semi-structured interviews, and secondary data. Primary data was transcribed and where necessary, translated into English. These materials were uploaded into NVivo software for structured coding and thematic analysis across events.

Guided by the analytical framework (Figure 1), two researchers independently read and coded all materials for event characteristics, impacts, ripple effects, intersectionality, and resilience measures. Initial coding focused on each disruptive event separately, resulting in detailed case narratives that are summarised in Section 4.1. Coding outputs were then compared, with recurring themes, convergent observations, and discrepancies identified through iterative discussion. Through this process, a shared and refined set of codes was developed.

Following event-specific coding, the analysis proceeded to a cross-event comparison to examine how impacts, ripple effects, intersectionality, and resilience measures manifested across the four disruptive events (Section 4.2–4.4). This two-step approach, comprising (1) within-event analysis and (2) cross-event comparison, enabled the identification of recurring patterns and key differences across cases.

To strengthen reliability, interpretations were cross-checked by both researchers and reviewed by a third researcher. Any discrepancies (e.g. differing interpretations of impacts or ripple effects) were resolved through discussion and by returning to the original data when necessary. Cross-source comparison was applied throughout the analysis to reduce bias associated with any single data source and to ensure consistency across focus groups, interviews, and media material.

Ripple effects analysis employed the scale and scope characteristics identified in the first focus group. Using these, the impact of each event was traced across three interconnected levels: transport network, supply chain, and societal systems (Kachali *et al*., 2018). We systematically traced the impact between these levels to understand how disruptions propagated through interconnected levels. The observed linkages were categorized into three types (see Section 2.2): 1) direct impacts, which were clearly attributable to operational consequences, 2) indirect or interacting impact where disruptions contributed to, but were not solely responsible for downstream impact, and 3) co-occurring effects that occurred in the same time frame, but no clear causal link was established. Stakeholder accounts were iteratively compared with secondary data to gauge whether operational disruptions propagated through shared dependencies, timing overlaps or structural bottlenecks.

Intersectionality analysis synthesised insights by examining how the disruptive events and their ripple effects interacted with existing vulnerabilities. The effect of the interplay of different disruptive events on similar transport modes and nodes was explored, along with broader contextual factors such as geopolitical tensions and energy prices.

Resilience analysis evaluated resilience measures across all three analytical levels (transport network, supply chain and societal). Following the conceptual framework established by Wei *et al.* (2022), these measures were categorized as either static (pre-existing structural capacities and resources) or dynamic (adaptive responses and adjustments to disruptions). Interviewees were questioned regarding their specific responses to disruptive events and any subsequent organisational actions implemented to enhance future preparedness capabilities. This information offered key insights into transport network resilience, while secondary data supplemented the analysis of resilience measures at the supply chain and societal levels.

4. Findings and discussion

This section begins by first describing each of the four disruptive events, highlighting their key characteristics and the extent of their impact. Then ripple effects, intersectionality and resilience are discussed.

4.1 Description of disruptive events

4.1.1 Floods along the Rhine-Danube corridor in December 2023. Northern and central Europe grappled with heavy rainfall in December 2023, with major rivers recording high water levels (F1, F4, F19). The Rhine-Danube corridor is central to linking industrial heartlands in Central Europe to the Black Sea and North Sea ports (F12, F16). The floods were an example of the increase in both frequency and magnitude of climatic disruptions to the transport network. According to interviewee #13: *"you suddenly also have a lot more disruptions from climate now impacting, [. . .] this will only increase as the climate crisis or the consequences of the changing climate evolves and unfolds [. . .] areas that were not before prone to disasters suddenly have disasters or disruptions, like Germany last year when you had the floodings"*.

Hydro-meteorological hazards such as floods are recurrent events in the joint Rhine-Danube and Rhine-Alpine corridors (F12, F16). In December 2023, shipping on the Rhine and Danube was stopped but could resume as flood waters receded as wider transport infrastructure damage was avoided, limiting the duration of the disruption (F17, F20). There was mass displacement of people from their homes, with outages to power and sewage lines (F13). Floods along this corridor are a recurrent disruption, preparedness is comparatively high, with practiced response mechanisms in place that contain the impact (F7, F16).

4.1.2 Rhine droughts of July–August 2022. The Rhine is a critical transport artery for Germany and Europe, as it links industrial centres in Germany, France, and Switzerland with seaports in the Netherlands and Belgium (D1, D6), especially for dry and liquid bulk commodities (D4). In summer 2022, drought and heatwaves reduced water levels to record lows, thus forcing vessels to drastically reduce their load (D6, D16, D17). This resulted in escalating costs and delays to shipments (D2, D6, D11). Inland waterway freight volumes dropped significantly in August 2022 at −26.8% compared to the previous year (D4, D13). Shipping firms halted or curtailed their operations (D1, D19). German industrial production falls by 1% for each month that water levels on the Rhine are low (D1, D14).

A significant shift to other transport modes was observed, which interviewee #6 regarded as an opportunity to highlight the advantages of road freight, saying: "*The trucks can adjust quite quickly to circumstances. So, what we see for the time being, everybody loves trucks because they are really flexible. [. . .] Fuel went down versus the electricity on rail is still on a very high level."*

While some freight was shifted to alternative transport modes, rail and road themselves faced capacity challenges (D1, D2). Rail freight infrastructure in Germany suffers from the long-term underinvestment that left it unable to respond to the sudden increase in demand and many road freight companies were struggling with a driver shortage (D3). Furthermore, not all freight that is usually carried on the river can be switched to other transport modes, especially in the case of inflammable and toxic chemicals (D1). Given that the drought overlapped with the energy crises induced by the war in Ukraine, coal trains were given priority over passenger trains on the German rail network to best utilise limited capacity (D5).

4.1.3 The port strikes in Finland in March–April 2024. The strike targeted the Finnish government's labour reforms, halted cargo handling at ports, disrupted freight rail, and complicated industry operations (S3, S6). In total, around 7,000 employees across key industries joined the strike, paralysing operations at ports and rail freight terminals (S11). Stevedoring operations were suspended, meaning containers could neither be picked up from nor delivered to Finnish ports during the strike (S12). As ports were operating at a fraction of their normal volumes (e.g. Hamina-Kotka ~10%, Vuosaari ~50%), shipments headed for Finland were either held at origin or ships waited offshore (S8). Shipping companies faced additional costs ranging from tens to hundreds of thousands of euros per vessel, depending on cargo type and daily transport costs (S8). Finland depends on sea transport for much of its imports and exports with 96% of its foreign trade moving through ports (S6, S8). Some cargo flows continued as truck-on-ferry services to Sweden and Estonia were not affected by the strikes (S6, S12). But many everyday consumer goods, such as seasonal imports of clothing, furniture, and electronics, were left waiting (S8). Heavy port users such as the forestry industry faced significant operational disruptions (S6).

4.1.4 War in Ukraine since February 2022. The Russian war on Ukraine escalated in February 2022 with Russia's invasion. Russia's role as a major energy supplier (gas, coal, oil) and Ukraine's as an agricultural hub (wheat, maize, sunflower oil, barley) made the war an immediate global supply chain shock (W5, W8, W15, W16). The war severely disrupted the European gas markets causing a surge in energy prices (W9), sparking discussion around energy dependency, also within the transport sector. As described by interviewee #15, *"And this disruption that we had on the Russian war, of course it helped us with this thing [transition away from fossil fuels] [. . .] looking for other alternatives than dependence on oil."*

The war affected food prices globally (S10). The war disrupted air cargo capacity, as Russia and Ukraine had significant roles in heavy-lift freight and Europe–Asia connections; flight bans reduced Europe–Asia cargo flights by nearly 20% year-on-year (W1). Black Sea and Azov Sea ports were blocked, halting Ukrainian grain shipments and disrupting global maritime trade (W4, W5, W17, W18). Rail transport between China and Europe via Russia/Belarus (Northern Corridor) was largely abandoned due to sanctions, insurance restrictions, and reputational risk; alternatives like the Middle Corridor emerged, though more costly and complex (W6, W7, W14, W19). Truck transport was hit by a worsening truck driver shortage as Ukrainian drivers returned home to fight (W11, W12).

4.2 Ripple effects of disruptive events

Table 4 summarises the observed impacts across the three analytical levels: transport network, supply chain, and society. We distinguish between direct impacts, indirect or interacting effects and co-occurring effects.

In the case of the port strikes in Finland, Table 4 shows how *direct effects* like the halted cargo handling at ports (S6, S11, S12, S20) and rerouting of vessels (S2, S8) rippled into broader *interacting effects* both within the transport network where for example jet fuel deliveries were disrupted (S1, S3), but also into the supply chain level, where there were production shut downs (S4, S10, S19), and into the societal level where fuel shortages affected public transport (S16, S17), going beyond freight transport to affect societal activities like commuting. Simultaneously, there were *co-occurring effects* as the strikes happened in a climate of increasing political polarisation (S3, S21, S22, S23, S24). Despite this disruptive event being comparatively small in its geographic and temporal extent, it thus has far-reaching effects that ripple across the three levels analysed in this study.

Similar patterns were observed across all cases. The initial disruptions we analysed all occurred at the transport network level, which produced *direct impacts* on freight flows and modal availability (Table 4). These direct impacts frequently intersected with existing vulnerabilities such as energy-price volatility and limited capacity across some modes leading to indirect or *interacting effects* in transport networks, supply chains, and society. Key

Table 4. Observed impact and linkage type for each disruptive event

Disruptive event	Linkage type	Observed impact	Analytical level
Rhine-Danube floods 2023	*Direct*	Suspension of inland waterway shipping on Rhine and Danube (F2, F14, F20)	Transport network
		Rail line closures and delays (F10, F13, F24)	Transport network
		Insufficient bridge clearance due to high water, preventing vessel passage (incl. traffic to Switzerland) (F20)	Transport network
		Critical river gauge thresholds exceeded, triggering precautionary stoppages (F8, F14)	Transport network
		Flooded roads and impassable street sections in affected regions (F10, F25)	Transport network
		Inundation of lower urban embankments along the Danube (e.g. Budapest riverfront) (F18, F19)	Transport network
		Navigation speed restrictions and special sailing rules on Rhine (even where not fully closed) (F8, F14)	Transport network
		Reduced barge capacity at Kaub (D8, D15, D19)	Transport network
	Interacting	Delays in coal, oil, grain, and feed deliveries (modal dependency) (F1, F15, F20)	Supply chain
		Increased pressure on alternative modes (rail/road) due to inland waterway disruption (F1, F2, F20)	Transport network
		Temporary fuel shortages (fuel logistics dependency) (F1, F20)	Supply chain
	Co-occurring	Evacuations and infrastructure outages (F3, F7, F8, F9)	Society
		Fallen trees and physical damage to buildings affecting accessibility and safety (F25)	Society
		Preventive removal/relocation of vehicles from flood-risk areas (F18, F19)	Society
		Prolonged emergency management and disaster-response operations (F3, F9, F21)	Society
		Large-scale flood alert and emergency readiness over long river sections (~1,200 km) (F18, F19)	Society
Rhine droughts 2022	*Direct*	Sections temporarily closed/"navigation halted" for some vessels due to critically low levels (D8, D15, D19)	Transport network
		Operational adaptation in fleet/technology (e.g. specialized vessels for low water) (D9, D19)	Transport network
		Freight rates/surcharges increase on inland waterways (cost shock driven by low water) (D8, D13, D15, D22)	Transport network
		Shift pressure to rail and road transport (capacity substitution) (D1, D3, D16, D23)	Transport network
	Interacting	Coal trains being prioritised on the German railway network (D5)	Transport network
		Disruptions in chemical, steel, coal industries (bulk transport dependency) (D1, D7, D9, D17, D25)	Supply chain
		Higher logistics costs for shippers (knock-on cost increase beyond waterways) (D10, D16, D21, D22, D24)	Supply chain
		Delivery delays/supply bottlenecks caused by constrained inland shipping (D16, D17, D25)	Supply chain
		Industrial production adjustments (e.g. changes in sourcing, routing, inventory strategy) (D1, D3, D9, D25)	Supply chain
		Fuel shortages at petrol stations (distribution constraints) (D16, D21, D22)	Society
		Drought framed as part of recurring/extreme low-water pattern (climate/stressor context) (D6, D7, D12, D19)	Society
	Co-occurring	Broader macro-economic concern (trade/economy at risk due to Rhine constraints) (D2, D5, D10, D11, D20, D24)	Society
		Heightened public concern about energy prices (D1, D2, D25)	Society

(*continued*)

Table 4. Continued

Disruptive event	Linkage type	Observed impact	Analytical level
Port strikes Finland 2024	*Direct*	Halted cargo handling at ports (S6, S11, S12, S20)	Transport network
		Rail freight disruptions/cargo rail affected alongside ports (S6, S11, S17)	Transport network
		Prioritisation of "essential" cargo while other goods wait (selective unloading/triage) (S8)	Transport network
		Rerouting of vessels to other European ports (S2, S8)	Transport network
		Shutdowns in pulp and paper mills (export dependency) (S4, S10, S19)	Supply chain
	Interacting	Shortages/stock-outs in retail channels for some goods (availability issues) (S9)	Society
		Supply chain delays and backlog accumulation (containers stuck at sea/other European ports; delays potentially weeks–months) (S4, S8, S17)	Supply chain
		Wage payment suspensions/temporary layoffs due to production stoppage and logistics paralysis (S4, S21)	Supply chain and society
		Airport fuel logistics disruption risk (jet-fuel deliveries interrupted) (S1, S3)	Transport network
		Refinery operations threatened (risk of production halt from logistics/storage constraints) (S25, S22)	Supply chain
		Export/import disruption explicitly targeted (trade flow disruption as strike mechanism) (S3, S22, S23, S24)	Supply chain
		Fuel shortages affecting public transport (fuel distribution dependency) (S16, S17)	Society
	Co-occurring	Political polarisation and public debate (S3, S21, S22, S23, S24)	Society
War in Ukraine from 2022	*Direct*	Blockage of Black Sea ports (W17, W18, W20)	Transport network
		Trade rerouting away from blocked/contested maritime lanes (route changes, new pathways) (W2, W22)	Transport network
		Abandonment of Northern rail corridor (W13, W14, W19)	Transport network
		Energy supply disruptions in Europe (geopolitical dependency) (W9, W21, W24, W25)	Supply chain
	Interacting	Fuel/natural gas market stress and price impacts (global gas market consequences) (W9, W25)	Supply chain
		Truck driver shortage worsened/compounded (labour availability constraint) (W11, W12)	Transport network and supply chain
		Inflation amplification via supply-chain disruption and rerouting (W23)	Society
		Market interventions/EU response measures affecting markets (W21)	Society and supply chain
		Food supply shocks and price volatility (global supply dependency) (W10, W15, W16, W17, W18)	Society
		Refugee flows and humanitarian knock-on effects (societal pressure) (W15)	Society
	Co-occurring	Cost-of-living pressures (W3, W6, W23)	Society
		Geopolitical volatility (W3, W10, W25)	Society

Source(s): Authors' own work

interacting effects on the transport network level included increased pressure on alternative transport modes (e.g. on road and rail in the flood and drought events), interdependencies between transport modes (e.g. jet fuel shortage in the strikes) and an exacerbation of existing problems (e.g. driver shortage related to the Ukraine war). On the supply chain level, key interacting effects included delivery delays (e.g. coal deliveries on the Rhine), shortages (e.g. fuel supplies being affected by all four disruptive events), altered production schedules (e.g. shutdowns of Finnish paper mills), and increased prices (e.g. for logistics services during the drought). Often, these particularly affected key industries like the paper supply chain in Finland or the chemical industry in Germany. Even supply chains that were distant to the site of the disruption were affected through ripple effects, for example because containers were stuck at sea or in different ports to where they were needed (S4, S8, S17). On the societal level, interacting effects arose when there were shortages of retail goods (S9) and fuel (D16, D21, D22) or when key infrastructure (F3, F7, F8, F9) or services (S16, S17) were disrupted. There were also broader interacting effects, especially with the war in Ukraine that significantly affected the food and energy markets globally and resulted in price volatility and inflation amplification felt across Europe (W10, W15, W16, W17, W18, W23). *Co-occurring effects* showcased the overall volatility in the European setting during the past few years. In the floods, co-occurring effects were quite local, related to the natural disaster's effects on aspects of life beyond transport and the disaster response through warnings, evacuations etc. (F3, F7, F8, F9, F21). The other disruptive events were linked to wider societal issues. Often, we saw a bidirectionality in the ripple effects as for example the constraints to Rhine shipping during the drought fed into a wider macro-economic concern due to the COVID-19 pandemic and the war in Ukraine, but the effects of the drought were also exacerbated by those wider issues (D2, D10, D11, D20, D24). Transport disruptions do not have a simple causal relationship to such wider societal co-occurring effects like the geopolitical volatility (W3, W10, W25), but they can be a highly visible symptom, as well as a contributor, and they can be exacerbated by them in turn. For example, the already heightened public concern about energy prices (D1, D2, D25) resulted in a higher awareness the crucial role inland waterway transport played in transporting coal and gas and that in turn fuelled concerns about energy prices.

The analysis of the four disruptive events in this study demonstrates how ripple effects unfold across different transport modes, industrial sectors, and society at large, confirming the warnings in the literature about the cascading nature of disruptions (Dolgui *et al.*, 2020; Ivanov and Dolgui, 2021). Despite the differences, the drought, strike, war, and the flood all revealed similar patterns of propagation on smaller scales: an initial transport blockage quickly caused production slowdowns, shortages of critical goods, and consumer-facing impacts such as fuel scarcity or delivery delays. In line with Kachali *et al.* (2018), these cases show that ripple effects evolve both sequentially within sectors and simultaneously across sectors, often in ways that outstrip the capacity of individual firms or nations to respond. The findings also highlight that ripple effects of transport disruptions extend beyond supply chains into the societal domain, with interactions varying by event and context. This echoes Kovács and Falagara Sigala's (2021) observations from the COVID-19 pandemic, where the ripple effect of localised disruptions materialised in widespread social consequences such as panic buying. The evidence here underscores that ripple effects are not confined to firms and industries but are felt acutely at the societal level. Ripple effects are not unidirectional. While transport network disruptions are intuitively linked to supply chain disruptions, the reverse can also be true, for example when issues with fuel supply chains disrupt transport.

4.3 Intersectionality of disruptive events and bidirectionality of impact

Intersectionality refers to the overlap and interaction of multiple disruptive events that occur either simultaneously or in close succession amplifying challenges at transport network, supply chain, and society level (Steinfield *et al.*, 2021). Unlike ripple effects, which focus on the propagation of disruption through interconnected systems (Dolgui *et al.*, 2020), intersectionality highlights how different disruptions interact and compound one another. The transport sector is increasingly shaped by the simultaneity of crises, with economic, climatic, and geopolitical shocks overlapping with the lingering effects of COVID-19 across all four disruptive events in this study. As interviewee #2 reflected, "*last three years has been the most crazy years in the world. You have COVID, then [. . .] we have a financial crisis, then we have the logistical crisis [. . .] one crisis following the other one.*"

The Rhine drought provides a clear example of intersectionality where the drought coincided with the energy crisis triggered by the Ukraine war (D11). As a result of the war, German energy policy had shifted suddenly to secure electricity production while gaining independence from Russian gas imports, switching back some of the electricity production to coal power stations that were supplied through inland waterway transport (D6, D15). At the same time, with the severely constrained shipping capacity on the Rhine and a lack of alternative transport modes that could shift such significant amounts of heavy coal, power stations were in danger of running out of coal. This convergence of climatic and geopolitical stressors placed power stations at risk of coal shortages (D3, D17). Furthermore, the drought intersected with remaining vulnerabilities resulting from the COVID-19 pandemic, with firms reporting a heightened sensitivity to supply chain disruptions after years of pandemic-related turbulence (D6). Consumers, too, were more alert to how transport and supply chain disruptions affected their daily lives, making fuel shortages at petrol stations a significant concern (D3, D11). Interviewee #6 confirmed the lingering effects of COVID-19: "*lots of disruptions that we are facing now, [. . .] have their roots in the COVID pandemic, I think, because everything started to collapse. It was a situation nobody was used to.*" Importantly, these outcomes did not result from the drought alone but from its interaction with broader energy-market dynamics and infrastructure dependencies.

The Finnish port strikes demonstrate how transport disruptions can intersect with political and economic contexts. Although a domestic political dispute, the Finnish strike unfolded against the backdrop of regional economic divergence. While Finland entered recession, neighbouring Nordic economies such as Sweden, Denmark, and Norway continued to grow, leading industry associations to warn of negative investor perceptions (S10). The strike also intersected with the legacies of prior disruptions: fears of fuel shortages resonated strongly with earlier crises such as the energy price spikes of 2022 due to the war in Ukraine (S3, S16), and its political nature made it part of a broader contestation over the future of the welfare state (S10, S15). The wider political background is beyond the scope of this study but illustrate the close relationship between transport disruptions and socio-political developments. Intersectionality was also evident across geographic scales. Finland-bound vessels that were rerouted to or waiting in other European ports and anchorages faced congestion in maritime infrastructure already under strain from the pressure the Ukraine war put on goods and energy flows (S8, W4, W14).

Across the four disruptive events, three common stress points emerged. First, *energy and fuel supply chains* constituted a critical vulnerability in all cases, reflecting their central role in both transport operations and societal functioning during a period of heightened energy-market instability. (W 4, W9, D1, D2, D25). Second, *food security* was a critical vulnerability. Food systems were exposed to both climate-induced challenges to production and transport (D12, D14) and geopolitical blockages (W5, W10, W16). The Finnish strikes highlighted the concern about spoilage (S3, S17), the short shelf life making food especially vulnerable in case of transport disruptions. The third common stress point concerned the *fragility of transport networks.* The Rhine drought showcased how insufficient investment in both river transport and rail alternatives resulted in a transport system that could not adequately respond to disruption (D3, D6, D18), while the Finnish strikes highlighted the risk of relying on one transport mode for 96% of foreign trade (S6).

These findings indicate that the impacts of transport disruptions cannot be understood in isolation. Intersectionality and bidirectionality highlight how disruptions interact with concurrent crises, structural dependencies, and stakeholder perceptions, reinforcing the need for a systemic and context-aware approach to analysing transport disruptions.

4.4 Resilience across different levels

In the analysed events, resilience measures were evident across all levels, encompassing both dynamic and static resilience (Wei *et al.*, 2022) (Table 5).

Static transport network resilience was evidenced through pre-existing infrastructure and institutional frameworks that maintained functionality during disruptions. The Rhine transport system possessed an established monitoring and forecasting infrastructure that continuously tracked water levels (F12, F16). While some rerouting took place, limited spare capacity in rail

Table 5. Synthesis of resilience across cases

	Static resilience	Dynamic resilience
Transport network	Continued use of truck-on-ferry routes to Sweden/Estonia as a bypass during port strikes (S6, S12) EU Civil Protection Mechanism mobilised cross-border equipment and personnel (F9, F21)	Dredging plans and investments in flood defences for Rhine adaptation (D6, D16, D17) Rerouting from Russia/Belarus to the “Middle Corridor” for China–Europe freight after Ukraine war sanctions (W14, W19)
Supply chain	Companies stockpiling raw materials in anticipation of Rhine low water (Evonik, Thyssenkrupp) to ensure continuity (D6, D17) Forestry and paper industries planning production suspensions and stockpiling during strikes to minimise losses and resume quickly (S18, S19)	Multinational firms reconfiguring supply chains after Ukraine war: diversification of sourcing and shortening supply chains (W5, W7, W8) Energy supply chain restructuring in response to Ukraine war, with rapid LNG import build-up replacing Russian gas (W9)
Society	Ensuring food security by 80% of food sold being produced domestically and a public discourse about food security (S17) Local preparedness measures (sandbags, temporary dykes) in flood-affected areas (F3, F4, F5)	Policy shifts toward energy diversification and renewables after Ukraine war to reduce future dependency risks (W9) Increased emphasis on public risk communication following floods, with calls for clearer translation of forecasts into actionable guidance (F21)

Source(s): Authors’ own work

and road networks constrained static resilience (D11, D15, D18). In the Finnish context, static resilience was demonstrated through existing multimodal transport infrastructure that offered inherent operational flexibility, including pre-established RoRo cargo handling capabilities at alternative ports that functioned independently of container port operations (S20). Dynamic transport network resilience emerged through adaptive responses and resource reallocation strategies, such as shifting to different transport modes or deploying shallower vessels during the drought (D2, D6, D9, D18). The Finnish port strikes prompted dynamic responses including the rerouting of ships to alternative ports (S6, S8). In response to the Ukraine war, airlines rerouted around Russia (W1, W7).

Static supply chain resilience manifested through pre-existing structural and institutional frameworks that maintained operational functionality during disruptions. Both the drought and strike revealed static resilience through existing contractual arrangements and institutional relationships that automatically enabled alternative operational pathways (S12, D18). Stockpiling was evident during the strike, the drought, and in relation to the Ukraine war (D6, D17, W5, W9, S6). Dynamic supply chain resilience emerged through active responses and resource optimisation strategies implemented during disruption events. Examples from the Finnish paper industry and the German chemical industry (S18, S19, D1, D17) show companies adapting their production schedules to minimise cost during supply chain disruptions. In response to the Ukraine war, many companies reconfigured their supply chains through multi-sourcing and sourcing from geographically closer areas (W5, W7, W8).

Static societal resilience was demonstrated through pre-existing practices and institutional Consumer food availability was preserved in Finland through the high share of domestic production (S17). Oil companies in Germany, having expanded reserves after the 2018 drought, were able to maintain most fuel supplies during the 2022 Rhine low water, avoiding widespread shortages (D3). Dynamic societal resilience was evidenced by adaptive behaviours and institutional responses that evolved during and after disruptions. In the floods, mass evacuations and rapid deployment of civil protection resources across borders illustrated the ability of society to reallocate resources in real time and to recover functionality quickly (F3, F9, F21). Following the Ukraine war, policy responses to shield households from energy price shocks, including price caps and fiscal relief packages, represented dynamic societal resilience at scale (W9). In Finland, public authorities issued guidance to households on safe fuel stockpiling during the strikes (S17). These examples show how societal resilience involves not only protective infrastructures but also collective behaviours, policy measures, and communication systems.

This study shows that resilience cascades upward from transport networks through supply chains and into society, mirroring ripple effects discussed earlier. Static resilience at the transport level, created a foundation that allowed supply chains to sustain essential flows and shielded societies from severe shortages. Where these foundations were weak, such as limited spare rail capacity during the Rhine drought, supply chain and societal vulnerabilities became more pronounced. Dynamic resilience then emerged through adaptive strategies that linked the levels: rerouted transport flows enabled firms to adjust production schedules, while firm-level adaptations, such as stockpiling or sourcing shifts, reduced strain on households and communities. Likewise, societal adaptations, from fiscal relief measures after the Ukraine war to flood defences also protecting transport infrastructure during floods, reinforced supply chain and transport network resilience. The cases illustrate that resilience can cascade back, with actions at one level shaping the resilience of the others.

5. Conclusions

5.1 Theoretical contributions

This paper examined the ripple effects and intersectionality of disruptive events in the European freight transport network, highlighting their impacts not only on transport systems but also on supply chains and wider society. By analysing four disruptive events (Rhine-Danube floods 2023, Rhine droughts 2022, Port strikes Finland, 2024, War in Ukraine from 2022), our findings highlight that transport disruptions are not just operational events, but multi-level phenomena embedded in broader societal systems. While the scale, duration, and predictability of the events differed, all cases revealed that disruptions to freight transport have consequences that extend well beyond the transport network itself, affecting production, goods flows, and everyday societal functioning.

First, the study contributes to disruption and resilience literature by repositioning freight transport networks as active sources of disruption rather than passive contextual conditions. Existing supply chain research has extensively examined disruption propagation and resilience at firm and supply chain levels (cf. Pettit *et al.*, 2019; Scholten and Schilder, 2015; Wei *et al.*, 2022; Shekarian and Mellat Parast, 2021), yet transport networks are often treated as background infrastructure. Our findings show that disruptions originating within transport networks substantially shape supply chain performance and societal outcomes. By foregrounding transport networks as a meso-level system that links economic activity and societal functioning, the study extends supply chain resilience research and responds to calls for more systemic analyses of disruption dynamics.

Second, the study advances ripple effect research (cf. Ivanov and Dolgui, 2021; Dolgui *et al.*, 2020) by operationalising ripple effects from transport network disruptions into three empirically traceable linkage types: direct, indirect or interacting, and co-occurring effects. This distinction highlights that ripple effects frequently emerge through configurations of interactions, timing, and shared dependencies rather than sequential cause–effect chains. The analysis further demonstrates that ripple effects may be bidirectional, as disruptions in energy or fuel supply chains can feed back into transport network performance and intensify system-wide stress. By tracing ripple effects across transport, supply chain, and societal levels, the study broadens the analytical scope of ripple effect research beyond firm-centric models. Beyond ripple effects, this study demonstrates that disruptions are best understood as overlapping and interacting crises rather than isolated events. Intersectionality has proven essential for explaining how climate hazards, geopolitical conflict, energy crises, and post-pandemic vulnerabilities interact and compound, producing complex and context-dependent impacts that are difficult to address through event-specific or sector-specific interventions alone.

Third, to mitigate the effects of transport disruptions at different levels, this study also examined resilience measures across transport networks, supply chains, and society. The findings indicate how static resilience (cf. Wei *et al.*, 2022) at the transport network level conditions the system's capacity to absorb shocks, while dynamic adaptive responses support recovery but remain unevenly distributed and structurally constrained. Strengthening resilience, therefore, requires coordinated, cross-level action across transport networks, supply chains, and societal systems rather than isolated firm-level interventions.

5.2 Policy and managerial implications

This study reveals common weaknesses and opportunities for strengthening resilience in Europe's transport networks. Based on these findings, four key recommendations can be made for policymakers and practitioners.

First, disruption preparedness should be designed around propagation across levels rather than around isolated event types. The findings show that disruptive events rarely remain confined to the transport system in which they originate. Instead, impacts propagate across interconnected transport networks, supply chains, and societal systems through shared dependencies, timing overlaps, and structural bottlenecks. The findings therefore suggest the need to move beyond event-specific contingency planning and to adopt preparedness approaches that explicitly anticipate how disruptions spread across levels. This underscores the importance of cross-sectoral scenario planning and coordination mechanisms that focus on critical interdependencies rather than on individual hazards.

Second, freight transport networks should be treated as strategic sources of disruption risk rather than passive service infrastructures. A key insight of this study is that disruptions originating within freight transport networks can trigger significant supply chain and societal impacts, even when firm-level operations remain intact. Managers should therefore more explicitly integrate transport network considerations into risk assessment, inventory policies, and contingency planning. For public authorities, this implies recognising freight transport networks as a strategic layer of economic and societal resilience, which warrants closer engagement with infrastructure managers and logistics operators.

Third, resilience investments should prioritise structural bottlenecks where assumed flexibility repeatedly fails in practice. Across the cases, the capacity to substitute between transport modes or routes was repeatedly constrained by long-standing structural limitations, such as underinvestment, labour shortages, or institutional rigidities. These constraints amplified ripple effects across supply chains and society. Rather than focusing on generic capacity expansion or redundancy, resilience investments are most effective when they target those points where adaptive flexibility is expected in theory but fails in practice, thereby limiting the escalation of disruptions across levels.

Fourth, societal impacts should be treated as integral elements of transport disruption management. The study shows that transport network disruptions are frequently associated with societal-level impacts, including concerns about fuel availability, access to essential goods, and heightened public and political attention. These effects are not merely secondary outcomes but may feed back into transport and supply chain dynamics, shaping response and recovery. Public authorities and firms should therefore incorporate societal considerations, particularly communication, prioritisation of critical goods, and coordination with public institutions, into disruption management strategies, recognising societal resilience as a component of transport system resilience.

5.3 Further research

This study highlights directions for future research. While resilience at the firm and supply chain level has been extensively examined (e.g. Pettit *et al.*, 2019; Scholten and Schilder, 2015; Shekarian and Mellat Parast, 2021; Wei *et al.*, 2022), disruptions originating in freight transport networks and their propagation across transport, supply chain, and societal levels remain insufficiently understood. Future research should therefore move beyond firm-centric perspectives and examine transport disruptions as multi-level phenomena embedded in interconnected technical, organisational, and societal systems (Albertzeth *et al.*, 2019; Cao *et al.*, 2025b).

Systematic, comparative research should focus on freight transport disruptions across transport modes and geographic contexts. Building on the ripple effect patterns identified in this study, future work should examine how disruption characteristics shape propagation dynamics and interdependencies. Such research would enable clearer identification of shared vulnerabilities and mode-specific resilience challenges within European and global freight transport networks. Future research should translate multi-level insights into operationally usable tools and frameworks. Research is needed to develop integrated analytical and decision-support tools that account explicitly for transport network constraints, cross-modal dependencies, and ripple effects, and that can support both policymakers and industry actors. The findings highlight the societal embeddedness of freight transport disruptions, pointing to the need for further research on societal-level dynamics. Future studies should examine how transport and supply chain disruptions are perceived, interpreted, and responded to by the public, and how communication, preparedness, and trust influence societal responses to disruption. In addition, further theoretical work is needed to better conceptualise bidirectional relationships between societal conditions and transport disruptions, including how societal pressures, political dynamics, and public responses can amplify or attenuate ripple effects.

Appendix

Table A1. Secondary data analysis

Rhine droughts (D)		
D1	German industry changes tack as river Rhine runs drier	https://www.reuters.com/markets/europe/german-industry-changes-tack-river-rhine-runs-drier-2023-07-26/
D2	Rhein: Niedrigwasser könnte Konjunktur wieder belasten	https://www.spiegel.de/wirtschaft/duerre-und-niedrige-pegel-niedrigwasser-am-rhein-koennte-konjunktur-wieder-belasten-a-354d04ff-d4fb-4e2d-8be8-8c57d9f9abef
D3	Was passiert, wenn Schiffe nicht mehr fahren können?	https://www.welt.de/wirtschaft/article240446345/Duerre-Sieben-Fakten-zum-Rhein-Niedrigwasser.html
D4	Lower river water levels.	https://www.portofrotterdam.com/en/building-port/sustainable-port/climate-adaptation/lower-river-water-levels?
D5	Germany to give energy essentials priority by rail if Rhine disruption worsens ∣ Reuters	https://www.reuters.com/markets/commodities/germany-give-energy-essentials-priority-by-rail-if-rhine-disruption-worsens-2022-08-14/#:~:text=BERLIN,%20Aug%2014%20(Reuters),six%20months,%20the%20draft%20said.
D6	Niedrigwasser am Rhein schadet Wirtschaft	https://www.dw.com/de/trockenheit-niedrigwasser-am-rhein-schadet-wirtschaft/a-62528630

(*continued*)

Table A1. Continued

Rhine droughts (D)		
D7	Rhein häufiger von Niedrigwasser betroffen	https://www.umweltwirtschaft.com/news/kuesten-hochwasser-und-gewaesserschutz/Rhein-haeufiger-von-Niedrigwasser-betroffen-IKSR-beginnt-ab-Herbst-2022-mit-Aktualisierung-der-Strategie-zur-Anpassung-an-den-Klimawandel–27619
D8	Rhine closes to barge traffic, with water depth set to hit record lows	https://theloadstar.com/rhine-closes-to-barge-traffic-with-water-depth-set-to-hit-record-lows/
D9	BASF deploys new freight vessel on Rhine River to cope with lower water levels	https://www.cleanenergywire.org/news/basf-deploys-new-freight-vessel-rhine-river-cope-lower-water-levels
D10	Europe’s Low Water Levels Threaten Rhine River, Hit $80B Trade Lifeline	https://www.bloomberg.com/news/features/2022-08-10/europe-s-low-water-levels-threaten-rhine-river-hit-80b-trade-lifeline
D11	Drought in Europe: Shipping threatened in Germany as Rhine water levels continue to drop | Euronews	https://www.euronews.com/2022/08/10/germany-drought-river-rhine-water-levels-could-fall-to-critical-low
D12	Strategie zur Anpassung an den Klimawandel – drittes extremes Niedrigwasser in 20 Jahren unterstreicht die Dringlichkeit	https://www.iksr.org/de/presse/pressemitteilungen/pressemitteilungen-einzeldarstellung/iksr-beginnt-ab-herbst-2022-mit-aktualisierung-der-strategie-zur-anpassung-an-den-klimawandel-drittes-extremes-niedrigwasser-in-20-jahren-unterstreicht-die-dringlichkeit
D13	Freight transport on inland waterways	https://inland-navigation-market.org/chapitre/2-freight-transport-on-inland-waterways-3/?lang=en
D14	Ripple effects - Exploring the impact of low Rhine water levels on the Dutch economy	https://www.abnamro.com/research/en/our-research/ripple-effects-exploring-the-impact-of-low-rhine-water-levels-on-the-dutch
D15	Rhine water levels fall to new low as Germany’s drought hits shipping	https://www.theguardian.com/world/2022/aug/12/germany-drought-rhine-water-levels-new-low
D16	Droughts are damaging supply chains on waterways	https://www.weforum.org/agenda/2023/10/drought-trade-rivers-supply-chain/
D17	Rhine’s low water levels hit German shipping	https://www.dw.com/en/rhines-low-water-levels-hit-german-shipping-minister-touts-dredging/a-62740312
D18	Droughts leave cargo riverboats high and dry	https://www.bbc.com/news/business-64553079
D19	Rhine River Water Level Hits New Low, Forcing Some Barges to Halt Transport	https://www.insurancejournal.com/news/international/2022/08/16/680610.htm
D20	ESA: Rhine River Runs Dry in Summer 2022	https://www.esa.int/ESA_Multimedia/Images/2022/08/Rhine_river_runs_dry?
D21	Drought in Europe: Shipping threatened in Germany as Rhine water levels continue to drop	https://www.euronews.com/2022/08/10/germany-drought-river-rhine-water-levels-could-fall-to-critical-low?
D22	Why low water levels on the Rhine river hurt Germany’s economy	https://www.reuters.com/business/environment/why-low-water-levels-rhine-river-hurt-germanys-economy-2022-08-15/?
D23	Low Water Levels In Germany’s Rhine River Disrupt Shipping and Increase Freight Costs	https://www.marineinsight.com/shipping-news/low-water-levels-in-germanys-rhine-river-disrupt-shipping-increase-freight-costs/

(*continued*)

Table A1. Continued

Rhine droughts (D)		
D24	Low water levels in Rhine river threat to German economic recovery – analysts	https://www.cleanenergywire.org/news/low-water-levels-rhine-river-threat-german-economic-recovery-analysts
D25	Europe | Rhine water levels disrupting supply chains	https://dragonflyintelligence.com/news/europe-rhine-water-levels-disrupting-supply-chains/
Floods (F)		
F1	Rhine flood creates several problems in Germany	https://www.azernews.az/region/219715.html
F2	Shipping comes to a halt on parts of the Rhine	https://www.projectcargojournal.com/transport-installation/2023/12/15/shipping-comes-to-a-halt-on-parts-of-the-rhine/
F3	German chancellor tours flooded regions	https://apnews.com/article/germany-floods-rain-scholz-chancellor-visit-ad45096b4bb35c94e963aec10e63d3aa
F4	Parts of northern and central Europe continues to struggle with floods	https://economictimes.indiatimes.com/news/international/uk/parts-of-northern-and-central-europe-continues-to-struggle-with-floods/articleshow/106355157.cms?from=mdr
F5	Floods in Europe: Hungary, Netherlands and Lithuania brace themselves	https://www.euronews.com/2023/12/29/floods-in-europe-hungary-netherlands-and-lithuania-brace-themselves
F6	On the flood situation in southern Germany: GFZ	https://www.gfz.de/en/press/news/details/anlaesslich-der-hochwasserlage-in-sueddeutschland
F7	Hochwasser November-Dezember 2023	https://www.bafu.admin.ch/bafu/de/home/themen/wasser/extremereignisse/hochwasser/hochwasser-ereignisse/hochwasser-november-dezember-2023.html
F8	Höchststände bei Hochwasser am Rhein überschritten | DIE ZEIT	https://www.zeit.de/news/2023-12/16/hoechststaende-bei-hochwasser-am-rhein-ueberschritten
F9	Flooding in Germany, December 2023 | Copernicus EMS - European Flood Awareness System	https://european-flood.emergency.copernicus.eu/en/news/flooding-germany-december-2023
F10	Deutschland: Hochwasserlage bleibt angespannt | tagesschau.de	https://www.tagesschau.de/inland/hochwasser-deutschland-126.html
F11	Hochwasser 2023 - eine Einordnung (daswetter.com)	https://www.daswetter.com/nachrichten/aktuelles/hochwasser-2023-eine-einordnung.html
F12	Ursachen für das Hochwasser in Niedersachsen 2023/2024 |	https://www.umwelt.niedersachsen.de/startseite/aktuelles/aktuelles-hochwasser-in-niedersachsen-228435.html
F13	Zeichen der Entspannung - aber weiter Hochwasser | tagesschau.de	https://www.tagesschau.de/inland/regional/hochwasser-evakuierungen-unwetter-100.html
F14	Hochwasser bringt Rhein-Schifffahrt zum Erliegen - Binnenschifffahrt Online	https://binnenschifffahrt-online.de/2023/12/featured/31713/hochwasser/
F15	ESOTC 2023 – Europe experienced an extraordinary year of extremes	https://www.copernicus.eu/en/news/news/observer-esotc-2023-europe-experienced-extraordinary-year-extremes-record-breaking
F16	Winterhochwasser 2023/2024	https://www.nlwkn.niedersachsen.de/jb2023/winterhochwasser-2023-2024-229709.html#:~:text=Das%20feuchte%20Wetter%20und%20die,in%20einen%20regelrechten%20Ausnahmezustand%20versetzt.
F17	From rain fall to resilience: Slovenia's 2023 record-breaking floods	https://www.wtwco.com/en-my/insights/2024/04/from-rainfall-to-resilience-slovenias-2023-record-breaking-floods
F18	Karácsonyi árvíz: a Duna tetőzött Budapestnél, de a Tiszán újabb árhullám érkezik (vg.hu)	https://www.vg.hu/vilaggazdasag-magyar-gazdasag/2023/12/karacsonyi-arviz-a-duna-tetozott-budapestnel-de-a-tiszan-ujabb-arhullam-erkezik

(*continued*)

Table A1. Continued

Floods (F)		
F19	Árvíz: csaknem 1200 kilométeren van készültség, a Duna Budapestnél csütörtökön tetőzik | hirado.hu	https://hirado.hu/belfold/cikk/2023/12/26/arviz-csaknem-1200-kilometeren-van-keszultseg-a-duna-budapestnel-csutortokon-tetozik
F20	River Rhine in south Germany remains closed to shipping | Reuters	https://www.reuters.com/business/environment/river-rhine-south-germany-remains-closed-shipping-2023-12-13/
F21	Fragen und Antworten zur aktuellen Hochwasserlage in Deutschland: GFZ	https://www.gfz.de/presse/meldungen/detailansicht/fragen-und-antworten-zur-aktuellen-hochwasserlage-in-deutschland
F22	ESOTC 2023: Series of five storms in December	https://climate.copernicus.eu/esotc/2023/flooding
F23	Flood list in Germany by ECMWF	https://floodlist.com/tag/germany
F24	Heavy rainfall causes flight cancellations in Germany	https://www.aljazeera.com/news/2023/8/17/heavy-rain-causes-flight-cancellations-floods-in-germany
F25	Ein Rückblick auf die Unwetterlage vom 22.06.2023	https://www.dwd.de/DE/wetter/thema_des_tages/2023/6/23.html
War (W)		
W1	Factsheet (iata.org)	https://www.iata.org/en/iata-repository/publications/economic-reports/the-impact-of-the-conflict-between-russia-and-ukraine-on-aviation/
W2	Economic implications of trade rerouting since Russia–Ukraine war	https://www.spglobal.com/marketintelligence/en/mi/research-analysis/economic-implications-of-trade-rerouting-since-ukraine-war.html
W3	Russia’s war on Ukraine holds still more pain for European business	https://www.ft.com/content/29d1618e-b6da-45d0-a7cf-067735aca1d6
W4	Russia-Ukraine War Impact: Global Supply Chain and Logistics Crisis | GEP Blogs	https://www.gep.com/blog/mind/russia-ukraine-war-logistics-impact
W5	War in Ukraine: the supply chain impact (themanufacturer.com)	https://www.themanufacturer.com/articles/war-in-ukraine-the-supply-chain-impact/
W6	Ripple effects from Russia-Ukraine war test global economies | MIT Sloan	https://mitsloan.mit.edu/ideas-made-to-matter/ripple-effects-russia-ukraine-war-test-global-economies
W7	How the War in Ukraine Is Further Disrupting Global Supply Chains (hbr.org)	https://hbr.org/2022/03/how-the-war-in-ukraine-is-further-disrupting-global-supply-chains
W8	The-War-in-Ukraine-and-its-Impact-on-Global-Supply-Chains	https://www.cardiff.ac.uk/__data/assets/pdf_file/0004/2628166/PARC-Industry-Insight_The-War-in-Ukraine-and-its-Impact-on-Global-Supply-Chains_FINAL.pdf
W9	The European energy crisis and the consequences for the global natural gas market	https://cepr.org/voxeu/columns/european-energy-crisis-and-consequences-global-natural-gas-market
W10	Update: how is the war in Ukraine affecting global food prices?	https://www.economicsobservatory.com/update-how-is-the-war-ukraine-affecting-global-food-prices
W11	Ukrainian war compounding Europe’s truck driver shortage - Inside Logistics	https://www.insidelogistics.ca/international-conflict/invasion-of-ukraine/ukrainian-war-compounding-europes-truck-driver-shortage-180416/
W12	Drivers taking up arms for Ukraine worsens European trucker shortage	https://www.freightwaves.com/news/drivers-taking-up-arms-for-ukraine-worsens-european-trucker-shortage
W13	The effects of the Ukraine war on China’s ‘new Silk Road’ (midnight-trains.com)	https://www.midnight-trains.com/post/the-effects-of-the-ukraine-war-on-chinas-new-silk-road
W14	Ukraine war shakes up China-Europe railway express – POLITICO	https://www.politico.eu/article/ukraine-china-silk-road-railway/

(*continued*)

Table A1. Continued

War (W)		
W15	Food shortages, millions of refugees, and global price spikes: the knock-on effects of Russia's Ukraine invasion	https://theconversation.com/food-shortages-millions-of-refugees-and-global-price-spikes-the-knock-on-effects-of-russias-ukraine-invasion-180559
W16	Why Russia pulled out of its grain deal with Ukraine	https://theconversation.com/why-russia-pulled-out-of-its-grain-deal-with-ukraine-and-what-that-means-for-the-global-food-system-210046
W17	Ukrainian grain exports explained - Consilium (europa.eu)	https://www.consilium.europa.eu/en/infographics/ukrainian-grain-exports-explained/
W18	How much grain is Ukraine exporting and how is it leaving the country? (bbc.com)	https://www.bbc.com/news/world-61759692
W19	Russia's War on Ukraine and the Rise of the Middle Corridor	https://www.swp-berlin.org/publikation/russias-war-on-ukraine-and-the-rise-of-the-middle-corridor-as-a-third-vector-of-eurasian-connectivity
W20	Maritime Trade Disrupted: The war in Ukraine and its effects on maritime logistics	https://unctad.org/publication/maritime-trade-disrupted-war-ukraine-and-its-effects-maritime-trade-logistics
W21	Impact of Russia's invasion of Ukraine on the markets: EU response	https://www.consilium.europa.eu/en/policies/eu-response-russia-military-aggression-against-ukraine-archive/impact-of-russia-s-invasion-of-ukraine-on-the-markets-eu-response/
W22	How the Russia-Ukraine war has impacted on logistics routes and supply chains	https://gmk.center/en/posts/how-the-russia-ukraine-war-has-impacted-on-logistics-routes-and-supply-chains/
W23	Economic analysis: Russia-Ukraine war impact on supply chains and inflation	https://kpmg.com/kpmg-us/content/dam/kpmg/pdf/2022/economic-analysis-russia-ukraine-war-impact-supply-chains-inflation.pdf
W24	Russian energy export disruptions since the start of Ukraine war	https://www.reuters.com/business/energy/russian-energy-export-disruptions-since-start-ukraine-war-2025-08-15/
W25	Explainer: what happens when Russian gas to Europe via Ukraine stops	https://www.reuters.com/business/energy/what-happens-when-russian-gas-europe-via-ukraine-stops-2024-10-08/

Strikes (S)		
S1	Helsinki-Vantaan lentokenttää uhkaa polttoainepula jo viikon päästä	https://yle.fi/a/74-20078553
S2	Rahtilaivat hakeutuvat toisiin satamiin lakon aikana	https://www.tekniikkatalous.fi/uutiset/rahtilaivat-hakeutuvat-toisiin-satamiin-lakon-aikana-toimituksiin-pahimmillaan-kuukausien-viive/785ef558-7794-4410-8cdc-b640035369e3
S3	Finnish unions announce two-week strike	https://www.helsinkitimes.fi/finland/finland-news/domestic/24980-finnish-unions-announce-two-week-strike-with-ramifications-for-cargo-transport-fuel-distribution.html
S4	Backlash from Finland transport strike brings supply chain chaos	https://theloadstar.com/backlash-from-finland-transport-strike-brings-supply-chain-chaos/
S5	Transport workers' strike in Finland extended again	https://theloadstar.com/transport-workers-strike-in-finland-extended-again/
S6	Strike paralyzes Finnish ports: A look at the widespread impact (helsinkitimes.fi)	https://www.helsinkitimes.fi/finland/finland-news/domestic/24996-strike-paralyzes-finnish-ports-a-look-at-the-widespread-impact.html

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Table A1. Continued

Strikes (S)		
S7	ETF: European Transport Workers' Federation | Political strikes close Finnish ports	https://www.etf-europe.org/political-strikes-close-finnish-ports/
S8	Finnish ports unloading essentials, but clothes and bicycles may sit dockside for months	https://yle.fi/a/74-20079108
S9	Osa juomista on Alkosta jo loppu - Kotimaa | HS.fi	https://www.hs.fi/kotimaa/art-2000010316195.html
S10	Fourteen-day strike announced at Finnish ports (euwid-paper.com)	https://www.euwid-paper.com/news/markets/fourteen-day-strike-announced-at-finnish-ports-060324/
S11	Finnish ports start two-week strike, anticipate delays and disruptions	https://www.worldcargonews.com/ports-terminals/2024/03/finnish-ports-start-two-week-strike-anticipate-delays-and-disruptions/?gdpr=accept
S12	The AKT strike will close cargo traffic at Finnish ports for two weeks	https://fi.kuehne-nagel.com/en/-/uutiset/aktn-lakko-tulee-sulkemaan-suomen-satamien-tavaraliikenteen-kahdeksi-viikoksi
S13	Finnish Unions Plans Two-Week Port Strike Protesting Government Policies	https://maritime-executive.com/article/finnish-union-akt-plans-two-week-port-strike-protesting-government-policies
S14	Relief as Finnish port strikes are set to cease in bid to start talks - The Loadstar	https://theloadstar.com/relief-as-finnish-port-strikes-are-seat-to-cease-in-bid-to-start-talks/
S15	Strikes in Finland close ports | ITF Seafarers	https://www.itfseafarers.org/en/news/strikes-finland-close-ports
S16	Strike-related diesel shortage threatens to disrupt public transport in Finland (helsinkitimes.fi)	https://www.helsinkitimes.fi/finland/finland-news/domestic/24999-strike-related-diesel-shortage-threatens-to-disrupt-public-transport-in-finland.html
S17	FAQ about the impact of Finland's strikes	https://yle.fi/a/74-20078549
S18	HS: Strikes force Finnair to add re-fuelling stops to long-haul flights (helsinkitimes.fi)	https://www.helsinkitimes.fi/finland/finland-news/domestic/24997-hs-strikes-force-finnair-to-add-re-fuelling-stops-to-long-haul-flights.html
S19	Printweek - Supplies from Finnish paper mills hit by strike	https://www.printweek.com/content/news/supplies-from-finnish-paper-mills-hit-by-strike/
S20	Lakot vaikuttavat tavaraliikenteeseen 11.–24.3. | Helsingin Satama	https://www.portofhelsinki.fi/tietoa-meista/helsingin-satama/ajankohtaista/lakot-vaikuttavat-tavaraliikenteeseen-11-24-3/
S21	How Finnish strikes over labour reforms are affecting companies	https://www.reuters.com/world/europe/how-strikes-over-finnish-labour-reforms-hit-companies-2024-03-11/
S22	Finnish workers on strike to protest labour reforms, welfare cuts	https://www.swissinfo.ch/eng/finnish-workers-on-strike-to-protest-labour-reforms%2C-welfare-cuts/72115670
S23	Finnish strikes extended for another week	https://www.worldcargonews.com/news/2024/03/finland-strikes-extended-for-another-week-port-disruptions-expected-to-continue/
S24	Finnish unions extend strikes over labour reforms by another week	https://www.reuters.com/world/europe/finnish-unions-extend-strikes-over-labour-reforms-by-another-week-2024-03-27/
S25	Finnish labour strikes threaten refinery	https://shipandbunker.com/news/emea/591621-finnish-labour-strikes-threaten-refinery

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