SARIL

Sustainability And Resilience for Infrastructure and Logistics networks

D5.1
Recommendations

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Executive summary

European freight transport systems face an unprecedented convergence of climate-related extreme weather, geopolitical instability, cyber threats, pandemics and systemic supply chain disruptions. These are no longer exceptional events but structural characteristics of the modern operating environment. At the same time, the European Union has set ambitious targets under the Green Deal and the Sustainable and Smart Mobility Strategy for decarbonisation, modal shift and strengthened multimodality. Deliverable D5.1 is the culminating recommendations document of the SARIL project (Horizon Europe, Grant Agreement 101103978). It translates three years of methodological development, scenario-based simulation and green resilience assessment into actionable guidance for the key stakeholder groups in European freight transport.

The evidence compiled in this report demonstrates that disruptions have become the norm. The 2021 Central European floods devastated transport infrastructure across Germany, Belgium and the Netherlands. Storm Eunice in 2022 caused severe coastal surges and widespread port disruptions across northern Europe. The 2022 wildfire season was the second worst on record in the EU, burning over 1.6 million hectares across 45 countries. The COVID-19 pandemic exposed the systemic vulnerability of globally interconnected logistics networks to non-physical disruptions originating from regulatory measures, workforce shortages and border restrictions. Geopolitical tensions — the war in Ukraine, Houthi attacks on Red Sea shipping, and the 2026 Strait of Hormuz crisis — have forced major container lines to reroute around Africa, adding weeks to transit times and significantly increasing costs. These disruptions share three critical characteristics: higher frequency as climate hazards and geopolitical tensions intensify, greater systemic impact due to the high interconnectivity of modes, nodes and international supply chains, and longer recovery times when critical infrastructure or strategic corridors are affected.

Despite more than two decades of European policy promoting modal shift, intra-European freight transport remains structurally road dominated. Rail freight market share has remained stagnant over the past decade, and short sea shipping growth has essentially paralleled overall trade volume growth rather than substituting road transport. This modal imbalance concentrates large cargo volumes along specific land corridors, limits systemic redundancy and increases exposure to corridor-level disruptions where incidents on critical road or rail axes generate cascading effects across borders. From a resilience perspective, heavy reliance on a single dominant mode reduces the system's capacity to absorb shocks and reallocate flows efficiently. The structural dependence on road freight therefore represents not only a sustainability challenge but also a fundamental resilience deficit within the European logistics system.

The SARIL project has developed a holistic Green Resilience Management framework that integrates vulnerability and risk assessment, transport and traffic modelling, resilience assessment including cascading effects, and incorporation of environmental and energy performance indicators. A key innovation is the concept of green resilience: the recognition that mitigation measures and contingency strategies must not undermine long-term decarbonisation goals. The project produced a portfolio of seven interoperable digital tools — ASTROIT for transport network simulation, the Vulnerability and Traffic Tool, Scour Monitoring for Decision Support, Natural Hazard Maps, the Disruption Information Interface, the Energy Module, and FlamMap/Forest Fire Risk Map — which were validated across three scenarios at regional, national and European scale.

The scenario-based simulations produced consistent and measurable results. In the European scenario, a major port-related disruption increased delivery times by approximately 11%, operational

costs by 4.4% and CO_2 emissions by 2.7% compared to the base case. In the national wildfire scenario, infrastructure disruption increased total travel time by more than 17%. Structural mitigation measures such as firebreaks reduced this by approximately 20%, while digital adaptation measures including early warning systems and improved traffic management reduced travel time by approximately 11% and slightly reduced emissions. Increased modal flexibility and synchro-modal routing options reduced both CO_2 emissions and operational costs simultaneously, highlighting the systemic value of multimodal integration. The simulations also revealed important trade-offs: low-emission vehicle deployment significantly reduced CO_2 but increased operational costs, confirming that resilience strategies must be assessed through structured modelling and KPI-based evaluation rather than implemented intuitively.

The report provides differentiated recommendations for three stakeholder roles. Infrastructure managers should move from reactive crisis management to proactive, resilience-by-design approaches, implementing real-time condition monitoring, predictive hazard modelling and integrated disruption information interfaces. Logistics network configurators should integrate resilience and sustainability as co-equal objectives in their optimisation models, simulating alternative configurations and disruption scenarios during the planning phase and investing in multimodal redundancy and flexible route design. Logistics operators and shippers should leverage real-time alerts and simulation-based decision support for dynamic rerouting and mode switching. Process mapping conducted within the project demonstrated that disruptions immediately multiply the workload of operations teams, and that operators equipped with SARIL's digital tools were able to significantly reduce response time and limit service degradation compared to reactive manual coordination.

At the policy level, the report recommends embedding resilience explicitly into TEN-T governance through systematic scenario-based stress testing of corridors and major nodes. European funding instruments, including the Connecting Europe Facility and cohesion policy funds, should incorporate resilience-related key performance indicators and incentivise investments in monitoring, early warning and digital decision-support systems. Digital interoperability must be strengthened through standardised data-sharing protocols across modes and Member States. Resilience and decarbonisation objectives must be aligned, requiring integrated evaluation of operational and environmental performance in disruption scenarios. Policy frameworks should support increased short sea shipping frequency, maritime digitalisation and autonomous vessel technologies as a complementary resilience layer within the European transport system.

Building on these policy recommendations and on an analysis of existing intra-European maritime freight services — which revealed significant gaps, particularly in east–west Mediterranean connections and north–south Atlantic links — the report proposes supplementing the TEN-T with a structured hub-and-spoke maritime freight network. Fourteen regional hub ports would be connected by seven backbone "highway" service routes: a North Sea–Baltic connector extending from Rotterdam through Gothenburg and Travemünde to Gdynia and Helsinki; a North Sea–Atlantic connector linking Rotterdam, Dublin, Bilbao and Sines; a Western Mediterranean loop connecting Barcelona, Genoa, Civitavecchia and Naples; an Adriatic–Eastern Mediterranean service from Trieste through Piraeus to Limassol; a cross-Mediterranean connector linking Barcelona, Civitavecchia and Piraeus as a "southern TEN-T corridor at sea"; a Norway–Continent direct service from Rotterdam to Bergen and Trondheim; and a Baltic–Mediterranean bypass from Gothenburg through Zeebrugge and Sines to Barcelona and Genoa, providing a complete maritime alternative that avoids all Alpine road and rail crossings. Spoke services using smaller, potentially autonomous vessels would extend the network to urban distribution hubs, island communities, rural ports and inland waterway connections. These services are designed to complement existing land corridors, providing modal redundancy and pre-configured alternative routing options that can be activated during major disruptions.

The SARIL project demonstrates that resilience in European freight transport can be modelled, quantified and operationalised. The transition from reactive crisis management to resilience by design requires infrastructure planned with redundancy and risk exposure in mind, logistics networks configured with multimodal flexibility, operational processes supported by real-time monitoring and simulation tools, and environmental and resilience indicators assessed jointly rather than separately. Resilience cannot be delegated to a single actor; it must be distributed across roles, aligned through shared data interfaces and supported by interoperable analytical tools. The SARIL framework provides the methodological foundation for this transformation. The next step is to systematically integrate it into European transport policy and investment practice.

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List of Acronyms

Acronym	Definition
AFIR	Alternative Fuels Infrastructure Regulation
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
ASTROIT	Advanced Simulation Tool for Resilient and Optimised Intermodal Transport (SARIL transport network simulation tool)
BIMCO	Baltic and International Maritime Council
BPMN	Business Process Model and Notation
C3S	Copernicus Climate Change Service
CCS	Carbon Capture and Storage
CEF	Connecting Europe Facility
CLECAT	European Association for Forwarding, Transport, Logistics and Customs Services
CO_2	Carbon Dioxide
COVID-19	Coronavirus Disease 2019
CSL	CSL (SARIL project partner – logistics operator)
CSRD	Corporate Sustainability Reporting Directive
DG MOVE	Directorate-General for Mobility and Transport (European Commission)
DII	Disruption Information Interface (SARIL tool)
DFDS	Det Forenede Dampskibs-Selskab (Danish shipping and logistics company)
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environment Agency / European Economic Area (context-dependent)
EFFIS	European Forest Fire Information System
eFTI	Electronic Freight Transport Information
ESG	Environmental, Social, and Governance
ETS	Emissions Trading System
ETRO	European Transport Regulation Observer
EU	European Union
FMCG	Fast-Moving Consumer Goods
GHG	Greenhouse Gas
GNV	Grandi Navi Veloci (Italian shipping company)
HELCOM	Helsinki Commission (Baltic Marine Environment Protection Commission)
IMO	International Maritime Organisation
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
IWT	Inland Waterway Transport
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
KPI	Key Performance Indicator
LNG	Liquefied Natural Gas
LoLo	Load on / Load off (typical cargo handling method for containers on ships)
L-PIT	L-PIT (SARIL project partner – logistics process innovation)
MASS	Maritime Autonomous Surface Ships

MODIS	Moderate Resolution Imaging Spectroradiometer
NCL	Norway Container Line
RoRo	Roll on / Roll off (typical cargo handling method for trailers on ships)
RoPax	Roll on / Roll off – Passengers (combined freight and passenger ferry)
SME	Small and Medium-sized Enterprise
SST	Sea Surface Temperature
SSMS	Sustainable and Smart Mobility Strategy
TEN-T	Trans-European Transport Network
TEU	Twenty-foot Equivalent Unit (standard container measure)
UIRR	International Union for Road-Rail Combined Transport
VIIRS	Visible Infrared Imaging Radiometer Suite
WP	Work Package

1 Introduction

The transport and logistics sector in Europe is undergoing a structural transformation. Increasing climate-related extreme weather events, geopolitical instability, cyber threats, pandemics, and systemic supply chain disruptions have demonstrated that disturbances are no longer exceptional events but structural characteristics of modern freight transport systems. At the same time, the European Union has set ambitious targets under the Green Deal and the Sustainable and Smart Mobility Strategy, aiming to significantly reduce emissions, promote modal shift, and strengthen multimodality while ensuring competitiveness and territorial cohesion.

As stated in Transport in the European Union (EU 2024): “An efficient transport system, ensuring connectivity and accessibility, is essential for exploiting the economic assets of all regions of the European Union, for supporting the internal market and growth, and for promoting economic, territorial and social cohesion.” This statement reflects the dual challenge currently faced by European transport systems: they must remain efficient, integrated and competitive, while at the same time becoming climate-neutral and resilient to increasingly frequent disruptions. Multimodality plays a central role in this transformation. By taking advantage of the strengths of different transport modes, such as convenience, speed, cost efficiency, reliability and predictability, multimodal logistics systems can offer more efficient and flexible transport solutions for both goods and passengers. However, multimodality is not only a sustainability instrument. The COVID-19 pandemic clearly demonstrated that diversified and flexible transport networks are also crucial for resilience. Systems capable of shifting flows between modes and corridors proved more robust in maintaining connectivity and ensuring continuity of supply chains during periods of severe disruption. The crisis also showed the readiness of society and market actors to embrace alternative and more sustainable transport solutions when necessary. In this context, resilience and sustainability cannot be treated as separate domains. Freight transport systems must not only withstand and recover from disruptions, but they must do so in a manner consistent with long-term decarbonisation objectives. These dual objective forms the foundation of the SARIL project.

Throughout the project, SARIL has developed a holistic Green Resilience Management framework integrating:

- vulnerability and risk assessment,
- transport and traffic modelling,
- resilience assessment including cascading effects,
- incorporation of environmental and energy performance indicators.

Based on three validated operational scenarios at regional, national and European scale, SARIL has co-created a portfolio of interoperable digital tools supporting infrastructure managers, logistics network configurators, logistics operators, and policymakers in preparing for, responding to and recovering from disruptive events.

SARIL has developed methodologies and software solutions for stakeholders in transport and logistics to deal with disruptions of various kinds, facilitating resilient logistics. This document describes how the SARIL results may be applied in practical processes and operations. The examples are inspired by the operations and experience of SARIL partners.

Deliverable D5.1 builds upon the methodological framework defined in WP1 and WP2, the enhanced modelling and tool architecture developed in WP3, and the validation and green resilience assessment results generated in WP4. While previous deliverables focused on methodology development, simulation modelling, tool integration and impact assessment, this deliverable translates these results into actionable recommendations.

The purpose of this document is therefore threefold:

- To provide role-based recommendations for key stakeholder groups in transport and logistics systems
- To demonstrate how SARIL tools can be applied in practical decision-making processes under different disruption scenarios
- To formulate cross-cutting policy recommendations supporting the transition towards a resilient and sustainable European freight transport system

The recommendations presented in this document are grounded in the empirical results of SARIL scenario modelling and simulation exercises. They reflect lessons learned from disruptions such as flooding, wildfires, pandemics, port congestion, and geopolitical instability. Importantly, they aim to operationalise the concept of “resilience by design” embedding resilience and sustainability considerations into infrastructure planning, network configuration, operational management and regulatory frameworks from the outset. By translating advanced modelling, monitoring, and simulation capabilities into concrete guidance for stakeholders, D5.1 serves as the bridge between SARIL’s research results and their practical deployment in European transport and logistics systems.

This deliverable is structured as follows. Chapter 2 describes the increasing normalisation of disruptions affecting European transport systems. Chapter 3 outlines the policy and strategic framework within which resilience and sustainability objectives must be achieved. Chapter 4 summarises SARIL’s conceptual and technological contributions. Chapter 5 presents role-based recommendations supported by process mapping and scenario application. Chapter 6 formulates cross-cutting recommendations for policymakers and regulators. The document concludes with key strategic insights and next steps for implementation and exploitation.

2 Disruptions Become the Norm

Over the past decade, the European transport and logistics system has been exposed to an unprecedented combination of natural and man-made disruptions. What were once considered rare, isolated events have increasingly become recurrent and systemic phenomena. Climate change, geopolitical tensions, global health crises, cyber threats, infrastructure ageing and market volatility are no longer independent risk factors they interact, amplify one another and generate cascading effects across interconnected transport networks. The COVID-19 pandemic, the blockage of the Suez Canal, severe flooding in Central Europe, widespread wildfires in Southern Europe, labour strikes in major ports, and geopolitical conflicts affecting energy and trade corridors have collectively demonstrated the structural vulnerability of highly optimised, cost-driven and just-in-time logistics systems. These events revealed not only operational fragilities but also strategic weaknesses in infrastructure redundancy, modal diversification, digital coordination and cross-border crisis management.

Importantly, disruptions increasingly exhibit three characteristics:

- Higher frequency, as climate-related hazards and geopolitical tensions intensify.
- Greater systemic impact, due to the high level of interconnectivity between modes, nodes and international supply chains.
- Longer recovery times, particularly when disruptions affect critical infrastructure or strategic corridors.

These three characteristics are not independent — they interact and compound. When disruptions occur more frequently than systems can fully recover from, the cumulative effect is a progressive erosion of baseline performance. Infrastructure, operational capacity and service reliability may never return to their pre-disruption state before the next event occurs. Rather than a cycle of disruption and full recovery, the system enters a pattern of repeated partial recovery, in which each successive event starts from a weaker position. This means that resilience must be understood not only as the ability to recover from individual events, but as the capacity to maintain long-term system performance under conditions of recurring and overlapping disruptions.

As transport systems become more digitised, interconnected and efficiency-driven, their exposure to cascading failures increases. A local disruption, such as a flooded bridge, a wildfire near a transport corridor or congestion at a major port, can rapidly escalate into network-wide performance degradation, affecting freight flows far beyond the original incident area. This evolving risk landscape requires a shift in perspective. Rather than treating disruptions as exceptional deviations from normal operations, transport systems must be designed and managed under the assumption that disturbances are a permanent feature of the operating environment. In other words, resilience must be embedded into infrastructure planning, network configuration and operational decision-making as a standard requirement — not an emergency add-on.

The following sections provide illustrative examples of natural and man-made disruptions affecting European transport systems. These examples reflect the types of events analysed within the SARIL project scenarios at regional, national and European scale. Together, they demonstrate why resilience, and sustainability must be jointly addressed to ensure continuity, competitiveness and environmental performance of European freight transport networks.

2.1 Severe Weather

Climate change is significantly impacting bad weather conditions all over Europe and beyond.

The severe flooding in the region covering the Netherlands, Belgium, and Germany occurred in mid-July 2021. The flooding was particularly devastating in parts of western Germany and eastern Belgium, with heavy rainfall leading to swollen rivers and widespread damage. This disaster resulted in significant loss of life and destruction of property in affected areas.

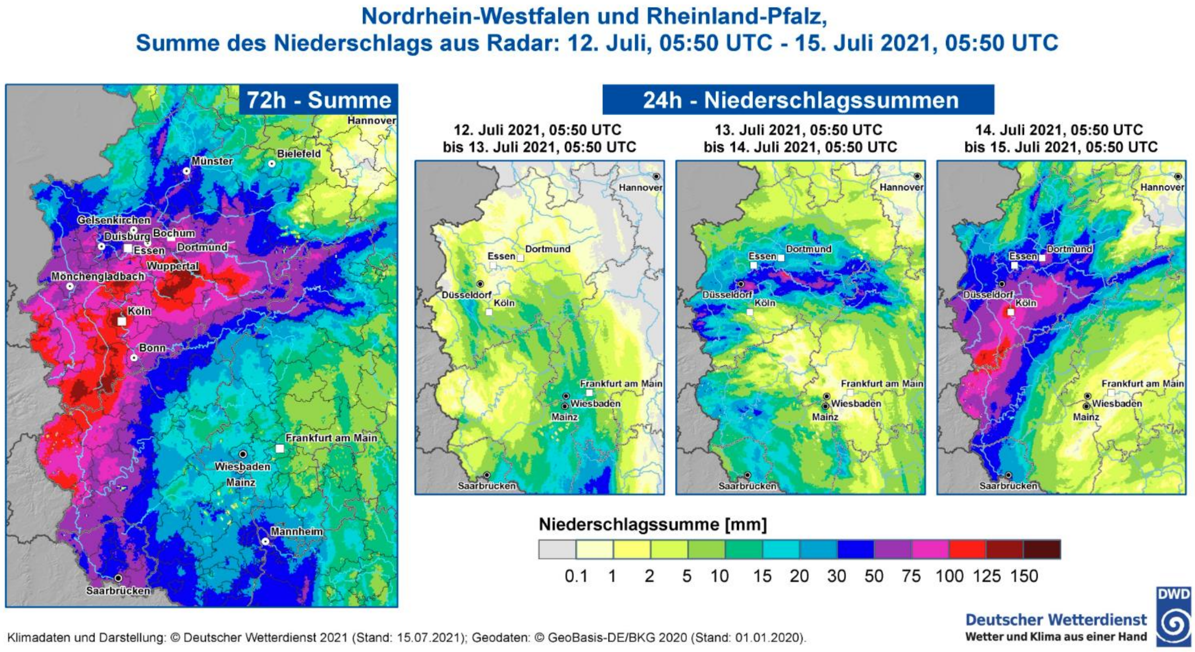

Figure 1: Areas affected by the floods in 2021. Source: Deutscher Wetterdienst

Severe weather is not only causing problems for transport on land. Also, European short sea shipping routes are impacted in several ways.

Severe weather is not only causing problems for transport on land. European short sea shipping routes and inland waterway connections are increasingly affected by climate-driven changes, with documented operational consequences across multiple categories of risk.

Increased Storm Intensity and Frequency

Climate change has led to more intense and frequent storms, particularly in the North Atlantic and the North Sea. These storms cause delays, damage to ships, and pose safety risks to crews. Storm Eunice (February 2022) was one of the most powerful storms to affect northern Europe since the Great Storm of 1987, causing severe coastal surges across the Netherlands and a 3.75-metre storm surge on the Hamburg Elbe, with widespread port and lock disruptions (Wikipedia/KNMI, 2022). In December 2025, Southampton suspended all shipside operations due to dense fog and experienced a 50-hour pilot closure, a 12-hour stoppage and multiple weather-related incidents over two weeks, including 15 containers falling overboard (Maritime News, 2026). Storm Hans (August 2023) severed Norwegian road links for days, demonstrating how a single weather event can disrupt both maritime hinterland connections and the fragile E6 road corridor along the Norwegian coast.

Rising Sea Levels

As sea levels rise due to melting ice caps and thermal expansion, ports along European short sea routes face increased flooding and erosion, which can disrupt shipping operations. According to the European

Environment Agency, a 10 cm rise in sea level typically increases the frequency of flooding to a given height by a factor of approximately ten (EEA, 2024). Research published in Maritime Economics & Logistics found that under the high warming scenario (RCP8.5), extreme sea level increases exceeding 0.5 metres will affect the largest part of the European coastline, with increases of more than 1 metre projected for the North Sea and the western part of the Baltic Sea. The study concludes that 25% more cargo could be affected by extreme water levels by the end of the century compared to moderate warming scenarios (Christodoulou et al., 2019). The scale of adaptation investment required is already substantial. Rotterdam's port adaptation strategy cost €90 million (Climate Scorecard, 2026). Venice's MOSE flood barrier system, built at a cost of €7 billion, was designed to activate approximately five times annually but has been deployed 97 times in its first four years of operation (Climate Scorecard, 2026), illustrating how rapidly conditions are outpacing original design assumptions.

Changing Wind Patterns

Altered wind patterns can lead to more challenging navigation conditions. The reduction of the Arctic-to-midlatitude temperature gradient has been linked to a weakening and increased meandering of the polar jet stream, which can cause weather systems to stall and generate prolonged extreme weather events (Francis & Vavrus, 2012). For short sea shipping, this translates into more unpredictable weather windows, affecting the reliability of schedules in exposed waters such as the North Sea and Skagerrak. The expansion of offshore wind farms in the North Sea introduces additional navigational constraints, potentially forcing detours that lengthen vessel exposure time in severe weather conditions.

Extreme Temperatures and Drought

Higher temperatures can lead to more intense heatwaves, affecting crew conditions and potentially causing equipment malfunctions. However, the most significant transport impact of extreme heat in Europe is on inland waterway connections to short sea shipping. The Rhine low water crises of 2018 and 2022 demonstrated this dramatically. In summer 2022, water levels on the Rhine dropped to critically low points, making it too shallow for many ships to pass (Euronews, 2022). Ships that would normally carry 2,200 metric tons of cargo were only able to transport about 600 tons. Researchers at the Kiel Institute for the World Economy found that in 2018, low water levels led to a drop in German industrial production of 1.5%, causing a decline in GDP of 0.4% (ABN AMRO, 2024). An ABN AMRO study found that thirty consecutive days below the critical water threshold at Kaub led to a cumulative 24% reduction in freight transport over two months (ABN AMRO, 2024). The Rhine carries more than three quarters of Germany's inland shipping freight (Umweltbundesamt, 2022), and shipping companies have acknowledged they are preparing for a "new normal" in which low water levels become structurally more frequent as global warming intensifies droughts (Euronews, 2022). Conversely, colder snaps can lead to ice formation in previously ice-free areas, complicating navigation in the Baltic Sea.

Increased Precipitation

More frequent and heavier rainfall can lead to higher river levels, affecting inland waterway routes that connect to short sea shipping. High-water closures have repeatedly shut down shipping on the Upper Rhine, most notably in 1999, 2016 and 2021 (Umweltbundesamt, 2022). The 2021 Central European floods devastated transport infrastructure across Germany, Belgium and the Netherlands, with the flooding being particularly devastating in parts of western Germany and eastern Belgium (see Section 2.1). The same waterway system that suffers from drought-related low water in summer can be completely shut down by flooding at other times, demonstrating the dual vulnerability of inland waterways to both extremes of precipitation. This results in delays and increases operational costs as cargo must be rerouted to road or rail at short notice.

Storm Surges

The combination of rising sea levels and more intense storms can lead to more severe storm surges, which can damage port infrastructure and disrupt shipping operations. During Storm Eunice (February 2022), the Netherlands experienced severe coastal surges, and the Hamburg Elbe surge reached 3.75 metres, causing widespread port and lock disruptions across northern Europe (Wikipedia/KNMI, 2022). According to the European Commission's JRC PESETA studies, estimated damages due to coastal sea floods are projected to increase from €5 billion in the control period to €17 billion per year in the reference scenario, with around half of these damages concentrated in the Central Europe North region, which includes the Netherlands (JRC, 2011). UNCTAD has warned that economic losses from direct damages to port infrastructure and operational disruptions across interconnected global supply chains can be extensive (UNCTAD, 2021).

The increasing frequency and intensity of severe weather events fundamentally alter the risk landscape for European transport and logistics systems. Floods, storms, extreme temperatures and sea-level rise not only cause immediate physical damage to infrastructure but also generate cascading operational disruptions across interconnected transport corridors and supply chains. Ports, inland terminals, rail networks and road corridors become simultaneously exposed to weather-related hazards, reducing network redundancy and limiting rerouting options.

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For logistics operators and infrastructure managers, this translates into higher uncertainty, longer recovery periods, increased maintenance and insurance costs, and reduced reliability of transport services. In highly time-sensitive and cost-optimised freight systems, even short-term weather-related interruptions can lead to significant economic losses and contractual penalties. Moreover, repeated severe weather events accelerate infrastructure degradation, increasing the long-term vulnerability of critical assets.

Consequently, severe weather must no longer be treated as an occasional operational disturbance but as a structural planning parameter. Transport infrastructure design, network configuration and operational management must incorporate predictive modelling, real-time monitoring, and contingency planning to ensure continuity of freight flows under extreme climatic conditions. Strengthening resilience against severe weather is therefore not only a safety imperative, but also a prerequisite for maintaining competitiveness, sustainability and territorial cohesion within the European transport system.

2.2 Climate-Driven Storminess

All European seas have warmed considerably since the late 1970s. According to the European Environment Agency (EEA, 2024), sea surface temperatures (SSTs) increased by between approximately 0.3 °C per decade in the North Sea and 0.5 °C per decade in the Black Sea during the period 1991– 2024. The Baltic Sea, the North-East Atlantic, the Bay of Biscay and the Mediterranean have all registered significant warming trends, with the North and Baltic Seas warming five to six times faster than the global average over the past quarter-century (EEA, 2012). In 2024, the Mediterranean Sea recorded its warmest year on record at 21.5 °C — 1.2 °C above the 1991–2020 average (C3S/ECMWF, 2025). Warmer surface waters enhance evaporation, thicken the moist boundary layer and feed more latent heat into passing low-pressure systems (IPCC, 2021). Meanwhile, the reduction of the Arctic-to-midlatitude temperature gradient has been linked to a weakening and increased meandering of the polar jet stream, which can cause weather systems to stall (Francis & Vavrus, 2012).

Several major European short sea shipping corridors are particularly exposed to these trends:

2.2.1 North-East Atlantic & English Channel

- In 2022, record-warm SSTs were observed in the Bay of Biscay, the English Channel and the Irish Sea (C3S/ECMWF, 2023). The north-eastern Atlantic around Europe saw SSTs reach 1.76 °C above average in June 2023 — the largest monthly anomaly in the ERA5 record (C3S/ECMWF, 2024). Warmer SSTs in this region have been associated with increased energy available to extratropical cyclones affecting the "Motorway of the Sea" feeder routes in the Celtic Sea and Western Approaches.
- Climate-related port disruptions are a growing concern across Europe. A study published in *Nature Climate Change* found that 5% of global ports are exposed to more than five days of annual weather-related downtime, with knock-on effects through freight supply chains (Verschuur et al., 2023).

2.2.2 North Sea & Skagerrak

The shallow North Sea basin amplifies storm surge. During Storm Eunice (February 2022), the Netherlands experienced severe coastal surges, and the Hamburg Elbe surge reached 3.75 m. The storm caused widespread port and lock disruptions across the region and was one of the most powerful storms to affect northern Europe since the Great Storm of 1987 (Wikipedia/KNMI, 2022).

The expansion of offshore wind farms in the North Sea introduces additional navigational constraints, potentially forcing detours that lengthen vessel exposure time in severe weather conditions.

2.2.3 Baltic Sea

The Baltic Sea is among the fastest-warming bodies of water in Europe, with SST rising at approximately 0.4 °C per decade since the early 1980s (C3S/ECMWF; EEA, 2024). Ice seasons have shortened, while the frequency and intensity of marine heatwaves have increased (EEA, 2024).

Higher SSTs and changing wind patterns have been linked to more intense autumn storm events in the Baltic. Such conditions affect Ro-Ro and Ro-Pax schedules on key routes such as Finland–Germany. [Note: Specific wave height statistics east of Gotland require further verification from HELCOM or national meteorological institute data.]

2.2.4 Mediterranean & Adriatic

Warmer SSTs fuel rapid cyclogenesis in the Mediterranean. Storm Gloria (January 2020) generated record-breaking significant wave heights of 8.44 m off the coast of Valencia — the highest ever recorded in the Mediterranean, surpassing the previous record of 8.15 m set near Mahón in 2003 (Amores et al., 2020; Puertos del Estado). The storm caused severe damage along the coasts of Catalonia and Valencia and forced widespread suspension of maritime services.

High SSTs in the Mediterranean have since been linked to subsequent extreme events including Storm Daniel (2023) and the severe flooding associated with Storm Boris (2024), reinforcing the pattern of climate-amplified weather disruption to shipping in the region (C3S/ECMWF, 2025).

Climate-driven storminess represents a particularly disruptive category of extreme weather due to its sudden onset, geographical spread and operational unpredictability. High winds, intense precipitation, coastal storm surges and lightning events increasingly affect both linear and nodal infrastructure elements, including rail overhead systems, road corridors, bridges, ports and intermodal terminals.

Unlike slow-onset climate phenomena, storm events often provide limited reaction time for infrastructure managers and logistics operators. This reduces the ability to implement preventive rerouting measures and increases the likelihood of emergency closures, service cancellations and asset damage. In maritime transport, intensified storm patterns may disrupt short sea shipping schedules and port operations, affecting hinterland connections and inland distribution chains.

For logistics systems characterised by tight delivery windows and synchronised multimodal flows, storm-induced interruptions can propagate rapidly across the network. A temporary port shutdown or rail corridor disruption may trigger congestion in alternative nodes, create imbalances in equipment positioning, and increase reliance on less sustainable emergency transport solutions. From a strategic perspective, climate-driven storminess introduces a new level of operational volatility that challenges traditional planning assumptions based on historical weather patterns. This necessitates enhanced forecasting capabilities, dynamic traffic management, reinforced infrastructure standards and flexible network design. Integrating real-time data, predictive modelling, and scenario-based stress testing becomes essential for maintaining continuity of operations under increasingly turbulent climatic conditions.

In this context, strengthening resilience against climate-driven storm events is not only a matter of infrastructure robustness but also of system adaptability. Transport networks must be capable of absorbing shocks, reallocating flows and restoring performance rapidly while preserving sustainability objectives. As such, storm resilience must be embedded into infrastructure planning, digital coordination mechanisms and multimodal network configuration as a core element of modern freight transport management.

2.3 Wildfires

The wildfire season in Europe typically spans from early June to late September. Wildfires occur increasingly frequently and are more extensive in southern parts of Europe than in the north. 2022 was the second-worst wildfire season in the European Union since 2000 when the Copernicus' European Forest Fire Information System (EFFIS) records began. Damages in 2022 exceeded those of 2021 and are only surpassed by those of 2017, according to data from the EFFIS Advance Report on Forest Fires in Europe, Middle East and North Africa 2022, which offers a preliminary assessment of last year's wildfires.

EFFIS observed fires in 45 countries in 2022, see Figure 2 (San-Miguel-Ayanz, J., et al. 2023). These countries suffered 16 941 fires that burnt 1 624 381 hectares (ha), which is about the size of Montenegro. When due to methodological differences the Ukraine totals are excluded, records show a 4% increase in burnt area and a 48% one in the number of fires between 2021 and 2022. If only data from the EU (except Luxemburg) is considered, the increase in burnt area is more significant, reaching 86 %. Excluding war-torn Ukraine, Spain was the most affected by wildfires with a total of 315 705 ha (almost 600.000 football fields). This is 3.5 times more than in 2021. Romania (16 2518 ha), Portugal

(11 2063 ha), Bosnia and Herzegovina (76 473 ha) and France (74 654 ha) were also among the five countries that were most affected.

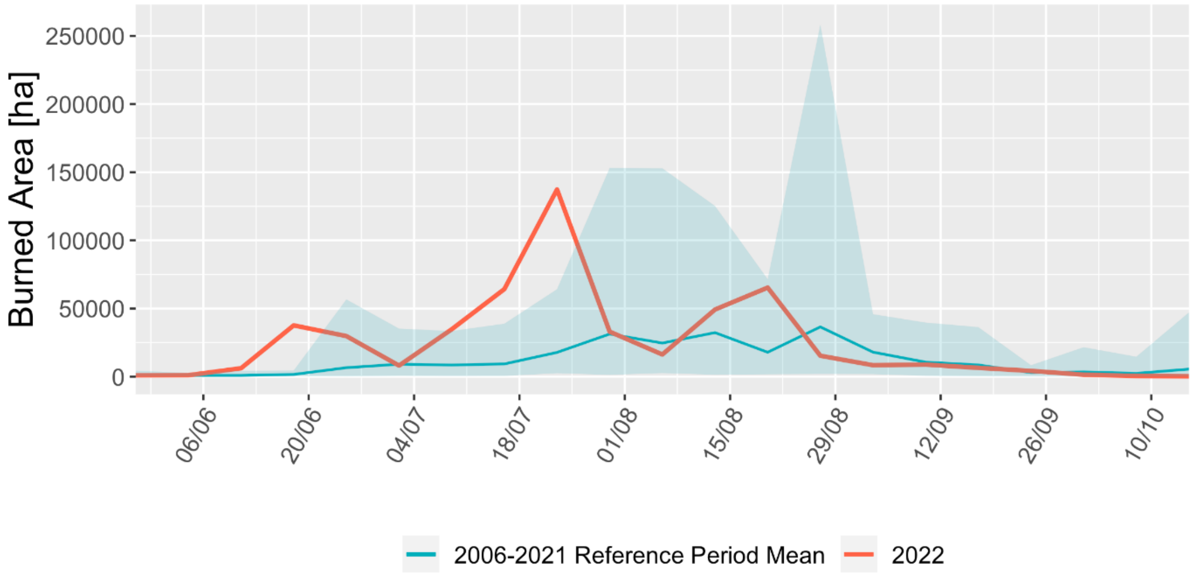

Figure 2: Weekly burnt area in the EU countries in summer 2022 (red) compared to the long-term average from 2006 to 2021 (blue). Data comes from blending of Sentinel-2, VIIRS and MODIS observations. Source: EFFIS

Wildfires are increasingly becoming a structural threat to transport infrastructure, particularly in Southern and Central Europe. Rising temperatures, prolonged droughts and changing land-use patterns increase the probability of large-scale fires affecting road corridors, railways, intermodal terminals and peri-urban logistics hubs. Unlike other extreme weather phenomena, wildfires combine direct physical damage with indirect operational disruptions. Smoke reduces visibility and air quality, forcing temporary closures of roads, railways and airports. Heat can damage signalling systems, overhead lines and road surfaces, while fire containment measures may restrict access to critical infrastructure.

The systemic impact of wildfires extends beyond the affected geographical area. Closure of a single transport corridor may overload alternative routes, increase travel times, and raise emissions due to longer detours. In multimodal networks, disruption of one node, such as a port hinterland connection, can destabilise freight flows across broader regions.

For logistics operators, wildfire events generate high uncertainty, last-minute rerouting, contractual penalties and elevated operational costs. Repeated seasonal fire risks further complicate long-term infrastructure investment and insurance models. Consequently, wildfire resilience requires not only emergency response mechanisms but also predictive modelling, spatial risk mapping and scenario-based planning. Embedding fire risk considerations into infrastructure design, network configuration, and land-use planning is essential for maintaining the continuity of freight transport under increasingly volatile climatic conditions. Wildfire resilience, therefore, forms a critical component of integrated green resilience management.

2.4 Global Health Crisis- The Pandemic (COVID-19)

The initial response to the pandemic led many European countries to implement strict border controls and health checks to curb the spread of the virus. This led to significant delays at border crossings, with long queues of trucks becoming a common sight. For instance, at the Polish German border, truck drivers often waited for days to be processed, causing severe backlogs and delays in delivery schedules. Similar situations were observed at other key crossings, such as the Brenner Pass between Austria and Italy and the French German border (Figure 3).

These delays had a profound impact on supply chains across Europe. Manufacturers and retailers struggled to maintain inventory levels, leading to shortages of essential goods. The transport and logistics sector saw a sharp decline in efficiency and profitability. Small and medium-sized enterprises (SMEs) that relied on just-in-time delivery models were especially vulnerable, facing increased costs and reduced revenues. The sector experienced a significant drop in freight volumes, exacerbating the economic downturn (Tzvetkova 2021).

Figure 3: Strasbourg, France, March 2020. Source: Dreamstime.com

The COVID-19 pandemic exposed the systemic vulnerability of globally interconnected logistics networks to non-physical disruptions. Unlike infrastructure damage, pandemic-related disruptions originated from regulatory measures, workforce shortages, border restrictions and demand volatility rather than asset failure.

Transport systems experienced sudden drops in passenger flows, shifts in freight demand patterns, container imbalances and congestion in strategic ports and terminals. Border controls and quarantine requirements disrupted cross-border flows, while labour shortages affected port handling, trucking capacity and warehousing operations. The pandemic demonstrated that resilience is not limited to infrastructure robustness. Institutional coordination, regulatory flexibility, digital information exchange and multimodal adaptability proved equally important. Networks capable of reallocating flows between modes, adjusting service frequencies and leveraging digital coordination tools showed greater capacity to absorb shocks.

Importantly, the pandemic highlighted the interdependency between transport reliability and societal stability. Ensuring the continuity of critical goods — such as medical supplies, food and energy — became a strategic priority at European and national levels. From a strategic perspective, global health crises underscore the need for redundancy, digital transparency and cross-border coordination mechanisms. Embedding resilience into regulatory frameworks, supply chain design and multimodal transport strategies is essential to mitigate the systemic risks associated with future pandemics or similar large-scale societal disruptions.

2.5 Geopolitical Tensions

Beyond climate-related hazards, European transport and logistics systems are increasingly exposed to geopolitical instability. Armed conflicts, trade disputes, sanctions regimes, and disruptions to strategic corridors directly reshape freight flows, infrastructure utilisation, and modal competitiveness. Unlike short-term weather events, geopolitical tensions often produce prolonged and structural impacts. Trade routes may become restricted or politically sensitive, maritime chokepoints can be blocked, and cross-border rail corridors may face operational or regulatory constraints. The blockage of the Suez Canal and the war in Ukraine have demonstrated how quickly global supply chains can be destabilised when a single strategic corridor is disrupted. The immediate example here is the war in Ukraine.

The New Silk Road comprises three corridors, like illustrated in Figure 4.

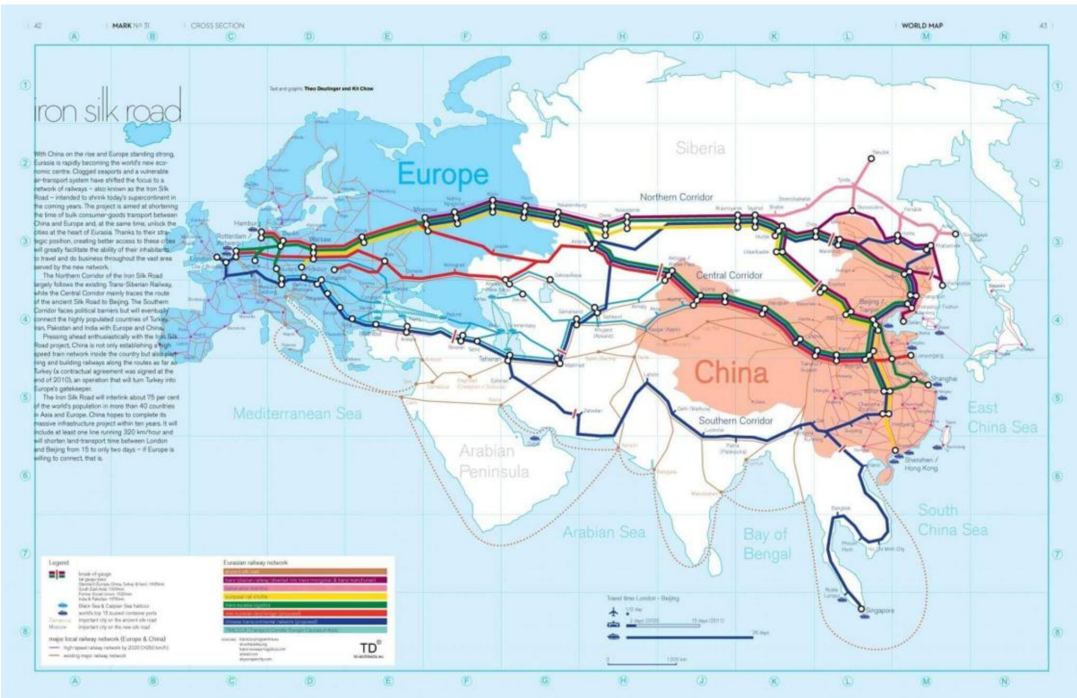

Figure 4: The New Silk Road. Source: TD 2014

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Particularly relevant in this context is the vulnerability of intercontinental rail freight connections between Europe and Asia, often referred to as the “New Silk Road”. Rail corridors linking China with Europe through Central Asia, Russia and Eastern Europe have gained strategic importance over the past decade as an alternative to maritime transport. However, geopolitical tensions affecting transit countries have significantly altered the risk profile of these routes, forcing logistics operators to reconsider routing strategies, diversify corridors and reassess long-term infrastructure investments. Geopolitical disruptions tend to generate cascading consequences across the transport network.

When one strategic corridor becomes unavailable, alternative routes experience congestion, capacity shortages and cost increases. Longer detours may lead to higher emissions, creating tension between resilience needs and sustainability objectives.

As can be seen in Figure 4, the Northern and Central Corridor of the New Silk Road are the one accommodating the highest volume of cargo. Both are passing through Russia and Ukraine. With the turbulent political situation in and around Russia, Ukraine etc., some shippers may find it too risky or politically incorrect to use these corridors. Hence, it is important to have alternatives.

Figure 5: Area controlled by the Houthis 2023-2025 and 2026-. Source: Mapbox.com

The conflicts in the Middle East have let to attacks on commercial shipping in the Red Sea by the Houthis, see with significant repercussions on global trade and regional security. These attacks, primarily targeting vessels linked to Israel or its allies, have disrupted one of the world's busiest shipping lanes, leading to increased shipping costs and delays. Many shipping companies have rerouted their vessels around the Cape of Good Hope, adding weeks to transit times and significantly increasing fuel costs. This rerouting has also contributed to a rise in insurance premiums for ships traversing the Red Sea.

On 28 February 2026, the United States and Israel initiated coordinated airstrikes on Iran under Operation Epic Fury, targeting military facilities, nuclear sites, and leadership. In response, Iran declared the Strait of Hormuz (Figure 6) "closed" on 4 March, and Iranian forces threatened and carried out attacks on ships attempting to transit. The disruption affected about 20% of the world's daily oil supply and significant volumes of LNG, prompting major shipping firms to suspend operations in the area. Container shipping lines Maersk, MSC, Hapag-Lloyd and CMA CGM all suspended transits through the strait and rerouted vessels around the Cape of Good Hope. The Houthis simultaneously announced they would resume attacks on shipping in the Red Sea, forcing Suez Canal traffic to also be rerouted around Africa.

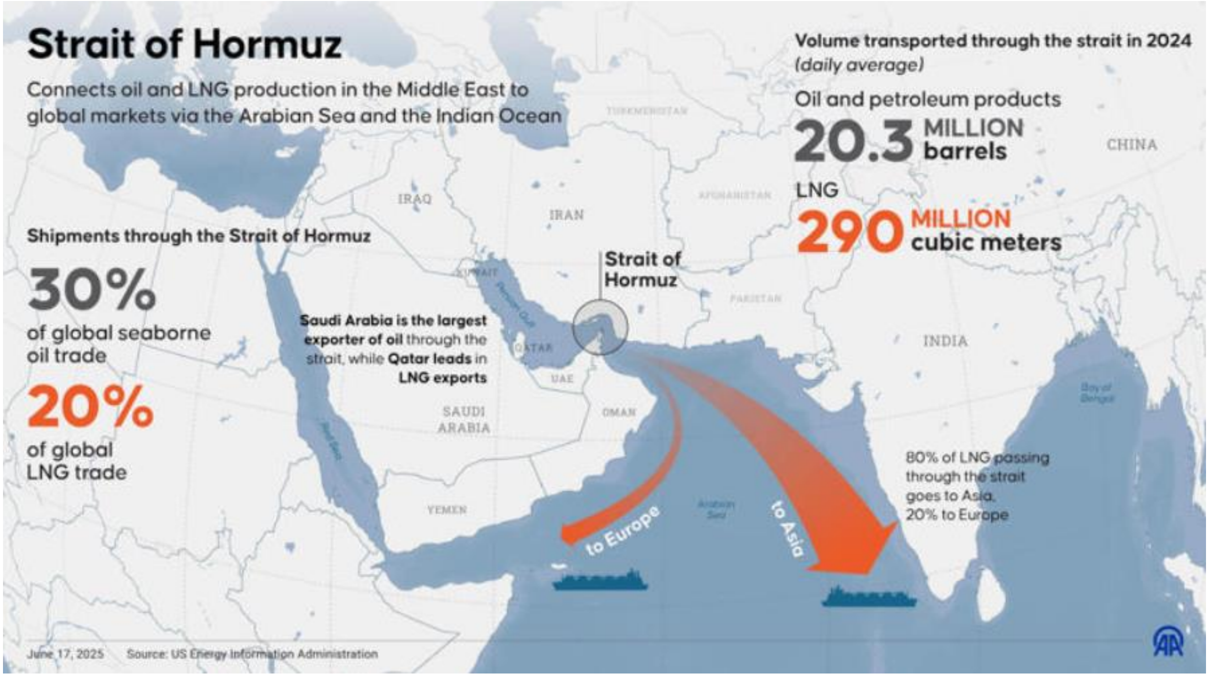

Figure 6 The Strait of Hormuz. Source: US Energy Information Administration, June 17, 2025

Geopolitical tensions and armed conflicts introduce a distinct category of long-term, systemic disruptions affecting trade corridors, energy supplies and strategic transport routes. Sanctions, trade restrictions, corridor closures and security threats can rapidly alter established logistics patterns and require structural reconfiguration of transport networks. Disruptions of major corridors - maritime chokepoints, border crossings or rail freight routes. may result in prolonged congestion, capacity shortages and price volatility. Unlike short-term weather-related events, geopolitical disruptions often require long-term strategic adaptation rather than temporary operational adjustments. The re-routing of flows to alternative corridors may increase transport distances, operational costs and environmental footprint, potentially conflicting with decarbonisation objectives. At the same time, reduced predictability increases investment risks for infrastructure managers and logistics operators.

Geopolitical disruptions demonstrate that resilience must be considered at transnational and European scale. Infrastructure redundancy, corridor diversification, strategic autonomy and coordinated EU-level policy responses become essential to maintaining freight continuity under unstable geopolitical conditions. In this context, resilience planning must integrate scenario-based stress testing, strategic vulnerability assessment and sustainability considerations to ensure that alternative routing solutions remain aligned with long-term environmental objectives.

2.6 Other Man-Made Disruptions

Beyond climate hazards and geopolitical tensions, European transport and logistics systems face an increasing range of other man-made disruptions, including cyber-attacks, labour strikes, technical system failures, industrial accidents and digital platform breakdowns. Although these events may not cause visible physical damage, their systemic impact can be equally severe.

Modern freight transport networks are highly dependent on digital coordination systems, automated traffic management, port community platforms and real-time data exchange. As digitalisation improves efficiency and transparency, it also increases exposure to cyber threats and data integrity risks. A failure or targeted attack on critical IT systems can disrupt traffic flows, block border procedures or paralyse port operations across multiple regions. Maritime transport is additionally exposed to security-related threats such as piracy and armed attacks on commercial vessels. Incidents in regions such as the Red Sea, Gulf of Aden or other strategic maritime corridors have demonstrated that security risks can rapidly alter shipping routes, increase insurance costs and force vessels to undertake longer detours. Such deviations may significantly extend transit times, increase fuel consumption and generate higher emissions, affecting both economic performance and sustainability objectives.

Piracy remains a significant issue for commercial shipping in several key areas around the world:

- *Gulf of Guinea*: Off the coast of West Africa, particularly around Nigeria, piracy is a major concern. This region has seen a rise in violent attacks, kidnappings for ransom, and hijackings of vessels.
- *Somalia and the Indian Ocean*: Although piracy off the coast of Somalia has decreased due to international naval patrols, it remains a threat. The waters around the Horn of Africa and the Indian Ocean are still areas where pirate attacks can occur.
- *Southeast Asia*: The waters around Indonesia, the Strait of Malacca, and the South China Sea are hotspots for piracy. While incidents have declined over the years, petty theft and hijackings still occur.
- *Latin America*: The Caribbean Sea and parts of South America, such as Venezuela, see piracy incidents, often involving smaller vessels but still posing risks to commercial shipping.
- *Red Sea and the Gulf of Aden*: Recent geopolitical tensions and attacks by groups like the Houthis have heightened piracy risks in these waters, affecting commercial shipping routes.

Labour strikes and technical failures at key hubs or corridors can similarly propagate congestion and delays throughout interconnected networks. In highly optimised, cost-driven logistics systems with limited redundancy, even short-term operational disruptions may generate cascading effects. Port blockades and operational shutdowns represent another category of high-impact man-made disruptions. These may result from labour disputes, security incidents, infrastructure damage or administrative restrictions. Given the concentration of freight flows in major European seaports, temporary closures or capacity limitations can quickly propagate congestion across hinterland networks, affecting rail and road corridors far beyond the port perimeter. In highly interconnected logistics systems, the disruption of a single strategic node may destabilise entire regional or transnational supply chains. Incidents like the Ever-Given blockage in 2021, see Figure 7 raised concerns about congestion and delays, prompting some operators to consider alternative routes.

Figure 7: Ever Given blocking the Suez Canal. Source: The International Chamber of Shipping

Within Europe, blockage of key ports (Figure 8) should be considered when investigating logistics network resilience.

- In 2020, the port of Hamburg (Germany) faced disruptions due to strikes by dockworkers, which affected operations and delayed shipping schedules.
- In early 2021, the port of Rotterdam (Netherlands) experienced delays due to severe weather conditions, including heavy snow and ice, which impacted container handling and transportation.
- In late 2021, the port of Felixstowe (UK) faced significant congestion and delays due to a combination of high demand, labour shortages, and supply chain issues, leading to ships being unable to dock promptly.
- In 2021, the port of Antwerp (Belgium) was disrupted caused by labour strikes and operational challenges, affecting the port's ability to service incoming and outgoing vessels.

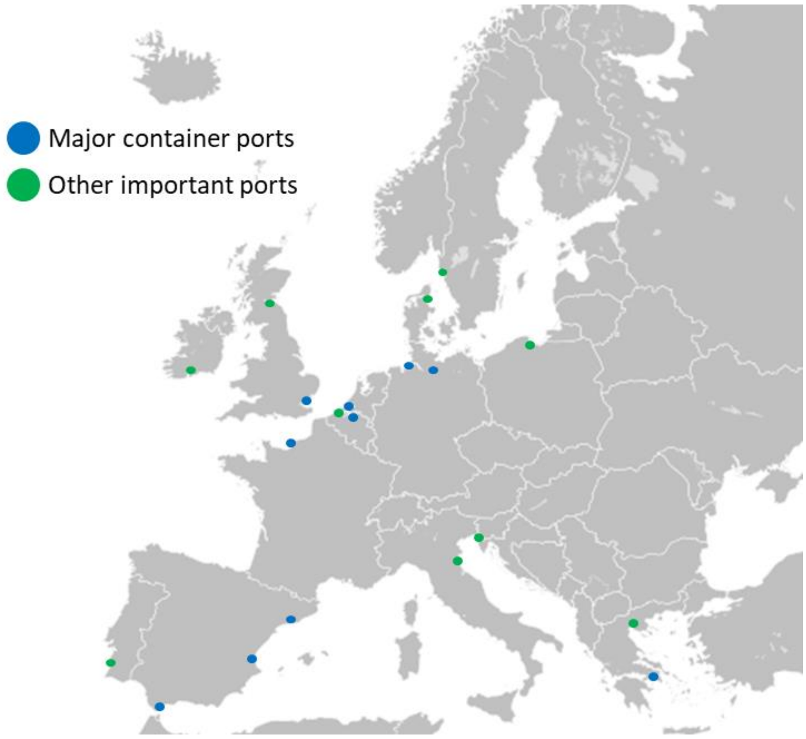

Figure 8: Key seaports in Europe. Source European Commission

The growing complexity and digitalisation of multimodal transport ecosystems therefore require a broader understanding of resilience. Strengthening cybersecurity, ensuring digital redundancy and improving institutional coordination are becoming as essential as maintaining physical infrastructure robustness to safeguard the continuity of freight operations.

Cyber-attacks targeting traffic management systems, port operations or logistics platforms can disrupt information flows, compromise operational visibility and undermine trust between stakeholders.

According to ENISA's 2025 Threat Landscape report, transport (ENISA 2025) is the second most targeted sector in the EU at 7.5% of all incidents, trailing only public administration. Ransomware attacks against the transport sector almost doubled between 2021 and 2022, rising from 13% to 25% of incidents. About a quarter of attacks are linked to hacktivist groups, primarily targeting European airports, railways and transport authorities through DDoS attacks.

Labour strikes or technical failures in major hubs may halt operations without causing physical infrastructure damage yet produce comparable network-wide consequences. These disruptions often propagate through digital and organisational interdependencies rather than physical asset damage. A failure in data exchange systems may paralyse coordination across multiple actors, amplifying delays and reducing system transparency.

The increasing digitalisation of transport, therefore, creates a paradox: improved efficiency and coordination come with heightened exposure to cyber and systemic risks. Building resilience requires secure data architecture, redundancy in digital systems, contingency planning and enhanced stakeholder coordination mechanisms. Ensuring resilience against man-made disruptions demands not only robust physical infrastructure but also institutional preparedness, cybersecurity integration, and operational flexibility. In a highly interconnected logistics ecosystem, digital and organisational resilience becomes as critical as physical resilience.

2.7 Summary

The examples presented in this chapter demonstrate that European transport and logistics systems are exposed to a broad and expanding spectrum of risks. Climate-related extreme weather events, wildfire and flooding, geopolitical instability, pandemics, cyber threats, piracy and port blockades represent different categories of disruption, yet they share a common characteristic: their ability to generate cascading effects across highly interconnected multimodal networks. Disruptions increasingly transcend geographical and sectoral boundaries. A flooded bridge, a blocked maritime corridor, a cyber-attack on a port system or a regulatory restriction at a border crossing may rapidly propagate through road, rail, inland waterway and maritime transport chains. As logistics systems become more digitalised, optimised and globally integrated, their vulnerability to systemic shocks grows correspondingly.

The normalisation of disruption fundamentally changes the planning paradigm for transport and logistics. Resilience cannot be treated as a reactive emergency response mechanism. It must be embedded into infrastructure design, network configuration, operational management and policy frameworks as a structural and long-term priority.

At the same time, resilience objectives must be aligned with sustainability goals. Emergency rerouting, corridor diversification or increased redundancy should not undermine decarbonisation targets or modal shift ambitions. The challenge for European freight systems is therefore not only to withstand disruptions, but to do so in a way that preserves environmental performance and supports long-term strategic objectives.

The following chapter places these challenges within the broader European policy and strategic context, outlining the regulatory and institutional framework within which resilient and sustainable freight transport systems must be developed.

3 The Policy and Strategic Context- an Efficient, Effective, and Resilient European Transport System

European freight transport operates within a complex and evolving structural environment shaped by regulatory frameworks, market forces, technological developments and sustainability objectives. While policy ambitions increasingly emphasise multimodality, decarbonisation and resilience, the operational reality of freight transport remains characterised by structural imbalances and limited systemic redundancy. Understanding these structural conditions is essential for framing resilience not as an isolated operational challenge, but as a systemic property of the European transport network.

This chapter outlines the key policy instruments, modal trends and emerging drivers that define the context within which the SARIL recommendations presented in Chapters 5 and 6 should be understood.

3.1 Structural Imbalance in European Freight Transport

Despite successive revisions of the Trans-European Transport Network (TEN-T) framework and strategic emphasis on multimodality, intra-European freight transport remains structurally road-dominated. Over recent decades, no substantial modal shift from road to rail or maritime transport has materialised at the scale necessary to rebalance freight flows.

This structural imbalance has several consequences. First, it concentrates large volumes of cargo along specific land corridors, increasing congestion and straining infrastructure. Second, it limits systemic redundancy, as alternative modal options are often insufficiently integrated or lack frequency and capacity. Third, it increases exposure to corridor-level disruptions, where incidents affecting critical road or rail axes can generate cascading effects across national borders.

From a resilience perspective, heavy reliance on a single dominant mode reduces the system's capacity to absorb shocks and reallocate flows efficiently. While the TEN-T framework provides a strategic structure for connectivity, modal concentration continues to represent a structural vulnerability within the European freight system.

Hence, new initiatives should be taken to balance the flow of cargo better between road, rail, and maritime transport.

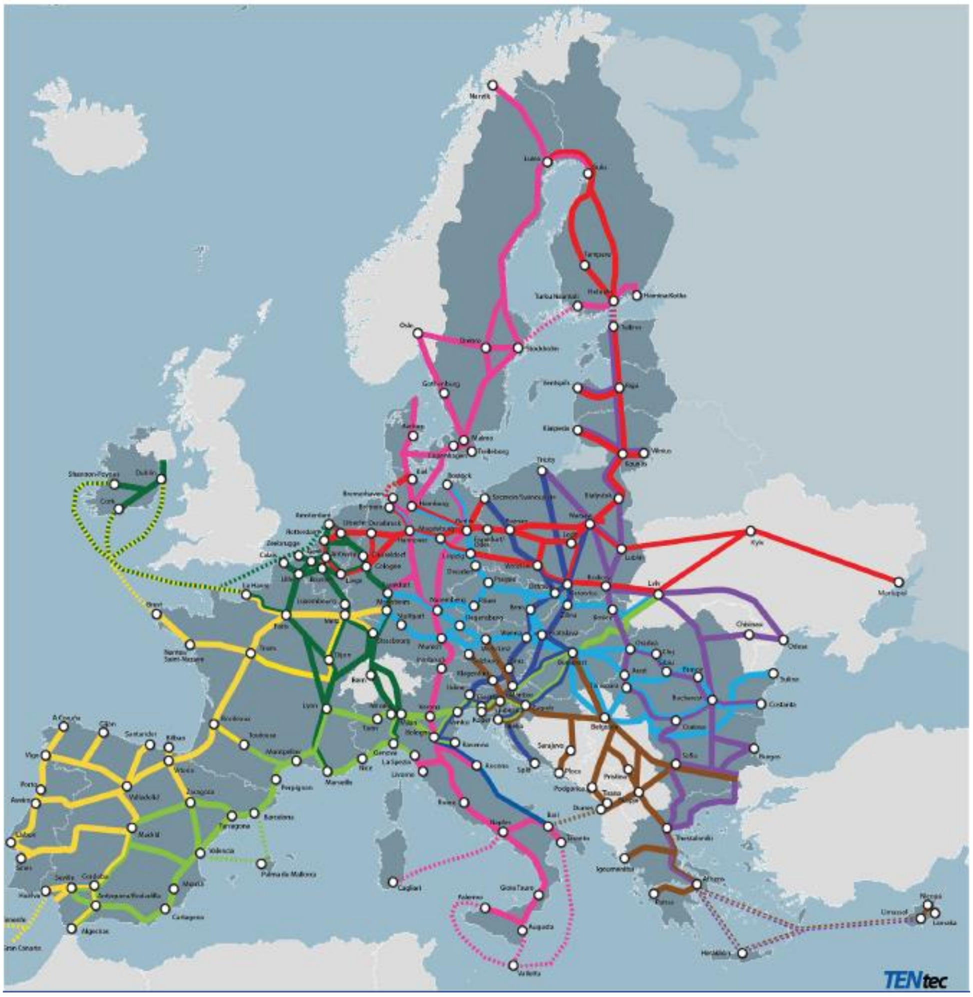

Figure 9: The TEN-T Network S. Source: European Commission, TEN-TEC Interactive Map Viewer, https://webgate.ec.europa.eu/tentec-maps/web/public/screen/home

3.2 Emerging Drivers of Maritime and Multimodal Transformation

Several structural developments are reshaping the conditions under which modal shift and multimodal integration may be pursued in European freight transport. These drivers span technology, regulation, market behaviour and climate policy, and together they may create new opportunities for strengthening both sustainability and resilience. The following subsections present the most relevant trends that inform the policy recommendations formulated in Chapter 6.

3.2.1 Rail Freight: Ambitions and Investment Requirements

Rail freight has long been identified as a key enabler of modal shift and decarbonisation within the European transport system. However, empirical data from Eurostat confirm that rail's market share in intra-European freight transport has remained largely stagnant over the past decade (see Section 4.3). Achieving the modal shift targets set out in the Sustainable and Smart Mobility Strategy will require substantial and sustained public and private investment.

The most targeted study on the road-to-rail freight shift is the UIRR-commissioned Roadmap to Zero Carbon Combined Transport 2050 (UIRR/d-fine 2022). It found that a public investment of approximately €490 billion would be needed in TEN-T rail infrastructure to handle the projected tripling of rail freight volumes (from 400 to 1,150 billion tonne-kilometres per year) by 2050, with the number of freight trains growing from 6,100 to 13,800 (CLECAT 2022). This amounts to roughly €16.3 billion per year in public investment (Railfreight.com 2022).

In addition, an estimated €47 billion in private-sector investment would be required for terminal infrastructure and intermodal assets, including approximately 300 new terminals, digitalisation of existing ones, and capacity upgrades that would effectively double terminal throughput. The UIRR further specifies approximately €16.5 billion annually in rail infrastructure modernisation and €1.5 billion annually in intermodal facilities, in addition to a supportive regulatory framework (PierNext 2023).

These figures underscore that rail freight development constitutes a long-term structural investment challenge that requires sustained policy commitment and coordinated public-private financing. From a resilience perspective, the availability of rail as a viable alternative mode is essential for reducing corridor dependency and absorbing shocks when road infrastructure is disrupted.

3.2.2 Maritime Freight: Vessel Trends and Service Frequency

The maritime sector, normally focused on the optimisation of unit cost from quay to quay, has progressively increased vessel sizes while simultaneously reducing service frequencies. According to BIMCO (BIMCO 2024), the average container ship has approximately doubled in size since 2006, reaching 4,580 TEU. While this trend has improved economies of scale, it has also reduced scheduling flexibility. In practice, this means that cargo must frequently wait for the next available sailing, unlike road transport, where trucks are typically available on demand.

For short sea shipping to become a competitive and credible alternative to road freight, the service model may need to evolve significantly. Higher frequencies, smaller and more flexible vessel types, and stronger hinterland integration would be required to match the responsiveness that road-based logistics currently offers. In this context, several recent developments in autonomous vessels, maritime digitalisation, new cargo-owner-driven business models, and alternative fuels are beginning to create the conditions under which such a transformation could be pursued (see Section 3.2.4).

3.2.3 The Motorways of the Sea Concept

The “Motorways of the Sea” concept (EU 2001) was introduced in the 2001 Transport White Paper with three main objectives: freight flow concentration on sea-based logistical routes, increasing territorial cohesion, and reducing road congestion through modal shift. Subsequent revisions of the White Paper (2011), an impact assessment (2016), and the *Sustainable and Smart Mobility Strategy* (2021) reiterated and reinforced these goals. The 2021 strategy specified as a milestone that transport by inland waterways and short sea shipping should increase by 25% by 2030 and by 50% by 2050.

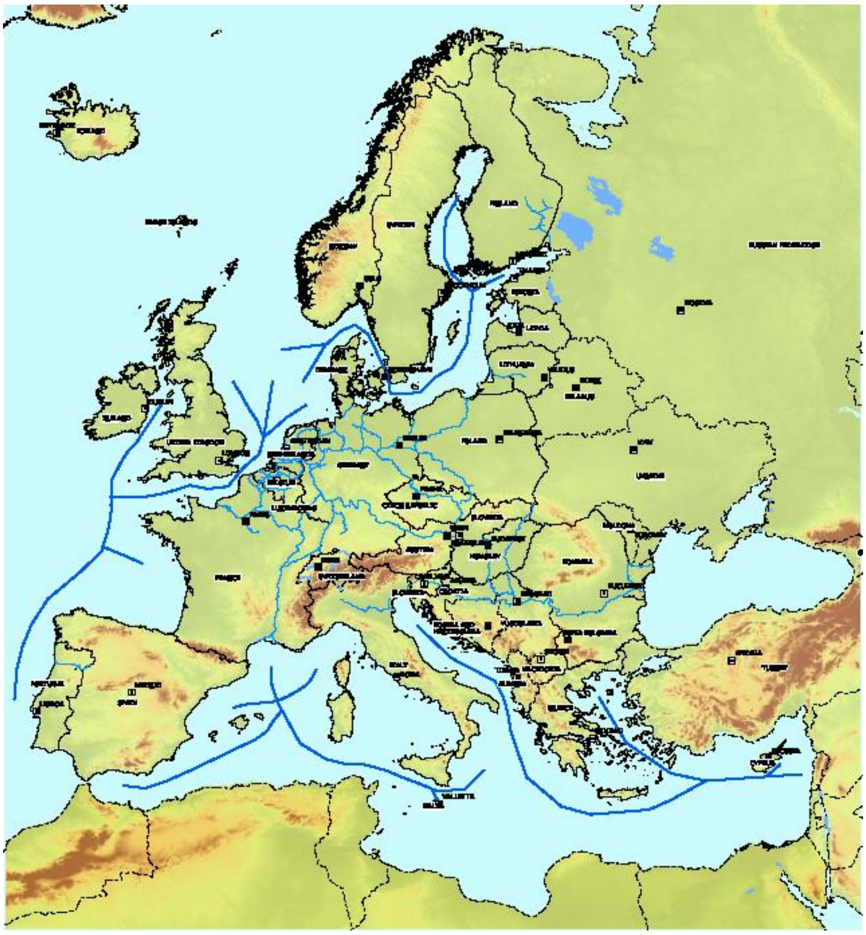

Figure 10: The Motorways of the Sea concept. Source: European Commission, DG MOVE

Despite these policy ambitions, data from the EU Statistical Pocketbook (EU 2025) indicate that growth in short sea shipping has essentially paralleled the growth in international container throughput at major European seaports. This suggests that no significant transfer of cargo from road to short sea shipping has been achieved, and that meeting the 2030 and 2050 milestones will require significant structural changes to maritime service offerings and logistics integration.

3.2.4 Four Enabling Factors for Maritime Transformation

Four relatively recent developments may be considered to have the potential to transform maritime freight services and improve the competitiveness of waterborne transport relative to road. These factors are relevant both to sustainability objectives and to the resilience considerations addressed by SARIL.

Autonomous and highly automated ships: Autonomous and highly automated vessels have been developed primarily in Norway. These ships can be designed for operation with minimal or no crew, which in turn makes it viable to deploy smaller and more flexible ships without the penalty of excessive crew costs. Yara, the world's leading crop nutrition company, was a pioneer in the development of autonomous ships by building Yara Birkeland and operating it in Porsgrunn, Norway. ASKO, Norway's largest grocery wholesaler, has integrated emission-free maritime transport and trucks for distribution using the ports of Moss and Horten as nodes. Maritime Autonomous Surface Ships (MASS) are on the EU research agenda, with Horizon Europe calls for development with deadlines in 2027.

Maritime digitalisation and standardisation: The mandatory use of electronic maritime single windows from January 2024, combined with the focus on energy savings through just-in-time arrival and departure and minimising time spent in and waiting for ports, has increased the focus on standardised and automated exchange of information between ships, ship management and parties on shore. The EU projects DYNAPORT (DYNAPORT 2025) and MISSION (MISSION 2025) are demonstrating digitalisation related to just-in-time shipping. These developments are in turn underpinned by IMO's development of the IMO Reference Data Model (IMO 2024) and the commitment of the main international standardisation organisations to implement this reference model in their respective standards.

New business models with stronger participation of cargo owners: The focus on Sustainable Development Goals has made many manufacturers considerably more interested in green and sustainable transport of their products. The ASKO and Yara projects can be considered results of this interest, and other larger producers such as IKEA and distributors such as Amazon have taken a keen interest in transport solutions and have even taken initiatives to reshape them. This trend creates opportunities for cargo-owner-driven maritime innovation.

New fuel types and higher fuel prices: Decarbonisation of shipping is expected to increase fuel prices significantly, possibly by a factor of four or more. This will also lead to new business models in the shipping sector, as ship owners and charterers will need to find new common ground on how to reduce and share these additional costs. Improved risk and benefit sharing may also lead to new ways of conducting maritime business. The "virtual arrival time" clause from BIMCO, to be used in voyage charters, is an example of such emerging mechanisms.

3.2.5 Existing Intra-European Maritime Freight Services

A detailed analysis of existing intra-European RoRo and freight ferry services is presented in Appendix 1. The analysis covers services across the North Sea, English Channel, Baltic Sea, Mediterranean, Adriatic, Atlantic and Norwegian Coast regions. Key observations from this analysis indicate that existing short sea shipping services are predominantly concentrated in the North Sea and Baltic basins, while Mediterranean east–west connections and Atlantic north–south links remain significantly underdeveloped. This geographic imbalance in maritime service coverage has direct implications for both modal shift potential and the systemic resilience of European freight transport networks.

3.3 Maritime Transport as a Strategic Complement to Land Corridors

Elements in the EU's "Sustainable &and Smart Mobility Strategy" in Flagship area 4 – "Greening of freight transport" relevant for this analysis include the following:

- A substantial part of the 75% of inland freight carried by road should shift to rail and inland waterways. Short-sea shipping can also contribute to greening freight transport in Europe.
- The existing framework for intermodal transport needs a substantial revamp.
- Multimodal logistics must be part of this transformation
- The scarcity of transhipment infrastructure, and particularly of inland multimodal terminals, is pronounced in certain parts of Europe.
- Rail freight needs serious boosting
- While successive action programs have helped inland waterways transport to largely maintain its modal share, actions are necessary to preserve this accomplishment and seize the untapped potential in a sustainable way.

European Transport Regulation Observer (ETRO 2021) says: "Boosting the share of intermodal transport in line with the objectives of promoting more sustainable freight transport as laid out in the Commission's SSMS will depend on the ability of the sustainable modes to improve their reliability, flexibility and resilience."

In short: the Commission's approach is multimodal and end-to-end combine cleaner vehicles and fuels with smarter operations, digital data flows, upgraded and climate-proof infrastructure, and robust crisis playbooks backed by harmonised rules and EU financing to keep freight both green and reliable.

3.4 From Policy Ambition to Operational Capability

While European transport policy frameworks strongly emphasise multimodality, modal shift and resilience, there remains a significant gap between strategic ambition and operational capability. Existing policy instruments define targets for decarbonisation, increased use of rail and short sea shipping, and improved corridor coordination. However, they rarely provide structured methodologies for stress-testing transport networks against disruption scenarios or for quantifying trade-offs between cost, performance and environmental impact under crisis conditions.

As demonstrated in Chapter 2, disruptions are no longer exceptional events but structural features of the transport system. In such an environment, resilience cannot rely solely on infrastructure investment or regulatory harmonisation. It requires analytical tools capable of identifying vulnerabilities, simulating cascading effects and evaluating mitigation strategies in advance.

The continued dominance of road freight and limited modal redundancy illustrate that policy ambition alone does not automatically translate into systemic resilience. Without quantitative modelling and scenario-based evaluation, multimodal planning risks remaining conceptual rather than operational.

In this context, SARIL provides a methodological and digital bridge between European policy objectives and practical implementation. By integrating vulnerability assessment, transport simulation, resilience KPIs and environmental indicators into a coherent framework, SARIL transforms resilience from a strategic principle into a measurable and design-oriented capability. This operationalisation of resilience directly supports the objectives of the TEN-T framework, the Sustainable and Smart Mobility Strategy and the European Green Deal.

4 SARIL Contribution to Resilient and Sustainable Logistics (Further Background Information)

4.1 Resilience

Within the SARIL project, resilience is understood as a systemic capability of transport and logistics networks to anticipate, withstand, adapt to and recover from disruptive events while maintaining an acceptable level of operational performance and environmental sustainability[1]. Resilience is therefore not limited to rapid recovery after failure. It encompasses the entire disruption lifecycle:

- Preparedness - identification of vulnerabilities, risk mapping and contingency planning before disruption occurs.
- Absorption capacity - the ability of infrastructure and services to continue functioning under stress.
- Adaptation - dynamic rerouting, modal shift and operational reconfiguration during disruption.
- Recovery and transformation - restoration of performance and improvement of system robustness after the event.

From the perspective of shippers and transporters, in this document, resilience means *the ability to fulfil transport operations as agreed between the stakeholders involved, even if there are disruptions like those described in Section 2*. SARIL deliverables D1.2, D2.1 presented in-dept definitions and explanations of resilience definitions. In this understanding to make resilience possible, the following must be in place:

- A holistic and resilient infrastructure, including all modes and connections between them.
- Services on the infrastructure that enable immediate evasive actions to be taken so that the negative effects of the disruptions are kept to a minimum.

A key contribution of SARIL has been the formalisation of resilience within a structured methodological framework. The SARIL General Methodology for Green Resilience Management integrates four core components:

- Vulnerability and Risk Assessment, including system characterisation, hazard identification and impact analysis.
- Transport and Traffic Modelling, enabling simulation of disruption scenarios and flow reallocation.
- Resilience Assessment, including cascade analysis and evaluation of mitigation measures.
- Incorporation of Green Aspects, ensuring that resilience strategies are aligned with environmental and energy performance objectives.

SARIL focused on both infrastructure and logistics services. Regarding infrastructure, methods and tools for coping with flooding and natural disasters were developed and tested, based on the methodology illustrated in Figure 11. Specific tools were developed for monitoring flooding and for observing and calculating the movement of forest fires and providing decision support for managing the impacted infrastructure. In the logistics domain, the key development was a transport network simulator that enables the establishment of a resilient transport and logistics network. This means that alternative services should be available in case of disruptions.

[1] SARIL Deliverable 2.1

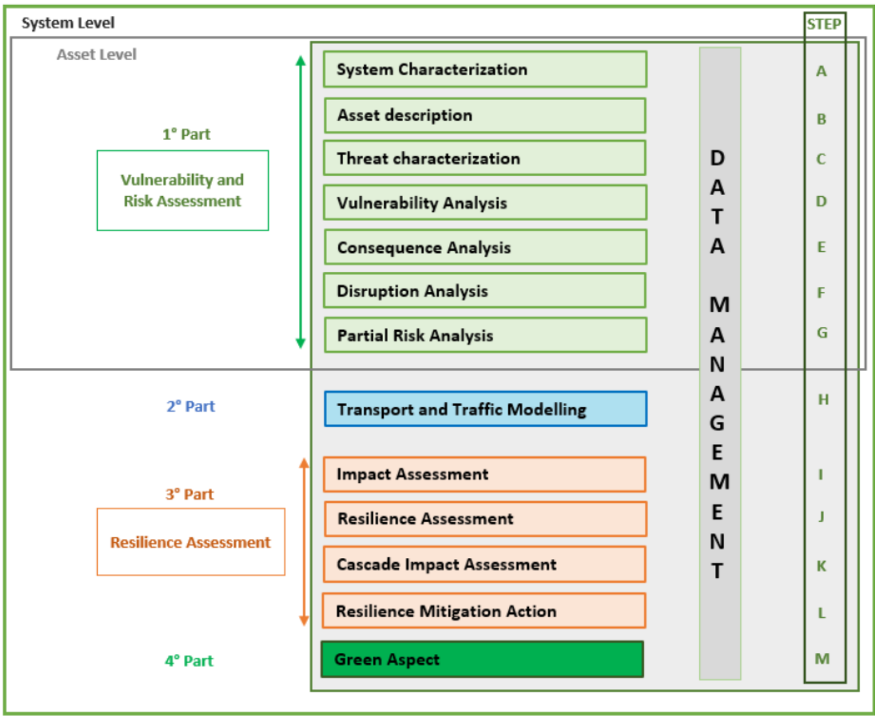

Figure 11: SARIL General Methodology for Green Resilience Assessment. Source: SARIL D2.2

SARIL bridges a gap that has traditionally existed in transport planning: resilience and sustainability are often treated as separate domains. In contrast, SARIL introduces the concept of green resilience, recognising that mitigation measures and contingency strategies must not undermine long-term decarbonisation goals. Rerouting strategies, redundancy investments and emergency interventions are therefore evaluated not only in terms of operational continuity but also in terms of environmental performance. Furthermore, SARIL defines resilience responsibilities across stakeholder roles. Infrastructure managers, logistics network configurators, logistics operators and policymakers each influence different dimensions of resilience. By clarifying these roles and linking them to specific analytical tools, the project operationalises resilience as a shared but differentiated responsibility within the transport ecosystem.

4.2 Resilient Logistics System

While several strategic documents refer to the concept of a "global" resilient transport system, this document focuses on the European transport and logistics ecosystem. In the European context, resilience must be understood in relation to highly interconnected multimodal corridors, cross-border dependencies and strong policy alignment with sustainability and decarbonisation objectives. As mentioned in Section 4.1, a resilient European transport and logistics system comprises two elements - holistic and resilient infrastructure and services on the infrastructure.

A resilient infrastructure goes beyond physical robustness. It requires identification of critical assets and vulnerabilities, monitoring of infrastructure conditions, redundancy and alternative routing options, multimodal integration across road, rail, inland waterways and maritime transport. Within SARIL, infrastructure resilience has been addressed through vulnerability mapping, risk assessment and hazard-specific monitoring tools developed in WP3 (e.g. the Vulnerability and Traffic Tool, hazard maps, infrastructure monitoring modules). These tools allow stakeholders to identify weak points within transport networks and to quantify potential cascading impacts. The regional scenario, for example, analysed infrastructure exposure to flooding and cyber-related risks. The national scenario addressed wildfire-related disruptions and their impact on corridor performance. At European scale, large-scale network simulations examined disruptions affecting international freight corridors.

Resilience is equally dependent on services operating on the infrastructure. Even a physically robust network can fail if logistics services are unable to reconfigure flows, adjust routes or coordinate across stakeholders during disruptions. SARIL has therefore emphasised:

- transport and traffic simulation tools,
- route attribute and energy modules,
- disruption information interfaces (DII),
- multimodal decision-support systems.

These tools enable operators to simulate alternative routing options, assess operational costs and evaluate environmental implications of mitigation strategies. By providing quantitative performance indicators - including delivery times, operational costs and CO_2 emissions, SARIL supports informed decision-making under stress conditions.

The European scenario simulations (D3.3) demonstrated that introducing alternative transport modes (e.g., rail services, e-trucks, or increased modal flexibility) mitigated the impact of disruptions on delivery performance while simultaneously influencing environmental outcomes. Similarly, national-level wildfire simulations showed that targeted mitigation measures (e.g. firebreaks, early warning systems) significantly reduced travel time losses and emissions compared to unmanaged disruption scenarios.

The green resilience assessment results confirmed that logistics systems equipped with monitoring capabilities, multimodal flexibility and pre-defined mitigation measures demonstrated the shorter recovery times, lower operational cost increases, reduced cascading congestion, and improved environmental performance compared to unmanaged scenarios. What was important, the simulations highlighted that resilience and sustainability objectives can be aligned when mitigation strategies are assessed systematically rather than implemented reactively.

The integration of infrastructure assessment, multimodal simulation and environmental KPI evaluation transforms resilience from a theoretical concept into an operational capability. By combining these elements within a coherent methodological framework, SARIL enables European transport and logistics systems to move from reactive crisis management towards proactive, design-oriented resilience.

A resilient European logistics system is not defined solely by strong infrastructure or by efficient services in isolation. It emerges from the interaction between robust multimodal infrastructure and adaptive, well-informed operational decision-making. The SARIL framework and toolset demonstrate that resilience can be modelled, measured and enhanced through simulation-based assessment and integrated monitoring approaches. By supporting infrastructure managers, network configurators, and logistics operators with quantitative and scenario-based decision-support tools, SARIL directly strengthens the resilience of European logistics systems while maintaining alignment with sustainability objectives.

4.3 Intra-European Freight Transport use Roads

Despite more than two decades of European policy promoting modal shift, the empirical data presented above clearly demonstrate that intra-European freight transport remains structurally road dominated. Rail freight has stagnated in market share, and short sea shipping has largely grown in parallel with overall trade volumes rather than substituting road transport. This structural dependence on road transport has important implications for resilience. Road-based logistics systems are highly flexible and offer high-frequency, door-to-door service. However, they are also exposed to congestion, extreme weather, fuel price volatility, driver shortages and border-related disruptions. When most freight flows rely on a single mode, systemic vulnerability increases.

From a resilience perspective, modal imbalance reduces redundancy. A transport system in which alternative modes are underdeveloped cannot easily absorb shocks affecting one dominant mode. The limited shift from road to rail or maritime transport therefore represents not only a sustainability challenge, but also a structural resilience deficit within the European logistics system.

The “Motorways of the Sea” concept (EU 2001) (see Figure 10) was introduced in the 2001 Transport White Paper with three main objectives:

1. Freight flow concentration on sea-based logistical routes.
2. Increasing cohesion.
3. Reducing road congestion through modal shift.

New revisions of the White Paper were published in 2011, an impact assessment in 2016 and lastly a new document was published in 2021 when the European Commission presented its “Sustainable and Smart Mobility Strategy”. These documents reiterated the goals of moving road transport to more sustainable modes, including short sea shipping. Specifically, the last document specified as a milestone that transport by inland waterways and short sea shipping will increase by 25% by 2030 and by 50% by 2050.

After and during the introduction of these documents, several research and development projects have been conducted to achieve these objectives. However, by looking at the statistics from the EU Commission (Statistical Pocketbook 2025), Figure 12 illustrates that the growth in short sea shipping in Europe is still essentially the same as the growth in international container throughput in major European seaports. This means that no or very little cargo has been transferred from road to short sea and that we are very unlikely to reach specified milestones in 2030 and 2050, unless significant changes are made.

A study by the European technology platform ALICE on rail transport in Europe (ALICE 2024) found that there was little or no transfer of goods from road to rail for intra-European transport over the period from 2008 to 2020 (Figure 13). This leads to the conclusion that all growth in intra-European freight transport has occurred on roads.

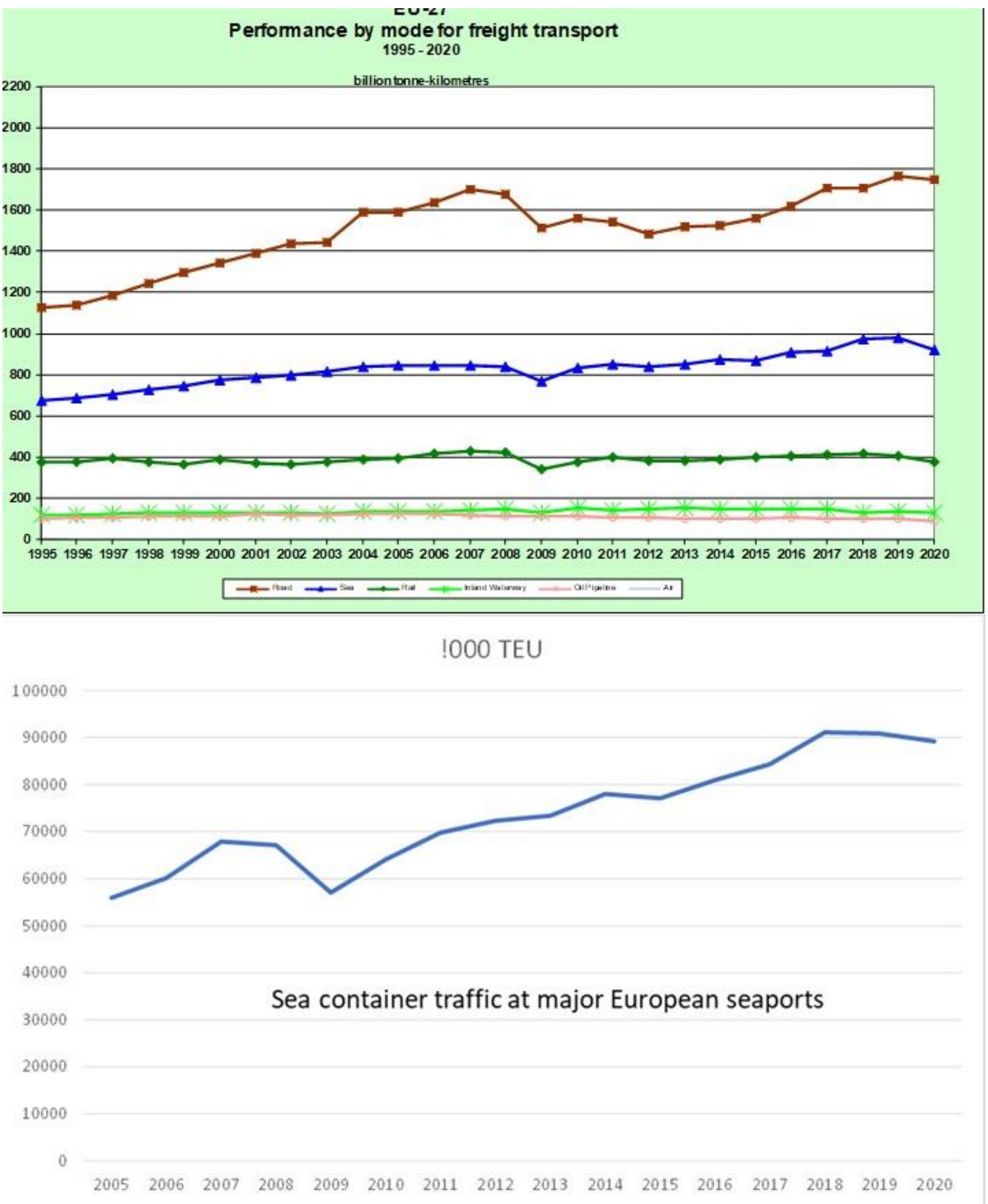

Figure 12: Performance by mode of freight transport and growth of sea containers at major ports Source Statistic Pocketbook 2025

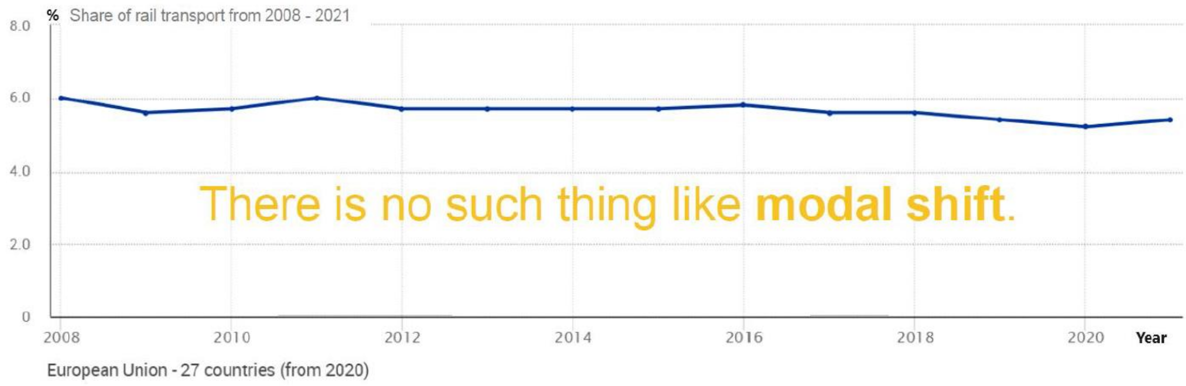

Figure 13: Market share of rail freight 2008 – 2021 (% of all modes incl. maritime, inland waterways, road transport, air freight) – source Eurostat

The data confirm that the resilience of European freight transport cannot be strengthened solely through incremental improvements within the road sector. A structurally resilient system requires genuine multimodal balance and viable alternatives capable of absorbing flows during disruptions.

The SARIL simulations illustrate that when alternative modal capacities are available and pre-configured, recovery times are shorter, congestion effects are reduced, and environmental performance can be preserved. Where such alternatives are lacking, disruptions propagate more widely and recovery becomes more costly and emission intensive. Therefore, strengthening multimodal integration is not merely a sustainability objective aligned with the Green Deal - it is a core precondition for systemic resilience. The SARIL framework demonstrates how simulation-based planning, vulnerability assessment, and green KPI integration can support a transition from road-dominated optimisation to a resilient multimodal configuration.

4.4 Other Drivers

In addition to modal shift policy objectives, additional structural factors are changing expectations regarding logistics resilience. Initiatives such as the Life-Links white paper highlight a growing awareness among cargo owners, logistics providers, and public authorities that supply chains must be designed to remain functional under increasing climatic and geopolitical stress. This need was also evident in market user research conducted as part of the SARIL project (D1.4).

In the foreword to the White Paper “Logistics in a +2^{0}C World” (KF&KCC 2025), the organisation Life-Links (LL 2025)

makes a case for “investing in making logistics infrastructure, operations, and the workforce more resilient from the outset” and introduces the term “truly resilient supply chains”. Life-Links aims to unite shippers, LSPs, and other stakeholders to co-invest in concrete solutions to keep supply chains “alive”, or mobilising companies, governments, development agencies and others to coordinate and co-invest in actions that make critical logistics links in global supply chains more resilient to climate-related disruptions, while reducing GHG emissions and enhancing sustainability at the same time.

The call for “truly resilient supply chains” reflects a shift from reactive crisis management to proactive investment in climate risk assessment, operational readiness, and robust physical infrastructure. Importantly, these drivers are not only from regulatory frameworks but also from market players responding to sustainability commitments, ESG requirements, and customer expectations. This convergence of political, market, and climate pressures presents an opportunity for a systemic transformation of European freight transport systems.

The priorities identified by Life-Links - climate risk assessment, operational resilience and physical infrastructure strengthening, closely align with the methodological and technological contributions developed within SARIL. Through its Green Resilience Management framework, SARIL operationalises these ambitions by providing tools for vulnerability assessment, scenario-based simulation, network reconfiguration and environmental performance evaluation. Rather than addressing resilience in abstract terms, SARIL offers concrete analytical capabilities enabling stakeholders to quantify risk exposure, test mitigation strategies and integrate resilience into design and investment decisions.

In this sense, SARIL does not introduce a parallel narrative to existing resilience initiatives; it provides the methodological backbone and digital support necessary to implement them effectively within the European transport context.

4.5 Summary

This chapter presents the conceptual and structural foundations of a resilient European transport and logistics system. Resilience is defined not as a reactive repair mechanism, but as a measurable, design-oriented capability encompassing preparedness, absorption, adaptation, and repair, consistent with sustainable development goals.
A resilient logistics system in the European context requires two interdependent elements: a robust, multimodal infrastructure and adaptive services that can be quickly reconfigured in the event of disruptions. An analysis of freight transport patterns shows that the continued dominance of road transport is not only a challenge to sustainability but also a resilience deficit. Limited modal balance reduces redundancy and limits the system's ability to absorb shocks.

At the same time, policy initiatives, market expectations, and climate pressure increasingly require supply chains to be designed for long-term resilience. The transition to resilient logistics systems cannot, therefore, rely solely on incremental improvements. It requires systematic vulnerability assessment, scenario-based stress testing, multimodal integration, and quantitative assessment of trade-offs between cost, efficiency, and environmental impact. The SARIL framework responds to this need by combining a methodological structure, simulation-based analysis, and environmental indicators within an integrated decision-support ecosystem. By operationalising resilience through measurable KPIs and role-based responsibilities, SARIL provides an analytical basis for strengthening European freight transport systems in conditions of structural uncertainty.

In the next chapter, we build on this foundation, translating conceptual insights into concrete recommendations tailored to the key roles of stakeholders in the transport and logistics ecosystem.

5 Role-Based Recommendations and Process Mapping (Core of SARIL)

The conceptual framework and analytical foundations presented in the previous chapter provide the basis for practical implementation. Strengthening resilience in European freight transport systems requires targeted action by different stakeholder groups, each operating at distinct levels of responsibility and influence. The SARIL simulations and green resilience assessments have demonstrated that system performance under disruption depends not only on infrastructure robustness, but also on network configuration choices, operational flexibility and regulatory conditions. Translating these findings into practice, therefore, requires differentiated, role-based guidance.

The recommendations presented in this chapter are grounded in the scenario-based assessments conducted within SARIL at the regional, national and European scales. The detailed modelling results, quantitative performance indicators and comparative analysis of mitigation strategies are documented in Deliverable D3.3 (Green Resilience Assessment Results). The following synthesis highlights the most relevant empirical insights supporting the recommendations.

Across the analysed scenarios, several consistent patterns were observed:

- In the European scenario, a major port-related disruption generated measurable cascading effects across the network, increasing delivery times by approximately 11%, operational costs by 4.4% and CO_2 emissions by 2.7% compared to the base case.
- In the national wildfire scenario, infrastructure disruption increased total travel time by more than 17%, demonstrating the high sensitivity of corridor-dependent logistics networks to physical closures.
- Structural mitigation measures, such as the implementation of firebreaks, reduced total travel time by approximately 20% compared to the unmitigated disruption case, confirming the effectiveness of infrastructure-based resilience strategies.
- Digital adaptation measures, including early warning systems and improved traffic management, reduced travel time by approximately 11% and slightly reduced CO_2 emissions, while improving overall network fluidity.
- Increased modal flexibility and synchro-modal routing options reduced both CO_2 emissions and operational costs simultaneously, highlighting the systemic value of multimodal integration and adaptive network configuration.

The simulations also revealed the presence of trade-offs between cost, time and environmental performance. For instance, low-emission vehicle deployment significantly reduced CO_2 emissions but increased operational costs. These findings confirm that resilience strategies should not be implemented intuitively but assessed through structured modelling and KPI-based evaluation. SARIL scenario assessments demonstrate that resilience is a measurable system property influenced by infrastructure robustness, modal balance, digital preparedness and governance coordination. The detailed quantitative evidence is provided in D3.3, while the following sections translate these validated insights into role-based recommendations for practical implementation.

The quantitative improvements observed in the analysed scenarios were achieved through the application of SARIL's modelling, monitoring and decision-support tools, as described in Deliverable D3.1 and further validated in D3.3. By enabling vulnerability identification, disruption simulation, comparative mitigation assessment and environmental KPI evaluation, the SARIL toolset provides stakeholders with structured analytical support for resilience-oriented decision-making. Rather than relying on reactive measures, infrastructure managers and logistics operators can use these tools to anticipate cascading effects, evaluate trade-offs and select mitigation strategies that balance operational continuity and sustainability objectives. In this sense, SARIL tools directly strengthen the resilience of European logistics systems by transforming it from a qualitative aspiration into a quantifiable, optimisable system property.

The scenario-based assessment demonstrates that resilience is shaped by the decisions of specific actors within the transport and logistics ecosystem. Infrastructure design, network configuration, operational management and regulatory conditions jointly determine how disruptions propagate and how effectively systems recover. Translating these empirical insights into practice therefore requires differentiated, role-based action. The following sections present targeted recommendations for infrastructure managers, logistics network configurators, logistics operators and policymakers, highlighting how SARIL tools can support resilience-oriented planning and decision-making across the European transport system.

5.1 Role 1: Infrastructure Managers

5.1.1 Key Challenges and Needs

Infrastructure managers play a key role in ensuring the continuity of transport network operations under normal and disrupted conditions. They are responsible for the technical condition, functionality, and adaptability of infrastructure, such as bridges, roads, ports, terminals, and inland waterways in the face of natural and anthropogenic hazards. During the SARIL project, key challenges and stakeholder needs in this category were identified, and support tools were developed to address some of them. Scenario-based assessments demonstrated that infrastructure failures generate measurable cascading effects across transport networks, including increases in travel time, operational costs and emissions (see D3.3).

The most important challenges for infrastructure managers identified during the SARIL project:

- Lack of ongoing monitoring of the technical condition of infrastructure, in particular bridges and structures exposed to water
- Insufficient predictive capabilities - lack of tools for forecasting hazards (e.g., floods, fires)
- Fragmented information flow and lack of integrated decision support systems enabling quick and coordinated corrective action
- Insufficient consideration of resilience in the infrastructure planning process, resulting in critical points with low resilience

Therefore, the needs of infrastructure managers have been identified in the form of a set of tools, methods, and guidelines that will enable them to:

- Monitor risks on an ongoing basis,
- Predict the effects of disruptions,
- Prioritize preventive measures,
- Design resilient infrastructure in accordance with the “resilience-by-design” approach.

5.1.2 SARIL recommendations and tools for infrastructure managers

The SARIL project provides integrated methods and tools that, as demonstrated in the scenario-based assessments, enable infrastructure managers to move from reactive crisis management to proactive, resilience-by-design approaches. Although some tools are more dedicated to Role 2 - Logistics Network Configurators or Role 3 Logistics operators and shippers, the tools can be used in many ways and support the functioning of recipients in each role. The table below presents recommendations and corresponding SARIL tools for role 1:

Table 1: Recommendations and tools for infrastructure managers.

Recommendation	Purpose	SARIL Tool
Implementation of ongoing monitoring of critical infrastructure (e.g., bridges)	Detects erosion and structural weakening during floods, supports preventive closure	Scour Monitoring for Decision Support (POLIMI)
Forecast and visualise flood-affected infrastructure zones	Generate dynamic flood risk maps for early warning and access management	Vulnerability & Traffic Tool (based on Sentinel/Copernicus + IoT sensors)
Centralise infrastructure-related disruption data	Integrate alerts, infrastructure status, and response plans	Disruption Information Interface (L-PIT)
Simulate wildfire spread to plan protective actions on transport infrastructure	Real-time modelling of fire movement and exposure prediction	Natural Hazard Map Tool (UVIGO)
Estimate cascading effects of infrastructure failures on transport flows	Predict network-wide delays and identify recovery priorities	Traffic Simulation Tool (UMINHO)
Analyse vulnerability of critical assets to large-scale disruptions	Risk scoring and bottleneck assessment across network levels	Vulnerability & Traffic Tool (RINA-C)
Evaluate environmental performance of alternative routes	Support green decision-making for rerouting and investment	Route Attributes / Energy Module (SIN)
Use scenario-based simulations to design resilient infrastructure networks	Stress-testing design and operational strategies for future crises	ASTROIT Advanced Simulation Tool for Resilient and Optimised Intermodal Transport

5.1.3 Recommendations for Infrastructure Managers – Application of SARIL Tools in Disruption Scenarios

Based on the disruption scenarios analysed and validated during the SARIL project, this section provides practical and strategic recommendations for infrastructure managers. These recommendations identify which SARIL tools should be applied to address specific types of disruptions and increase infrastructure resilience in short-, medium- and long-term timeframes.

5.1.3.1 Flooding and Hydrological Extremes (e.g. Po Valley, Mantua)

Problem: Extreme precipitation and river flooding lead to erosion of bridge foundations, road closures and loss of infrastructure availability, often with insufficient warning time for intervention. In the regional SARIL scenario, targeted monitoring and risk-based interventions demonstrated significant reductions in systemic risk compared to blanket infrastructure closures.

SARIL Recommendations for Infrastructure Managers:

- It is recommended to implement the Scour Monitoring for Decision Support Tool to enable real-time monitoring of bridge foundation conditions and early detection of ground erosion.

This tool supports pre-emptive closure or restriction of at-risk structures, prevention of catastrophic structural failures, prioritisation of protective interventions and maintenance.

- It is recommended to use flood mapping and alert systems, based on Copernicus satellite data and IoT sensors, to identify high-risk zones dynamically, plan detours and alternative routes in advance, support coordinated emergency operations.
- It is recommended to integrate hydrological and infrastructure data using the Disruption Information Interface (DII), which may provide a central platform for operational decision support, synchronised action plans with transport operators and emergency services, improved transparency and situational awareness.

Expected impact of implementing SARIL solutions would be faster and better-informed decisions, fewer emergency closures, enhanced infrastructure protection and user safety.

5.1.3.2 Wildfires, Storm Damage, Infrastructure Disruptions (e.g. Galicia and Northern Portugal)

Problem: Forest fires and severe storms cause sudden and widespread loss of transport connectivity across roads, railways, and terminals, limiting time for reaction and complicating infrastructure recovery planning. The national wildfire scenario showed that unmanaged corridor disruption significantly increased total travel time, while targeted structural and digital mitigation measures reduced performance degradation.

SARIL Recommendations for Infrastructure Managers:

- It is recommended to deploy the Natural Hazard Map Tool to model the spread of wildfires in real-time, allowing infrastructure managers to anticipate which transport assets may be exposed, plan preventive closures or emergency reinforcements, support spatial allocation of firefighting and repair resources.
- It is recommended to use the Transport Simulation Tool to assess the network-level consequences of damaged assets (e.g. bridges, tracks), supporting prioritisation of infrastructure restoration efforts, estimation of cascading effects on freight flows, optimisation of recovery investments.
- It is recommended to manage operational data using the Disruption Information Interface, which facilitates integration of alerts from weather, fire, and transport systems, coordination between road, rail and port infrastructure stakeholders, harmonised communication with end users and logistics operators.

The expected impact of SARIL solutions in this regard would be improved emergency coordination, prioritised infrastructure recovery, and strengthened preparedness for seasonal disruptions.

5.1.3.3 Systemic and Long-Term Disruptions (e.g. Pandemic, Geopolitical Conflicts)

Problem: Long-term disruptions expose critical vulnerabilities in cross-border infrastructure such as ports, terminals, border crossings, and inland transport corridors, leading to congestion, delays and fragmented responses. European-scale simulations confirmed that bottlenecks at key nodes can amplify cascading delays across multimodal networks if redundancy and alternative routing options are not pre-configured.

SARIL Recommendations for Infrastructure Managers:

- It is recommended to use the Vulnerability & Traffic Tool to identify bottlenecks and assess their impact on the overall transport network, enabling resilience-informed investment planning, redundancy design in transport infrastructure, anticipation of alternative routing needs.

- It is recommended to apply the Energy & Route Attributes Module to evaluate the environmental and energy performance of detour routes, ensure alignment with Green Deal targets, integrate sustainability considerations into resilience planning.
- It is recommended to apply scenario-based modelling and decision support, as developed in SARIL, to test and stress-check future crisis responses related to pandemics, port closures or corridor breakdowns, large-scale political and regulatory disruptions.

The expected impact of implementation SARIL solutions would be improved strategic preparedness, better-informed investment decisions, and greater alignment with EU resilience and sustainability policy frameworks.

5.2 Role 2: Logistics Network Configurators

5.2.1 Key challenges and needs

Logistics Network Configurators are responsible for designing, configuring and optimising the structure of logistics and transport networks. This includes selecting transport modes, intermodal hubs, routes, buffer capacities, and service configurations that meet performance, cost, and sustainability criteria under variable conditions. Scenario-based simulations conducted within SARIL demonstrated that limited modal flexibility and corridor redundancy significantly amplify cascading delays and operational costs during major disruptions (see D3.3).

During the SARIL project, the following key challenges were identified for this role:

- Limited capability and integrated simulation support to anticipate network-level impacts of infrastructure or service disruptions
- Insufficient tools to evaluate trade-offs between resilience, emissions, time and cost under disruption scenarios
- No unified methodology for integrating resilience into network configuration processes
- Difficulty in justifying additional redundancy in the system under current cost-driven optimisation models

While many logistics network configurators and shippers have adopted sustainability indicators and actively seek to reduce the environmental footprint of their transport operations, this commitment typically remains conditional on cost impact. In practice, sustainability objectives tend to be pursued only up to the point where they do not significantly erode operational margins. When the cost differential becomes too large — for example, when rail options are available but substantially more expensive than road — configurators revert to cost-based decision-making. The result is that sustainability criteria function as secondary optimisation parameters rather than binding constraints. Without stronger regulatory incentives, shared financing mechanisms or a sector-wide commitment to internalising environmental costs, the transition towards genuinely sustainability-driven network configuration is unlikely to materialise at the pace and scale required by European climate policy objectives. In response, the SARIL project identified several tools and methodologies to support Logistics Network Configurators in:

- Analysing vulnerability and risks at the network level,
- Simulating and comparing disruption scenarios and routing alternatives,
- Balancing performance and resilience objectives,
- Integrating resilience into design and investment planning from the start.
- As a configurator, how and why should I incorporate sustainability??...and if my standard cost is higher?

The technologies and methodologies developed within SARIL directly address these structural gaps by enabling quantitative, scenario-based network design.

5.2.2 SARIL recommendations and tools for logistics network configurators

The SARIL project provides integrated analytical tools that, as validated in scenario-based assessments, enable Logistics Network Configurators to design and stress-test resilient multimodal configurations. These tools enable evaluation of alternative configurations, simulate disruption impacts, and guide strategic decisions in network planning and policy development.

Table 2: Recommendations and tools for logistics network configurators.

Recommendation	Purpose	SARIL Tool
Evaluate network vulnerability and critical links	Identify bottlenecks and high-risk segments across the multimodal network	Vulnerability & Traffic Tool (RINA-C)
Simulate different disruption scenarios and their impact on flows and service quality	Support scenario-based evaluation of alternative configurations and strategies	Traffic Simulation Tool UMINHO
Model and compare multimodal routing options under normal and disrupted conditions	Optimise mode choices, hub selection and flow allocation	Traffic Simulations / ASTROIT
Assess the environmental footprint of routing decisions	Support low-carbon and energy-efficient network design	Route Attributes / Energy Module (SIN)
Integrate KPIs for resilience and sustainability into network planning	Operationalise performance-driven configuration strategies	SARIL General Methodology (D2.2)

In the European-scale simulations, increased modal flexibility reduced both CO_2 emissions and operational costs compared to rigid routing configurations, confirming the strategic importance of adaptive network design.

5.2.3 Recommendations for Network Configurators – Application of SARIL Tools in Disruption Scenarios

This section outlines how SARIL tools can be applied by Logistics Network Configurators in different types of disruption scenarios to improve network design, adaptability and continuity of service.

5.2.3.1 Flooding and Local Infrastructure Failure (e.g. Po Valley)

Problem: Localized but severe disruptions (e.g., flooded road segments, closed bridges) require fast rerouting and verification of the feasibility and performance of available alternatives. Regional simulations confirmed that pre-defined alternative routing significantly reduced network-level performance degradation compared to ad hoc rerouting.

SARIL Recommendations for Network Configurators:

- Use the Transport Simulation Tool to assess the impact of infrastructure closures on network performance, including delays, capacity losses, and changes in modal share.
- Apply the Vulnerability & Traffic Tool to identify critical nodes and links that are likely to fail or become bottlenecks under such conditions, supporting pre-emptive redesign of flows.

- Incorporate the Energy Module to assess the emissions trade-offs of detour routes or mode shifts (e.g., from road to rail or IWT).

The expected impact for network configurators would be the ability to make faster, smarter rerouting decisions, minimise delays and emissions, and improve service continuity in regional flows.

5.2.3.2 Wildfires and Large-Area Disruptions (e.g. Galicia/Portugal)

Problem: Widespread disruptions block access to terminals or main corridors, requiring reconfiguration of intermodal chains and redesign of flows between logistics hubs. European-scale modelling demonstrated that dependency on single corridors amplifies cross-border cascade effects, highlighting the need for redundancy and diversified routing strategies.

SARIL Recommendations:

- Apply the ASTROIT transport simulation framework to model new transport chains across modes and geographies, enabling stress-testing of route alternatives.
- Use the Route Attributes Module to evaluate not only accessibility and cost, but also sustainability KPIs under new configurations.
- Implement scenario-based network redesign simulations to compare multiple response strategies and select the most resilient configuration.

Implementation of SARIL-supported network design approaches is expected to result in faster network reconfiguration, improved robustness of national logistics flows, and enhanced sustainability through better mode and hub choices.

5.2.3.3 Border Closures, Geopolitical Shocks (e.g. Ukraine Conflict, Pandemic)

Problem: Closures of corridors or terminals due to war, embargoes or pandemics lead to large-scale re-routing needs and breakage of end-to-end transport chains.

SARIL Recommendations:

- Use the Vulnerability Tool to reassess corridor dependencies and identify where additional redundancy or diversification is needed.
- Leverage SARIL Scenario Modelling to simulate alternative international configurations and test the feasibility of rerouting through secondary hubs or corridors.
- Integrate KPIs for resilience and GHG emissions into redesign processes using the SARIL General Methodology and associated tools.

The expected impact for network configurators would be the strategic resilience-building in international supply chains, better anticipation of future disruptions, network configurations aligned with long-term policy targets.

5.3 Role 3: Logistics Operators and Shippers

5.3.1 Key Challenges and Needs

Logistics operators and shippers are responsible for planning, execution and supervision of freight movements, often under constraints related to time, cost, emissions, and increasingly resilience. They operate in dynamic environments where unexpected disruptions can lead to delays, penalties, customer dissatisfaction or loss of contracts. Scenario-based assessments within SARIL demonstrated that delays and performance degradation at network level translate directly into increased delivery times, operational costs and service instability for logistics operators.

Based on the SARIL project findings, key challenges faced by Role 3 stakeholders include:

- Lack of real-time visibility on infrastructure status, delays or disruptions
- Limited capacity and decision-support tools for dynamic rerouting and mode switching during disruptions
- Difficulties in integrating environmental and resilience performance indicators into day-to-day operations
- Absence of simulation environments for training or stress-testing emergency response procedures

Operators and shippers therefore require:

- enhanced situational awareness and early warning capabilities,
- dynamic decision-support tools for route and mode switching,
- integration of resilience into standard operating procedures,
- ability to simulate, evaluate and improve disruption response strategies.

5.3.2 SARIL recommendations and tools for logistics operators and shippers

SARIL provides operational and tactical-level tools that, as demonstrated in the scenario simulations, enhance responsiveness to disruptions and support resilient service continuity.

Table 3: Recommendations and tools for logistics operators.

Recommendation	Purpose	SARIL Tool
Monitor disruptions and infrastructure status in real time	Enable timely reaction to events affecting shipments	Disruption Information Interface (L-PIT)
Simulate alternative transport chains and modes	Support fast reconfiguration of planned transport	ASTROIT Traffic Simulation Tool
Support dynamic decision-making for rerouting and mode switching	Evaluate best options for time, cost and emissions	ASTROIT Traffic Simulation Tool
Analyse the energy efficiency and environmental performance of routing choices	Select low-emission alternatives under time pressure	Route Attributes / Energy Module (SIN)

Simulation results confirmed that operators equipped with pre-defined alternative routing and modal options were able to reduce service disruption and limit cascading delays compared to reactive, ad hoc responses.

5.3.3 Recommendations for Logistics Operators – Application of SARIL Tools in Disruption Scenarios

The following disruption scenarios illustrate how SARIL tools can be applied by logistics operators and shippers to increase operational resilience, minimise service interruption, and make informed decisions under pressure.

5.3.3.1 Infrastructure Disruption Due to Flooding (e.g. Mantua)

Problem: Local floods disrupt access to terminals or intermodal hubs, forcing logistics operators to quickly reroute shipments or change delivery schedules. Regional simulations showed that delayed rerouting decisions significantly increased travel time, highlighting the importance of real-time visibility and rapid operational adjustment.

SARIL Recommendations:

- Use the Disruption Information Interface to receive early warnings and real-time updates on infrastructure closures, enabling operators to initiate corrective actions rapidly.
- Deploy ASTROIT to assess possible transport alternatives (e.g., from rail to road or inland waterway) and select the most suitable in terms of time and CO_2.
- Apply the Energy Module to compare environmental performance and costs of rerouted flows to maintain green KPIs despite disruptions.

Expected impact: Reduced delays, cost-efficient and sustainable contingency transport planning, improved customer communication and reliability.

5.3.3.2 Terminal Closure Due to Wildfire or Storm (e.g. Galicia/Portugal)

Problem: Loss of access to a key intermodal hub due to a natural hazard requires rapid reconfiguration of logistics operations and coordination with alternative terminals or corridors. In the national scenario, closure of key terminals led to substantial reallocation of flows, demonstrating the need for pre-identified fallback hubs and dynamic chain reconfiguration.

SARIL Recommendations:

- Apply ASTROIT transport chain and traffic tools simulation to model feasible alternatives and identify viable fallback options for disrupted services (e.g., use of a different port or dry terminal).
- Leverage the Disruption Information Interface to coordinate actions with infrastructure managers and inform customers proactively.

Expected impact: Higher operational readiness, ability to implement alternative plans efficiently, reduced loss of service and improved business continuity.

5.3.3.3 Corridor Disruption Due to Geopolitical Conflict (e.g. Ukraine war)

Problem: Cross-border logistics routes are blocked or disrupted due to war, trade restrictions or sudden regulatory changes, requiring global rerouting of goods. European-scale modelling confirmed that reliance on single corridors increases exposure to systemic risk, requiring operators to maintain flexible, multimodal alternatives.

SARIL Recommendations:

- Use the Vulnerability Tool to evaluate corridor exposure and prioritise reallocation of flows via less affected hubs and routes.
- Deploy scenario-based planning to anticipate possible escalation and prepare for medium- and long-term alternative service configurations.
- Apply ASTROIT to recalibrate transport chains in real time, ensuring time-definite deliveries across multimodal combinations.
- Use the Disruption Information Interface to gather information about disruptions, reroute and inform customers proactively

Implementation of SARIL-supported operational tools is expected to reduce delays, improve flexibility and agility in supply chain execution, and minimise disruption-related losses.

5.4 Increasing supply chain resilience with SARIL tools – mapping the logistics process

One of the key objectives of the SARIL project was to demonstrate how the tools and methods developed within the project can realistically increase supply chain resilience at the operational level. In addition to analyses focusing on infrastructure or the transport network, SARIL placed particular emphasis on the logistics process carried out by the operator, as it is at this level that disruptions are felt most quickly and generate the greatest organisational and cost burdens. Scenario-based assessments conducted within SARIL demonstrated that disruptions propagate rapidly from infrastructure and network levels to the operational logistics process, directly affecting delivery time, cost exposure and organisational workload.

To this end, in cooperation with partners L-PIT and CSL, a detailed mapping of the actual sea container import process was carried out. This process was described based on actual operational activities carried out by CSL and mapped in BPMN 2.0 notation. The analysis covered three variants of the process: business as usual, disruption, and an optimised variant using tools developed in the SARIL project.

This approach made it possible to identify critical moments in the process, assess the impact of disruptions on order fulfilment time and the involvement of the operational team, and show how digital support can mitigate the negative effects of undesirable events.

5.4.1 Logistics process under normal conditions – AS-IS (business as usual)

In the absence of disruptions, the sea container import process carried out by the logistics operator runs in an orderly and predictable manner. The operator coordinates sea transport, monitors the ship's voyage, plans inland transport and last-mile delivery, and the entire process is completed within the planned time frame. From the customer's perspective, this process is perceived as stable and effective.

At the same time, analysis of the AS-IS process shows that its efficient functioning is largely dependent on the stability of the external environment. Information flows to the operator from many sources, primarily via email and telephone. However, there is no single, integrated tool that would provide full visibility of the situation and enable early identification of potential threats. As a result, the process, although effective under normal conditions, remains **vulnerable to disruptions**, and its resilience is largely illusory.

In the absence of disruptions, the process of importing a sea container carried out by a logistics operator is relatively predictable and linear. The operator:

- Receives an order from the customer,
- Organises sea transport,
- Monitors the ship's voyage,
- Plans inland transport (rail + last mile),
- Coordinates the delivery and return of the empty container.

Although this process is operationally efficient, its implementation relies heavily on manual information exchange (emails, phone calls), fragmented data sources, and a lack of a single, shared view of the situation. In practice, this means that the process only works well if the environment is stable. The absence of disruptions masks the process's structural vulnerability to external events. The logistics operator acts as an “information coordinator” rather than a user of system-based decision support.

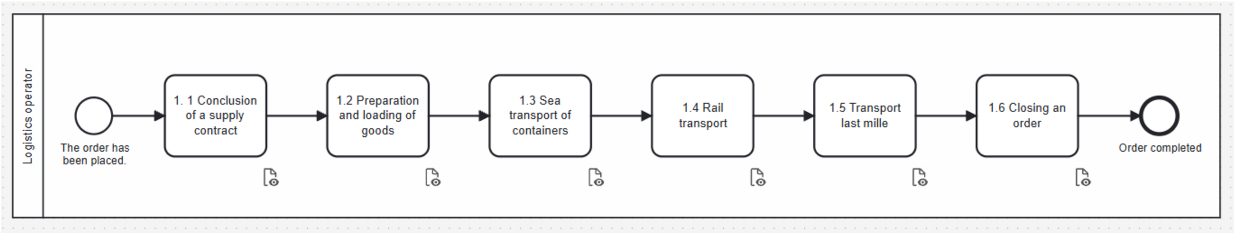

Figure 14: Basic logistics process map. Source: L-PIT own elaboration

Detailed process maps of the logistics process are placed in Appendix 2

5.4.2 Logistics process under disruption – a sudden increase in process complexity

When disruption occurs the logistics process is immediately destabilized. The logistics operator is faced with a situation that requires quick decisions to be made without complete and reliable information. The first signs of disruption are often unofficial and come from various channels, which requires additional verification and manual data collection. The European scenario analysed within SARIL, including the port strike case, confirmed that even a single-node disruption can rapidly increase delivery time and operational costs across the logistics chain.

At this stage, the workload of the operations team increases significantly. It becomes necessary to organize crisis meetings, frequently update the status of the voyage and port operations, and maintain constant contact with carriers, terminals, and customers. Every decision regarding a change of route, means of transport, or port of discharge must be made quickly, without the support of simulation tools, which increases the risk of error.

From the perspective of a logistics operator, a disruption means not only the risk of delivery delays, but also a significant increase in indirect costs. The working time of the operational team is multiplied, overtime occurs, and the risk of additional charges, such as demurrage or detention, increases with every hour of uncertainty. Importantly, many of these costs are not directly visible in the accounts but affect organizational efficiency and customer service quality.

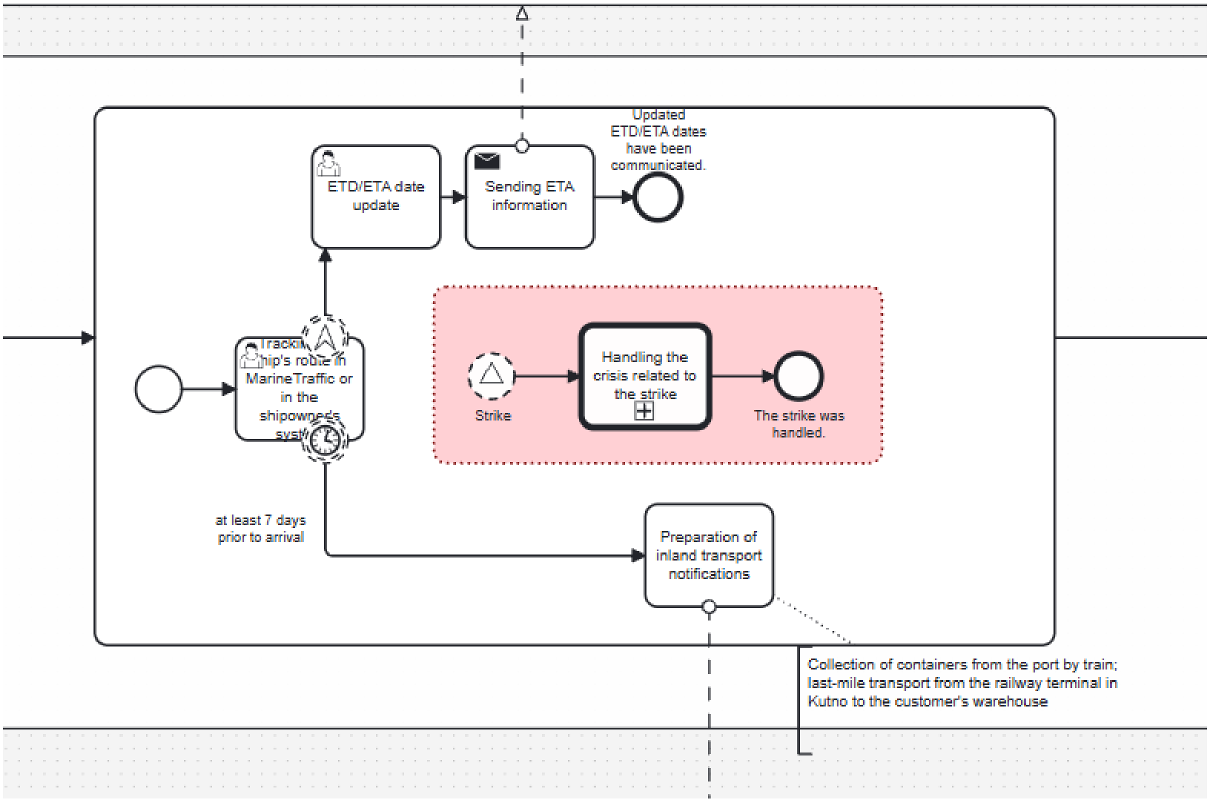

Figure 15: Disruption in logistics operation process - strike in port as a crisis – part of the process. Source: L-PIT own elaboration

When a disruption occurs in the case analysed, a strike by port workers in Hamburg, the logistics process very quickly loses its linearity and predictability. Detailed process map of the disrupted logistics process can be found in Appendix 2.

Disruption triggers a cascade of operational problems:

- Lack of clear, reliable information. The operator receives information from various sources (shipowner's agent, industry media, terminal), often inconsistent and unofficial.
- Time and decision-making pressure. Every hour of delay in deciding increases the risk of losing rail slots, demurrage and detention charges, and failure to meet the delivery deadline to the customer.
- High involvement of the operational team. In practice, this means calling internal crisis meetings, manually updating statuses every few hours, constant phone calls and emails to carriers and terminals.
- Lack of tools for quick comparison of alternatives.
- Decisions about changing ports, changing means of transport, replanning last miles are made by "experts," but without simulation support.

5.4.3 Logistics process supported by SARIL tools - reduction of time and organisational pressure

The third process variant assumes the implementation of tools developed in the SARIL project, which do not replace the logistics operator, but significantly support them in the event of a disruption. The key change is the shift in focus from manual information gathering and ad hoc decision-making to automated analytical and decision-making support. This shift from reactive coordination to structured analytical support reflects the resilience-by-design approach developed within SARIL and validated through scenario modelling.

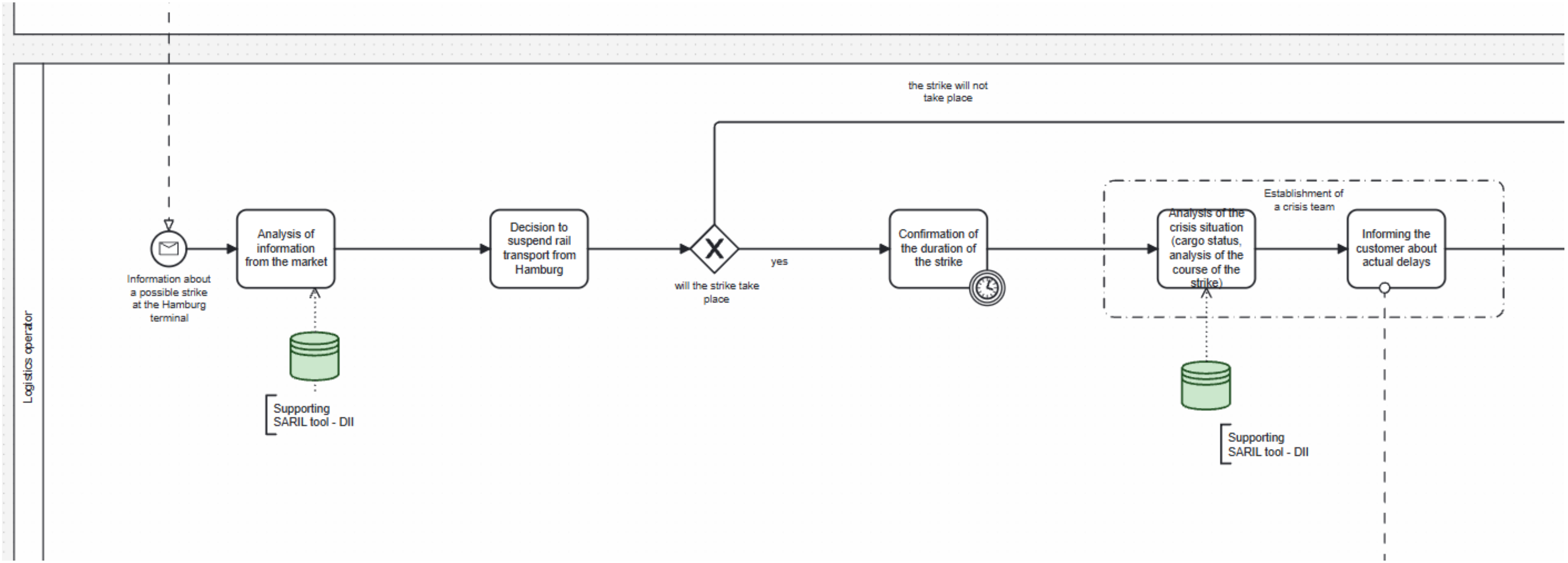

Figure 16: Part of logistics process with support of the DII Tool. Source: Own elaboration

By using the Disruption Information Interface, the operator receives an integrated picture of the situation in one place, instead of relying on fragmentary information from emails and phone calls. Early alerts about disruptions allow action to be taken before the effects of the event become critical. In turn, simulation and synchro-modal tools allow you to quickly compare available transport options, considering time, cost, and environmental impact. In practice, this means a significant reduction in the time needed to plan alternatives. Tasks that previously required hours of analysis and the involvement of several people can now be completed in a much shorter time with the support of the system. The number of manual interactions is reduced, and the operations team can focus on customer communication and coordination instead of constantly collecting and verifying data.

5.4.4 Process resilience as the foundation of logistics network resilience

The analysis of the logistics process in three variants confirms that supply chain resilience is not solely determined by infrastructure robustness or network configuration. It is strongly influenced by the operator's ability to respond rapidly and systematically under time pressure and uncertainty.

The use of SARIL tools leads to shorter response times, less manual work, and reduced cost risk. As a result, individual logistics processes become more resilient, and logistics operators become more predictable and stable links in the transport network. In systemic terms, this means that increasing resilience at the operational process level directly translates into increased resilience of entire logistics networks, which is one of the key objectives of the SARIL project. By integrating monitoring, simulation and decision-support capabilities into the operational workflow, SARIL tools transform resilience from an ad hoc response into a structured and measurable process capability.

6 Cross-cutting Recommendations for Policymakers and Regulators

The scenario-based evidence generated within SARIL confirms that resilience deficits in European freight transport systems are not solely operational challenges, but structural governance issues. While infrastructure managers, network configurators and operators play critical roles, the enabling regulatory and financial framework ultimately determines whether resilience is embedded systematically or addressed only reactively. Strengthening supply chain resilience therefore requires coordinated action at European and national policy levels. The following cross-cutting recommendations translate SARIL findings into strategic guidance for regulators, funding bodies and institutional stakeholders.

6.1 EU A Holistic and Resilient Transport Infrastructure- Embedding Resilience into TEN-T Governance

The revised TEN-T Regulation strengthens the objectives of sustainability, connectivity and multimodality. However, SARIL modelling results indicate that modal concentration and corridor dependency remain structural sources of vulnerability. Disruptions affecting critical nodes or corridors generate measurable cascading effects across borders, influencing travel time, operational costs and emissions.

To address this, resilience should be explicitly integrated into TEN-T governance mechanisms. This includes:

- systematic scenario-based stress testing of TEN-T corridors and major nodes,
- incorporation of vulnerability mapping and cascade analysis into corridor work plans,
- recognition of multimodal redundancy and routing flexibility as resilience indicators.

Resilience assessment should become a standard planning parameter alongside capacity, connectivity and decarbonisation targets.

6.2 Aligning Funding Instruments with Resilience Objectives

Current infrastructure and transport funding mechanisms primarily evaluate projects based on cost-benefit, capacity, and environmental criteria. SARIL simulations demonstrate that resilience-enhancing measures, such as redundancy, alternative routing capability and digital preparedness, can significantly reduce recovery time and limit systemic cascade effects, even when immediate cost-efficiency gains are limited.

European funding instruments, including the Connecting Europe Facility (CEF) and cohesion policy funds, should therefore:

- incorporate resilience-related key performance indicators (e.g. recovery time, cascade exposure, modal flexibility),
- incentivise investments in monitoring, early warning and digital decision-support systems,
- promote multimodal solutions that balance efficiency and robustness.

Embedding resilience metrics into funding frameworks would support long-term stability of European supply chains and reduce the economic impact of large-scale disruptions.

6.3 Strengthening Digital Integration and Data Governance

SARIL process mapping and simulation activities confirm that fragmented information flows significantly increase operational workload and delay decision-making during disruptions. Limited interoperability between infrastructure managers, operators and authorities remains a structural vulnerability.

Policymakers should promote:

- interoperable digital platforms enabling real-time exchange of infrastructure status and hazard alerts,
- standardised data-sharing protocols across modes and Member States,
- integration of modelling and simulation tools into operational crisis management frameworks.

Improved digital interoperability enhances coordinated response capacity, reduces uncertainty and shortens recovery time across borders.

6.4 Aligning Resilience and the Green Transition

SARIL assessments demonstrate that resilience and decarbonisation objectives are interdependent. Certain mitigation strategies reduce emissions while enhancing flexibility, whereas others involve trade-offs between cost, time and environmental performance. Scenario-based modelling is therefore essential to avoid unintended consequences when designing adaptation and mitigation measures. A systemic/life-cycle perspective in considering adaptation and mitigation measures to avoid unintended consequences, trade-offs, and identify potential co-benefits is considered one of the key takeaways from Saril deliverable 4.3.

Policy frameworks should:

- require integrated evaluation of operational and environmental KPIs in disruption scenarios,
- align climate adaptation planning with resilience stress testing,
- support modal diversification strategies that contribute to both emission reduction and systemic robustness.

Resilience policy must reinforce, not undermine, the objectives of the European Green Deal.

6.5 Enhancing Modal Balance and Maritime Redundancy

SARIL findings highlight the importance of diversified routing options and modal flexibility in strengthening systemic resilience. The European-scale simulations conducted within the project demonstrated that configurations incorporating multimodal alternatives reduced both delivery time increases and CO_2 emission growth under disruption conditions, compared to road-only configurations. In this context, maritime transport, and particularly short sea shipping, can serve as a strategic complement to land-based corridors by providing alternative pathways during major disruptions.

Policy frameworks should therefore:

- support increased service frequency and reliability in short sea shipping,
- facilitate integration between maritime hubs, rail corridors and inland waterways,
- encourage technological innovation (automation, digitalisation, alternative fuels) that enhances maritime flexibility.

Rather than replacing existing corridor structures, maritime development should be understood as a complementary resilience layer within the European transport system.

6.5.1 Rail Freight

Improving rail freight performance and market share is essential for both modal balance and systemic resilience. The investment requirements for achieving the EU's rail freight targets are substantial and have been extensively documented. Section 3.2.1 presents a detailed discussion of the UIRR Roadmap to Zero Carbon Combined Transport 2050 and associated investment estimates, which indicate that approximately €490 billion in public investment and €47 billion in private-sector investment would be needed to achieve the projected tripling of rail freight volumes by 2050. It is beyond the scope of this deliverable to formulate recommendations beyond those already provided in the referenced studies.

From a SARIL perspective, the key finding is that the availability of rail as an alternative mode significantly reduces cascading effects during road corridor disruptions. In the European-scale simulations, configurations that included rail alternatives demonstrated shorter recovery times and lower emission increases compared to road-only scenarios. Consequently, strengthening rail freight capacity and interoperability should be regarded as both a sustainability and a resilience priority.

6.5.2 Maritime Freight Transport

Investment in maritime freight infrastructure and services differs fundamentally from rail. Unlike rail, where large-scale public infrastructure investment constitutes the primary prerequisite, maritime transport can be developed through a combination of service innovation, vessel technology, digitalisation and regulatory enablement. This makes it possible for a research project such as SARIL to identify development pathways that could make maritime transport better positioned to attract cargo from land to sea and to contribute to improved resilience.

SARIL Deliverable 1.2[2] defined a set of resilience factors that should be considered when shaping a logistics network, among which *flexibility* was identified as a key dimension. As discussed in Section 3.2.2, the current maritime service model — characterised by increasingly large vessels and low frequencies — is structurally mismatched with the flexibility requirements of resilient logistics systems. Section 3.2.4 describes four enabling factors (autonomous ships, maritime digitalisation, new business models, and new fuel types) that are creating conditions under which a transformation of maritime freight services could be pursued.

Based on the SARIL analysis, the following recommendations are formulated for enhancing maritime freight transport as a resilience instrument:

- Maritime service design should prioritise frequency and reliability over vessel size, to better match the responsiveness requirements of logistics operators and shippers.
- Autonomous and remotely operated vessel technologies should be leveraged to enable smaller, more flexible services connecting hub ports to secondary ports and coastal communities.
- Digital integration between maritime services and hinterland transport chains should be strengthened, building on the electronic maritime single window and just-in-time shipping initiatives.
- Cargo owners should be engaged as active partners in designing and co-investing in new maritime services, following successful models such as ASKO and Yara in Norway.

[2] SARIL Deliverable 1.2: Resilience Factors for Logistics Network Design

Section 6.6 below presents a conceptual framework for supplementing the TEN-T with structured maritime freight services based on these principles. Detailed service proposals and route specifications are provided in Appendix 3.

6.6 Supplementing the TEN-T with Maritime Freight Services

The policy context and enabling factors described in Section 3.2, combined with the SARIL simulation results demonstrating the resilience value of multimodal alternatives, provide the basis for a proposal to supplement the TEN-T with new maritime freight services. The analysis of existing intra-European maritime services presented in Appendix 1 reveals significant geographic gaps, particularly in east–west Mediterranean connections and north–south Atlantic links. The service proposals outlined below are intended to address these gaps and to strengthen the overall redundancy of the European freight transport network.

6.6.1 The Hub-and-Spoke Maritime Network Concept

The suggested approach is taken from the hub and spoke solutions used in land transport, and the principle is illustrated in Figure 17. This approach comprises three interconnected elements:

1. **Regional Hub Ports:** Approximately 12–15 selected TEN-T core ports would be configured as highly efficient transhipment hubs with 24/7 automated operations, high-capacity cargo handling (both LoLo and RoRo), and excellent hinterland connections.
2. **Backbone Feeder Loop Services (“Highways”):** High-frequency maritime freight ferry services between hub ports, with vessel sizes matched to actual cargo volumes rather than maximum capacity. These form the “highways” of the system, with a target of at least five departures per week in each direction.
   First/Last-Mile Spoke Services: Smaller, potentially autonomous or remotely operated vessels connecting hubs to cities, rural ports, local industry, and island communities. These are the “local roads” of the sea.

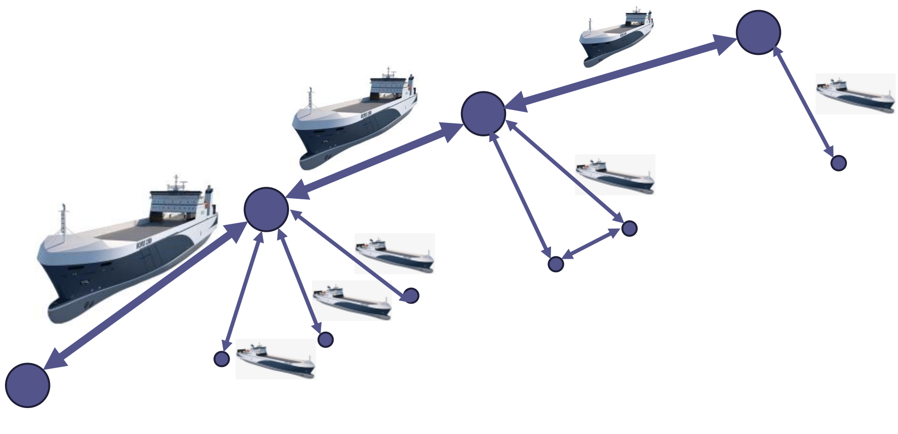

Figure 17: Hub and spoke. Source: Motorways of the Sea

The hub-and-spoke approach directly addresses the barriers identified by shippers: lead times can be reduced through higher frequencies on backbone routes; punctuality may improve through dedicated, optimised services; and accessibility increases through spoke connections to smaller ports. Critically, the system creates the redundancy and resilience that the SARIL project identifies as essential for a robust European transport network.

6.6.2 Proposed New Maritime Services for the TEN-T

Based on existing TEN-T core port status, cargo volumes, hinterland connections and geographic positioning, a set of regional hub ports and backbone service routes have been identified. The detailed proposals, including hub port specifications and seven route group descriptions (Route Groups A through G), are presented in Appendix 3. The following table provides a summary of the proposed backbone service corridors.

Table 4: Proposed new short-sea-shipping servicesti facilitate a more resilient European transport system (Source: SARIL analytics)

Route Group	Corridor	Strategic Purpose
A: North Sea–Baltic Connector	Rotterdam/Zeebrugge – Gothenburg – Travemünde/Lübeck – Gdynia	Continuous loop linking Benelux, Scandinavia and Eastern Baltic; parallels congested E45/E47 road corridors through Denmark and northern Germany
B: North Sea–Atlantic Connector	Rotterdam/Zeebrugge – Dublin – Bilbao/Sines	Atlantic corridor bypassing the Channel and French motorway network; post-Brexit direct Ireland–EU freight link
C: Western Mediterranean Loop	Barcelona – Genoa – Civitavecchia – Barcelona	High-frequency loop serving automotive and FMCG flows between Spain and Italy; alternative to the A7/E80 Riviera corridor
D: Adriatic–Eastern Mediterranean	Trieste/Koper – Piraeus – (Limassol)	Missing eastern Mediterranean unitised freight link; geopolitical resilience corridor as an alternative to Suez-dependent routing
E: Cross-Mediterranean Connector	E: Cross-Mediterranean Connector	East–west Mediterranean link; “southern TEN-T corridor at sea”; provides Alpine bypass redundancy
F: Norway–Continent Direct	Rotterdam – Bergen area – Trondheim – (Bodø/Tromsø)	Direct high-frequency services to Norwegian West Coast; candidate corridor for autonomous vessel deployment
G: Baltic–Mediterranean Bypass	Gothenburg – Zeebrugge – Sines – Barcelona – Genoa	Complete maritime alternative to the Scandinavian–Mediterranean land corridor; avoids all Alpine road/rail crossings

These services are designed to complement, not replace, existing TEN-T land corridors. They would provide modal redundancy, reduce corridor dependency, and create pre-configured alternative routing options that can be activated during major disruptions — directly supporting the resilience-by-design approach developed within SARIL. The detailed justification and service specifications for each route group, together with the proposed list of regional hub ports, are provided in Appendix 3 - Proposed Spoke Services (First/Last Mile). From each hub port, spoke services using smaller vessels (potentially autonomous) would connect to urban distribution hubs, island communities, rural and industrial ports, and inland waterway connections. Detailed spoke service descriptions are provided in Appendix 3

7 Conclusions and Next Steps

7.1 From Disruption Response to Resilience by Design

Disruptions in European freight transport systems are no longer exceptional events; they are conditions in which we must learn to function systematically. Climate-related threats, geopolitical tensions, vulnerability to digital threats, and systemic traffic congestion interact, causing a domino effect in multimodal networks. Research conducted as part of the project at regional, national, and European levels shows that resilience cannot be achieved through isolated remedial measures. Systems based solely on reactive responses have seen a significant increase in travel time, operating costs, and emissions. In contrast, configurations based on structured vulnerability assessments, predefined alternative routes, and digital decision-making tools show measurable improvements in recovery time and environmental performance. The results point to the need for a paradigm shift - resilience must evolve from crisis management to design resilience which means that:

- infrastructure is planned with redundancy and exposure to risks in mind
- logistics networks are configured with multimodal flexibility in mind
- operational processes are supported by real-time monitoring and simulation tools
- environmental and resilience indicators are assessed together rather than separately

The SARIL framework shows that resilience is not an abstract principle, but a measurable property of a system that can be modelled, stress tested and improved using integrated digital tools.

7.2 Systemic Role-Based Responsibilities in a Resilient Transport Ecosystem

The SARIL project has demonstrated that increasing resilience in freight transport is not a one-size-fits-all challenge. Each actor across the logistics ecosystem, from infrastructure managers to network planners to operational service providers, faces distinct constraints, operates on different decision horizons, and requires tailored tools to act effectively in the face of disruptions.

The following synthesised recommendations distil the most actionable insights and outcomes from SARIL for each of the three main roles identified in the project:

7.2.1 Infrastructure Managers (Role 1)

Infrastructure Managers operate at the structural level. Their decisions shape the physical and digital backbone of the transport system. Vulnerability mapping, monitoring of critical assets, predictive hazard modelling and resilience-oriented investment planning determine whether disruptions escalate into network-wide failures or remain contained.

To improve network-level resilience, infrastructure managers should move beyond static asset management and adopt a proactive, risk-informed approach. This includes:

- Implementing real-time condition monitoring tools (e.g. for scour and flood risk),
- Using predictive modelling for hazard mapping and asset prioritisation,
- Establishing integrated interfaces for sharing disruption alerts and response plans.

The SARIL toolkit provides scalable solutions such as the Disruption Information Interface and flood alert systems that enable earlier interventions, improved coordination and optimised infrastructure performance during disruptions.

Project research confirmed that infrastructure-level mitigation measures (e.g. targeted protection, monitoring, preventive closure strategies) significantly reduce cascading effects across corridors.

However, infrastructure robustness alone does not guarantee continuity if network configuration and operational flexibility are insufficient.

7.2.2 Logistics Network Configurators (Role 2)

Logistics Network Configurators operate at the structural–strategic interface. They determine modal allocation, hub selection, routing logic and redundancy within multimodal transport chains. Network designers and planners are urged to integrate resilience and sustainability as co-equal objectives in their optimisation models. They should:

- Simulate alternative configurations and disruption scenarios in the planning phase,
- Use KPIs that capture vulnerability, emissions, and service continuity,
- Invest in multimodal redundancy and flexible route design.

SARIL tools, such as the Vulnerability & Traffic Tool and ASTROIT simulation environment, support data-driven decisions that balance cost-efficiency with robustness under stress.

The European-scale simulations conducted in SARIL showed that corridor dependency and limited modal flexibility amplify disruption impacts, whereas diversified configurations and synchro-modal routing reduce both travel time increases and emission growth under stress conditions. Network configurators, therefore, play a critical role in embedding resilience into system architecture before disruptions occur.

7.2.3 Logistics Operators and Shippers (Role 3)

Logistics Operators and Shippers act at the operational level. They translate infrastructure and network design into day-to-day execution. Operational actors at the heart of freight flows must be equipped to respond more quickly and effectively when the unexpected occurs. SARIL recommends:

- Leveraging real-time alerts and route updates to trigger a timely response,
- Using decision support tools to evaluate mode-switching and rerouting options,
- Embedding environmental and risk data into customer-facing logistics decisions.
- Inform system configurators or planners (assist redesign circle)

Process mapping conducted within SARIL demonstrated that disruptions immediately increase organisational workload, decision pressure and indirect cost exposure. Operators equipped with integrated disruption alerts, simulation-based decision support and predefined alternative routing options were able to reduce response time and limit service degradation compared to reactive, manual coordination approaches. By adopting SARIL's digital decision support as ASTROIT and process simulation tools, operators can significantly reduce manual workload, cut response time, and limit disruption-related losses while enhancing the transparency and reliability of their services.

Summary

The interaction between these roles determines overall system performance:

- Infrastructure resilience enables routing flexibility.
- Network design enables operational adaptability.
- Operational responsiveness prevents local disturbances from escalating into systemic failures.

Resilience cannot be delegated to a single actor. It must be distributed across roles, aligned through shared data interfaces and supported by interoperable analytical tools.

Importantly, SARIL findings highlight that resilience and sustainability objectives must be coordinated across these roles. Infrastructure investments, network configuration decisions and operational rerouting strategies influence not only recovery time and cost exposure, but also greenhouse gas emissions and energy performance. Without coordinated evaluation of environmental and resilience KPIs, mitigation strategies risk shifting vulnerability or increasing carbon intensity elsewhere in the system. A resilient European freight transport ecosystem requires vertically integrated responsibility, from infrastructure planning through network design to operational execution, supported by shared digital platforms and scenario-based stress testing. Only through coordinated action across roles can resilience become a structural characteristic of the European transport system rather than a reactive response to recurring crises.

7.3 Scaling and Replicating the SARIL Framework

The SARIL project was not designed as a location-specific pilot, but as a transferable methodological and technological framework for strengthening green resilience in transport and logistics systems. The tools, modelling architecture and governance insights developed within the project demonstrate strong replication potential across geographical scales, transport modes and institutional contexts.

7.3.1 Replication Across Geographic Scales

SARIL has validated its methodology at three interconnected levels: regional, national and European. The consistency of results across these scales confirms that the Green Resilience Management framework is scalable. As this framework integrates vulnerability assessment, transport simulation, resilience indicators, and environmental indicators within a unified methodology, it can be applied to:

- other TEN-T corridors,
- cross-border logistics regions,
- port and hinterland systems,
- inland waterway networks,

This architecture does not depend on a specific geographical location, but on the integration of data and coordination of stakeholders.

7.3.2 Replication Across Modes and Infrastructure Types

Although the SARIL project focused primarily on freight transport, its methodological structure is independent of the type of transport. The basic principles such as vulnerability mapping, scenario-based stress testing, cascade analysis, and key performance indicator-based assessment are also applicable to:

- passenger transport systems
- urban multimodal transport networks
- energy transport infrastructure
- critical supply corridors (e.g., food, medical supplies)

Similarly, the hazard modelling logic developed for floods and forest fires can be extended to other climate-related hazards such as heat stress, landslides, or coastal erosion. The digital architecture for monitoring and decision support provides the basis for integrating additional layers of risk as new hazards emerge.

The transport simulation environment and route attribute modules can be recalibrated to consider alternative vehicle technologies, energy sources, and modal configurations, allowing the system to adapt to future technological developments.

7.3.3 Digital Interoperability and Integration Potential

The SARIL toolkit has been designed with interoperability in mind. Its components, such as vulnerability analysis, disruption information interface, transport simulation tools, and environmental modules, can operate as standalone applications or be integrated into existing digital ecosystems.

This creates significant opportunities for:

- integration with European digital freight transport initiatives (eFTI, single window environments)
- the inclusion of resilience indicators in the assessment of CEF-funded projects
- integration into transport observatories and corridor monitoring platforms
- use in training environments and emergency preparedness exercises

Because SARIL tools translate complex modelling results into operationally relevant indicators (travel time changes, cost exposure, emission changes), they can be accessible not only to researchers but also to practitioners and policymakers.

7.4 Policy and Research Agenda for a Green and Resilient European Freight System

The SARIL project demonstrates that resilience in European freight transport systems can be modelled, quantified and operationalised. However, transforming analytical capability into structural change requires stronger policy embedding and continued research development.

First, resilience assessment should be systematically integrated into European transport governance. Scenario-based stress testing, vulnerability mapping and resilience KPIs should become standard elements of TEN-T corridor planning and major infrastructure investment appraisal. Without institutional anchoring, resilience risks remaining a project-level innovation rather than a structural requirement.

Second, digital interoperability must be strengthened. Fragmented data flows and limited cross-border coordination significantly delay response during disruptions. Future policy efforts should prioritise harmonised data standards, integration of modelling tools into operational environments and secure, interoperable digital infrastructures.

Third, further refinement of resilience metrics is needed. Standardised KPIs, including recovery time, cascade exposure and modal flexibility, should be developed and aligned with environmental performance indicators to ensure that resilience and decarbonisation objectives are addressed jointly.

Finally, climate adaptation and transport planning must be more closely aligned. As climate-driven hazards intensify, proactive integration of adaptation modelling into transport network planning will be essential to avoid reactive and costly post-disruption responses.

The transition towards a green and resilient European freight system, therefore, requires coordinated action across governance, digitalisation, funding frameworks and research. SARIL provides a methodological foundation for this transformation; the next step is to systematically integrate it into European transport policy and investment practice.

7.5 Enhancing TEN-T through Maritime Complementarity

The analyses conducted in this report indicate that strengthening maritime services can enhance systemic redundancy within the TEN-T framework and reduce corridor dependency. Rather than redefining the TEN-T structure itself, the focus should be placed on reinforcing multimodal complementarity, particularly through structured short sea shipping services. Several strategic directions emerge from this analysis.

1. **Define maritime services explicitly in TEN-T planning.** The European Maritime Space coordinator should work with Member States and industry to identify and formally designate backbone maritime freight routes connecting core and comprehensive network ports, comparable to how rail freight corridors are defined.
2. **Adopt the hub-and-spoke model.** Rather than trying to create point-to-point connections between all ports, organise services around 12–15 hub ports with high-frequency backbone loops and spoke connections, as described in this document.
3. **Prioritise intra-EU routes for early implementation.** Route Groups A, C, D, and E avoid customs complexity and can benefit from EU-wide regulatory harmonisation. The Western Mediterranean loop (Group C) and the North Sea–Baltic connector (Group A) should be pilot corridors.
4. **Set service-level targets.** Backbone services should target minimum 5 departures per week per direction; spoke services should target daily or near-daily frequency. The aim is to match the reliability expectations of road-based shippers.
5. **Invest in hub port automation.** Allocate CEF and national funding to equip designated hub ports with 24/7 automated RORO and LoLo handling, shore power, and digital integration capabilities.
6. **Integrate maritime services into resilience planning.** Use the SARIL network simulator and similar tools to model maritime alternatives to land corridors and pre-plan rerouting scenarios for major disruption events.
7. **Engage cargo owners as partners.** Follow the ASKO/Yara model of cargo-owner-driven logistics innovation. Major European manufacturers and retailers should be actively engaged in designing and co-investing in the new services.
8. **Fast-track autonomous vessel regulations.** Norway’s leadership in autonomous ship development should be leveraged through EU–EEA cooperation to create a regulatory framework enabling crewless and remotely operated spoke vessels.
9. **Establish monitoring and KPIs.** Track actual modal shift (not just total short sea volumes), service frequency, reliability, and end-to-end costs to ensure the milestones of 25% increase in waterborne transport by 2030 and 50% by 2050 are on track.
10. **Create an open maritime freight marketplace.** Address the “information gap” identified in the Norwegian Shippers Survey by developing a digital platform showing available maritime services, schedules, and booking options, integrated with the eFTI ecosystem.

In this context, maritime development should not be seen as a separate policy domain, but as an integral component of a resilience-oriented, multimodal TEN-T system.

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SARIL-Deliverables referred to in this document:

Deliverable	**Title**
D1.2	Framework for a sustainability and resilience evaluation of strategic logistics networks
D1.4	Co-creation of requirements and strategies for resilience and sustainability dealing with disruptions
D2.1	Survey of methodologies for resilience management
D2.2	Integrated Assessment framework for the SARIL case scenario
D3.1	Enhanced models and tools
D3.3	Green Resilience Assessment Results
D4.3	Environmental and Economic Impact Assessment

9 Appendix 1 Analysis of Existing Intra-European Maritime Freight Services

9.1 Overview of the European Short Sea Shipping Market

The European short sea shipping market can be divided into five major regional markets: the Baltic Sea, the North Sea, the Atlantic, the Mediterranean, and the Black Sea. Short sea shipping currently accounts for approximately 40% of all freight moved in Europe, though a significant portion of this is bulk cargo (liquid and dry bulk) rather than unitised cargo suitable for road-to-sea modal shift.

The most important short sea countries by volume include the Netherlands, Italy, Spain, and the Nordic countries. Rotterdam is the largest European short seaport. Most short sea flows occur between partner ports in the Mediterranean (28%) and the North Sea (27%).

9.2 Existing RoRo and Freight Ferry Services by Sea Region

The following table summarises the principal existing regular RoRo and unitised cargo services operating within European waters. These services form the de facto maritime freight network, though they are not formally integrated into TEN-T planning.

9.2.1 North Sea and English Channel

Table 5: RoRo and unitised cargo services operating in the North Sea and English Channel. Source: SARIL analysis

Operator	Route	Frequency
DFDS	Gothenburg – Ghent	6/week
CLdN / DFDS	Zeebrugge – Gothenburg	4/week
DFDS	Immingham – Rotterdam	Daily
CLdN	Zeebrugge – London Gateway	Daily
DFDS	Calais – Dover	Multiple daily
Stena Line	Hoek van Holland – Killingholme	Daily
CLdN	Rotterdam – Killingholme	6/week
DFDS	Esbjerg – Immingham	6/week

9.2.2 Baltic Sea

Table 6: RoRo and unitised cargo services operating in the Baltic Sea. Source: SARIL analysis

Operator	Route	Frequency
DFDS	Klaipėda – Kiel	6/week
Stena Line	Gothenburg – Frederikshavn	Multiple daily
Stena Line	Karlskrona – Gdynia	Daily
Finnlines	Helsinki – Travemünde	Daily
TT-Line	Trelleborg – Travemünde	Multiple daily
TT-Line	Trelleborg – Rostock	Multiple daily
Stena Line	Travemünde – Liepāja	4/week
Viking Line	Turku – Stockholm	Daily
Tallink/Silja	Helsinki – Stockholm	Daily
Unity Line/Polferries	Trelleborg/Ystad – Świnoujście	Multiple daily

9.2.3 Mediterranean and Adriatic

Table 7: RoRo and unitised cargo services operating in the Mediterranean and Adriatic. Source: SARIL analysis

Operator	Route	Frequency
Grimaldi Lines	Barcelona – Civitavecchia	3–4/week
Grimaldi Lines	Salerno – Valencia	3/week
Grimaldi Lines	Genoa – Barcelona	3/week
GNV/Grandi Navi	Genoa – Palermo/Sicily	Daily
U.N. RoRo	Pendik (Istanbul) – Trieste	3/week
U.N. RoRo	Pendik – Toulon	2–3/week
Neptune Lines	Multiple Med ports	Regular
DFDS (FRS)	Algeciras – Tanger Med	Multiple daily

9.2.4 Atlantic

Table 8: RoRo and unitised cargo services operating in the Atlantic. Source: SARIL analysis

Operator	Route	Frequency
Brittany Ferries	Portsmouth – Caen/St Malo	Daily
CLdN	Zeebrugge – Dublin	6/week
Stena Line	Dublin – Holyhead/Birkenhead	Multiple daily
Irish Ferries	Dublin/Rosslare – Cherbourg	4–6/week
Brittany Ferries	Bilbao – Portsmouth	2/week

9.2.5 Norwegian Coast and North Sea (Norway–Continent)

Table 9: RoRo and unitised cargo services operating in the Norwegian Coast and North Sea. Source: SARIL analysis

Operator	Route	Frequency
DFDS	Oslo – Ghent/Brevik–Ghent	1–2/week
Various feeders	Rotterdam – West Norway ports	1–2/week
ASKO (pilot)	Moss – Horten	Regular
Color Line	Oslo – Kiel	Daily
Fjord Line	Bergen – Stavanger – Hirtshals	3–4/week
NCL	Rotterdam - Stokmarknes	Weekly

9.3 Key Observations on Existing Services

Several critical observations emerge from this analysis:

- **Concentration in the North Sea:** The densest network of regular RoRo freight services exists between the Benelux ports and the UK/Scandinavia. This is driven by high trade volumes and established operators like DFDS and CLdN.
- **Mediterranean underdevelopment:** Despite 28% of short sea volumes, regular RoRo freight services in the Mediterranean are far less developed. Grimaldi and U.N. RoRo provide some services, but frequencies are low and coverage patchy.

- **Norway–Continent gap:** As highlighted in the Logistics 2030 study, performed in the Norwegian Sustainable Shipping program[3], services from the Benelux to Norway's West Coast operate at low frequency (typically once or twice per week), with operators often sailing on the same days, further reducing effective availability.
- **Peripheral regions poorly served:** Atlantic Iberia, the Eastern Mediterranean, the Adriatic, and island nations (Cyprus, Malta, Greece's islands) have minimal regular unitised freight services.
- **No east–west Mediterranean connections:** There is virtually no regular RoRo/unitised service linking the Western and Eastern Mediterranean for intra-European freight (as opposed to deep-sea feedering).
- **Resilience concerns:** The SARIL project demonstrates that climate events, geopolitical tensions, and infrastructure failures require redundant transport options. The current maritime network provides little resilience to land-based disruptions because services are too infrequent and poorly integrated.

[3] https://grontskipsfartsprogram.no

10 Appendix 2

10.1 Logistics process maps – Process without disruption

The Figure 18 illustrates a standardised logistics process for sea freight import under normal, disruption-free conditions, representing the AS-IS operational scenario within the SARIL framework. The process is executed by a logistics operator and follows a sequential and structured flow of activities, starting from order placement and ending with order completion.

The process begins with the formal conclusion of a supply contract, followed by the preparation and loading of goods at the origin location. Subsequently, the cargo is transported via maritime transport, which constitutes the main leg of the logistics chain. Upon arrival at the destination port, the process continues with rail transport, representing an inland distribution stage within a multimodal transport system. The final stages include last-mile transport to the end receiver and the administrative closure of the order. The process is characterised by a linear, uninterrupted flow, where each activity is dependent on the successful completion of the previous one.

In the context of SARIL, this process represents the reference operational baseline used for comparison with disrupted scenarios. It reflects a stable system with no external disturbances, enabling efficient coordination between transport modes and stakeholders. This baseline is essential for assessing the impact of disruptions and evaluating the effectiveness of resilience-enhancing measures and SARIL tools in more complex scenarios.

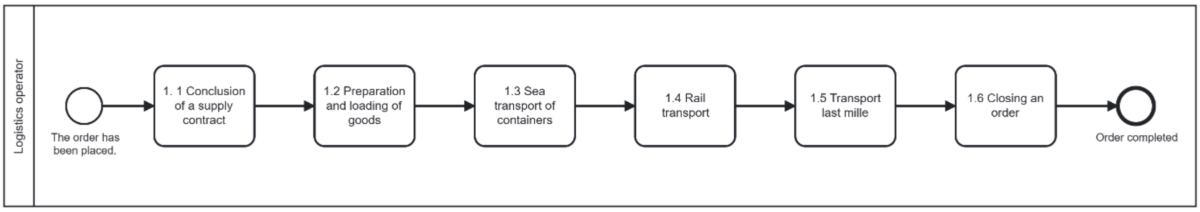

Figure 18: Process map - Sea freight import Process nr 1.

The Figure 19 illustrates a decomposed subprocess of the main logistics process, focusing on the initial stage of placing a delivery order (Process 1.1). This subprocess provides a detailed view of the interactions between key stakeholders, namely the customer, logistics operator, and shipowner, within a standard operational environment.

The process is initiated by a customer enquiry, which triggers a sequence of activities performed by the logistics operator. These include reading and verifying the order details, followed by entering the relevant data into the order management system. This system acts as a central information repository supporting process coordination and data consistency. Subsequently, the logistics operator sends requests for quotations to external service providers (e.g. shipowners), using communication channels such as online platforms or email. The process continues with the reception of offers, which are then evaluated and compared based on predefined criteria such as cost, transit time, or service conditions. A decision-making point is introduced through the comparison of offers, after which the selected proposal is communicated to the customer. The process concludes with the customer's acceptance of the offer, resulting in the formal placement of the order.

From the SARIL perspective, this subprocess highlights the importance of information exchange, coordination between actors, and decision-making under time constraints (e.g. deadlines for submitting offers). It represents a critical stage where visibility, collaboration, and data integration play a key role in ensuring efficient and resilient logistics operations. This level of process granularity is essential for identifying potential vulnerabilities and assessing how disruptions or delays in information flow may impact subsequent stages of the logistics chain.

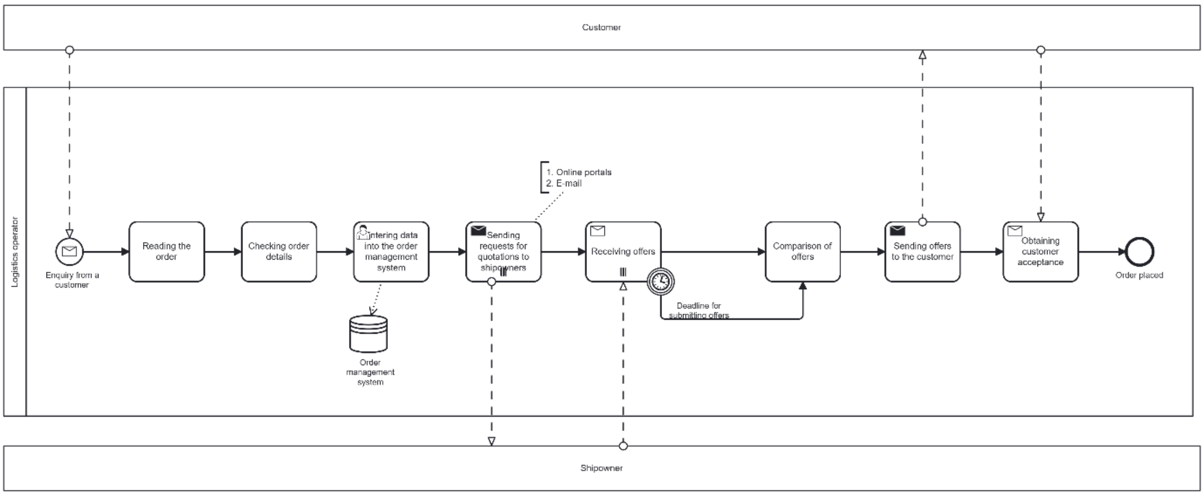

Figure 19: Placing a delivery order Process 1.1.

The Figure 20 illustrates a detailed subprocess of the main logistics chain, focusing on the preparation and loading phase of cargo (Process 1.2). This subprocess captures the operational and information flows between multiple stakeholders, including the logistics operator, shipowner, port terminal, and customer.

The process is initiated after the order is concluded and involves booking the shipment within the shipowner's system. Following this, booking details are received and communicated to the customer, ensuring transparency and alignment regarding shipment parameters such as vessel, port of loading, and destination terminal. A key stage of the process is the completion and validation of shipment data, including sender and recipient details as well as container specifications. This step is supported by IT systems, which act as central enablers for data management and process coordination. However, the figure also indicates the use of additional communication channels, such as email and spreadsheets, reflecting a partially digitalised and fragmented information environment. The subprocess continues with ongoing communication and coordination with the shipowner, shipping agent, and port terminal to ensure proper execution of loading operations. The process concludes with the confirmation of cargo loading, marking the transition to the next stage of the logistics chain.

From the SARIL perspective, this subprocess highlights the critical role of data accuracy, system interoperability, and stakeholder coordination in ensuring efficient operations. The reliance on both structured IT systems and unstructured communication channels introduces potential vulnerabilities, particularly regarding visibility, data consistency, and response time. These aspects are essential when analysing resilience, as disruptions or delays in information exchange at this stage may propagate downstream, affecting transport execution and delivery performance.

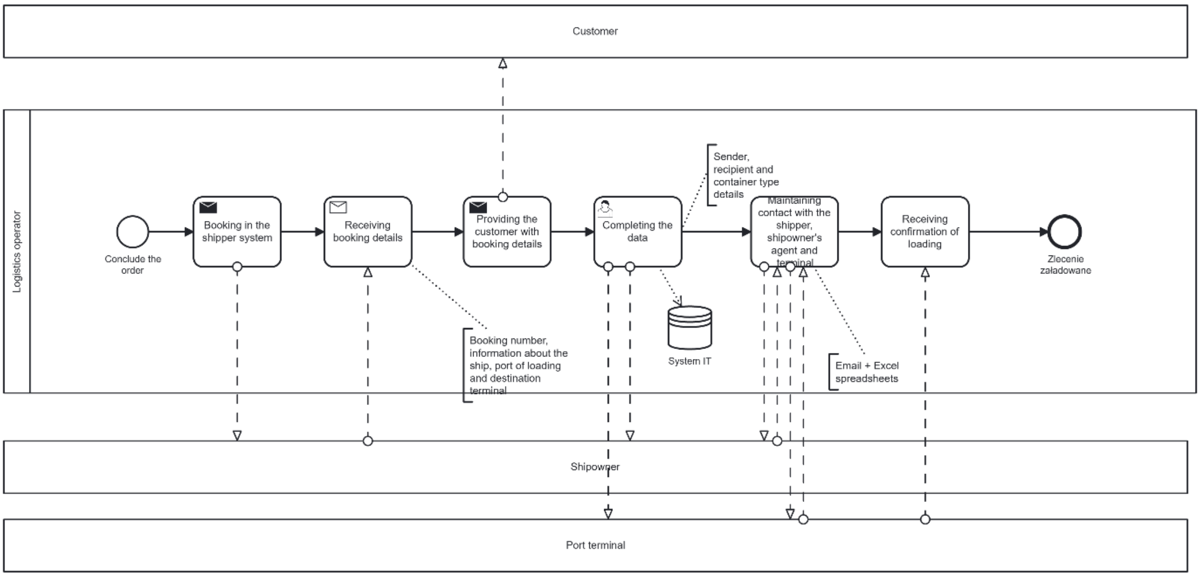

Figure 20: Preparation and loading of the cargo – Process 1.2.

The Figure 21 illustrates the subprocess related to the handling of sea transport operations (Process 1.3), incorporating both standard operational flow and a disruption scenario. The process is executed primarily by the logistics operator, in coordination with the shipowner and the port of destination, while maintaining communication with the customer.

Under normal operating conditions, the process begins with monitoring the shipment status using maritime traffic or shipowner systems. Based on this monitoring, estimated time of arrival (ETA) and estimated time of departure (ETD) data are updated and communicated to the customer. This ensures visibility and allows stakeholders to prepare for subsequent logistics activities. A key operational element is the preparation of inland transport notifications, which enables coordination of cargo collection from the port and its further distribution, for example via rail transport and last-mile delivery to the customer's warehouse. This step reflects the integration of maritime and inland transport within a multimodal logistics chain. The process also incorporates a disruption scenario, represented by a port strike. In this case, a dedicated crisis-handling subprocess is triggered, illustrating how the system responds to unexpected events. The crisis management phase includes handling operational impacts of the strike and ensuring continuity of logistics operations. Once the disruption is resolved, the process returns to the standard flow.

From the SARIL perspective, this subprocess highlights the importance of real-time monitoring, information sharing, and adaptive response mechanisms. The integration of disruption handling within the process flow demonstrates how resilience is operationalised through preparedness and recovery capabilities. The ability to update ETA/ETD dynamically and adjust inland transport planning is critical for maintaining service continuity and minimising the cascading effects of disruptions across the logistics network.

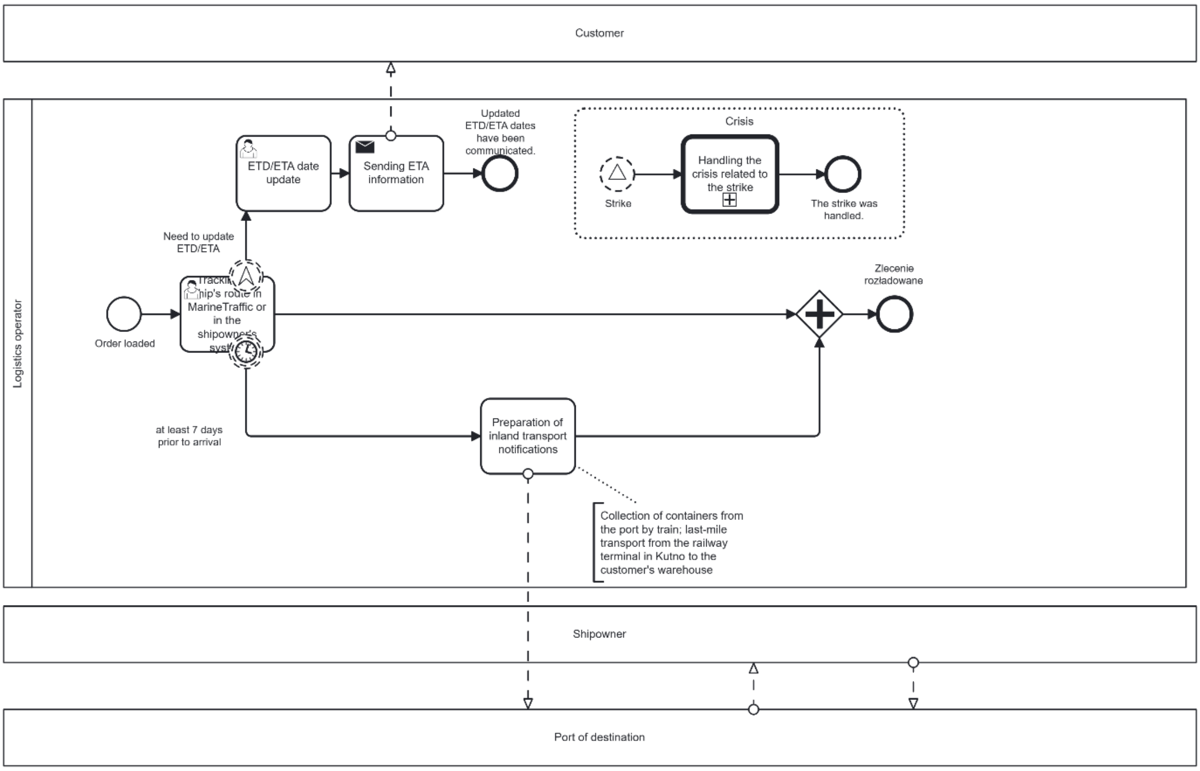

Figure 21: Process of handling of sea transport ordered by the forwarding agent 1.3.

The Figure 22 illustrates the subprocess related to rail transport handling (Process 1.4), representing the final stages of inland logistics operations following cargo arrival at the terminal. The process is coordinated by the logistics operator in collaboration with railway operators, last-mile carriers, and depot infrastructure, with continuous communication with the customer.

The process begins with the unloading of the cargo at the terminal and the preparation of last-mile delivery operations. This includes the allocation and notification of last-mile drivers, ensuring that transport resources are available and properly coordinated. A synchronisation point is introduced where multiple preparatory activities converge before proceeding to delivery execution. Subsequently, the customer is informed about the planned transport and delivery schedule, ensuring visibility and enabling operational readiness at the receiving end. The delivery itself is executed, followed by confirmation of unloading, which marks the successful transfer of goods to the customer. An important component of this subprocess is the management of empty containers after delivery. This includes assigning a designated return location and coordinating the return flow to a depot. This reverse logistics element is essential for maintaining container circulation efficiency and optimising asset utilisation. The process concludes with informing the customer about the completion of the transport order, closing the operational cycle.

From the SARIL perspective, this subprocess highlights the importance of coordination across multiple actors in the final stages of the logistics chain, where timing, resource availability, and information accuracy are critical. The integration of forward and reverse logistics flows, combined with real-time communication, contributes to system efficiency and resilience. Any disruption at this stage may directly impact customer satisfaction and overall supply chain performance, making visibility and coordination key resilience factors.

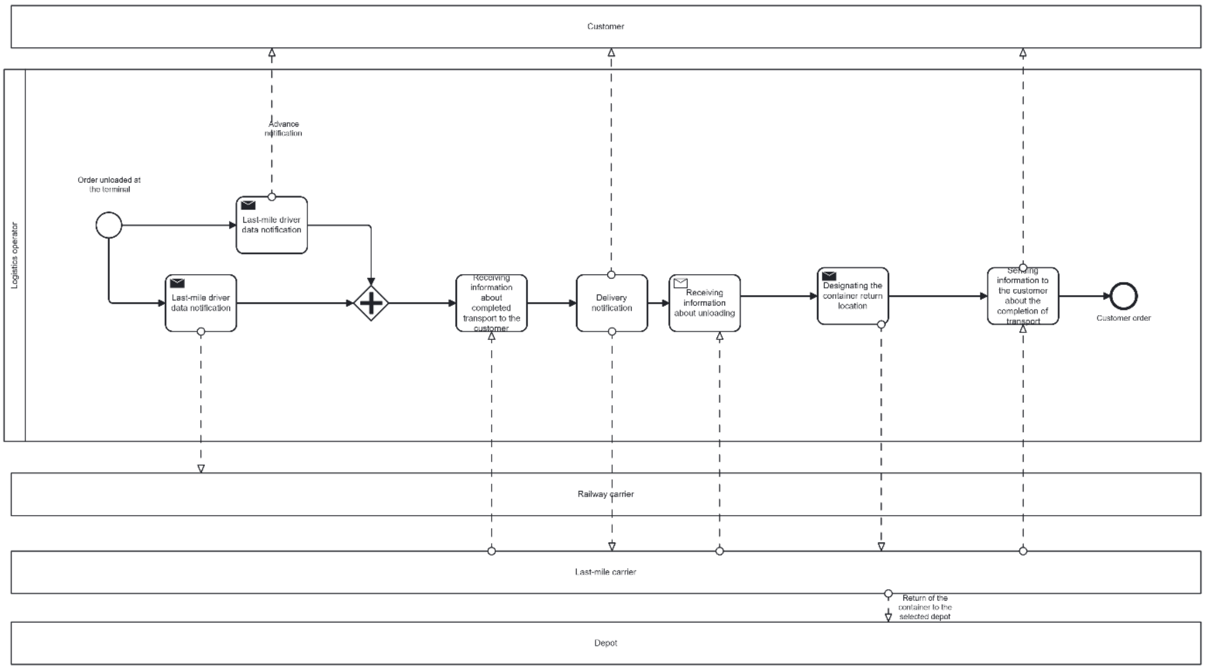

Figure 22: Process of rail transport handling Process 1.4.

The Figure 23 illustrates the subprocess related to last-mile delivery operations (Process 1.5), representing the final execution phase of the logistics chain where goods are physically delivered to the end customer. The process is managed by the logistics operator in coordination with last-mile carriers, railway operators, and depot infrastructure.

The process begins with the unloading of cargo at the terminal and the preparation of last-mile delivery. This includes notifying and allocating drivers responsible for the final transport segment. Multiple preparatory activities converge at a synchronisation point, ensuring that all required resources and information are aligned before delivery execution. Following this, the customer is informed about the planned delivery, increasing transparency and enabling readiness at the destination. The delivery operation is then carried out, after which confirmation of unloading is received, signalling the successful completion of the transport service from an operational perspective.

An integral part of this subprocess is the management of empty container flows. After delivery, a designated return location is assigned, and the container is transported back to a depot. This reverse logistics activity is essential for maintaining asset availability and ensuring efficient circulation of transport units. The process concludes with formal communication to the customer confirming the completion of the order.

From the SARIL perspective, the last-mile delivery stage is a critical point in the logistics chain, where operational performance directly impacts customer satisfaction. It is also a stage highly sensitive to disruptions, such as delays, resource shortages, or coordination failures. Therefore, real-time information exchange, coordination between actors, and efficient management of both forward and reverse flows are key factors contributing to resilience and overall system performance.

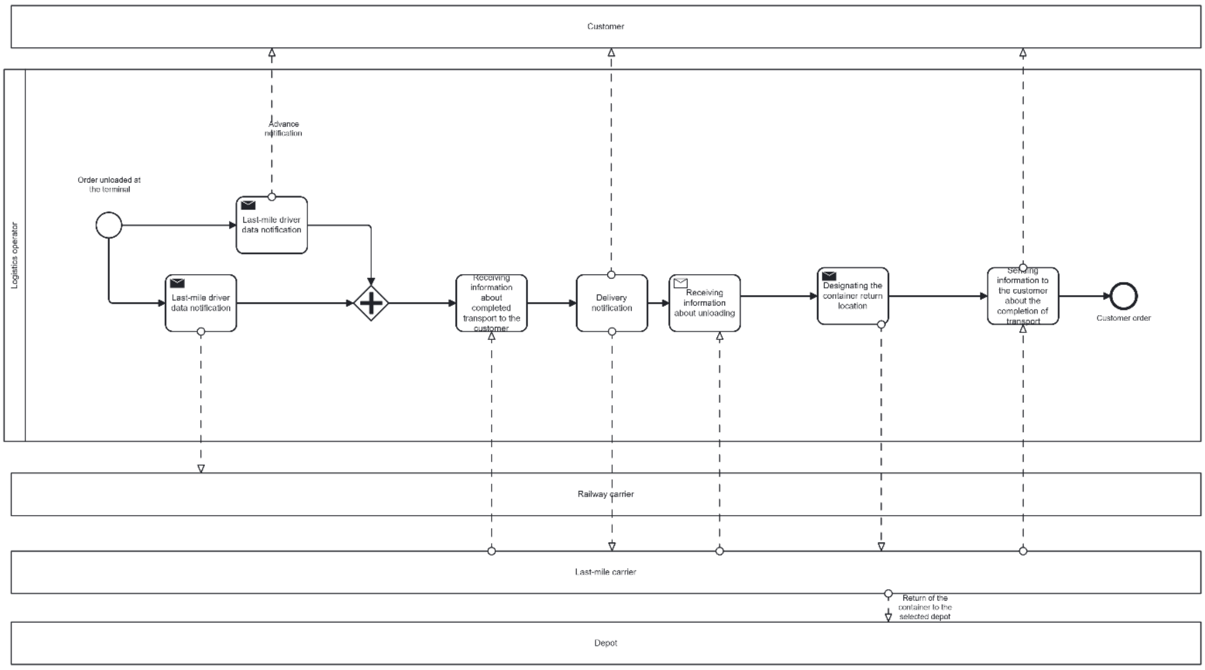

Figure 23: Last mile delivery of the cargo Process 1.5.

The Figure 24 illustrates the final subprocess in the logistics chain – the closure of the order (Process 1.6). This stage is executed by the logistics operator and represents the transition from operational execution to evaluation, documentation, and process finalisation.

The process begins once the order has been delivered and involves verification of order completion within the system. This includes checking whether all required elements have been fulfilled, such as document collection, container return, and customer notification. This validation step ensures data completeness and operational consistency. Following verification, a final report is generated, summarising the execution of the transport process. This report is further enriched with key performance indicators (KPIs), such as time performance, adherence to schedules, and cost-related metrics. The inclusion of KPI evaluation introduces a performance assessment layer, enabling the analysis of operational efficiency.

Subsequently, documentation is archived, ensuring traceability and compliance with organisational and regulatory requirements. The process concludes with formally marking the order as completed in the system, closing the operational cycle.

From the SARIL perspective, this subprocess plays a crucial role in supporting the "learning" and "adaptive capacity" components of resilience. By collecting performance data and analysing KPIs, organisations can identify inefficiencies, assess the impact of disruptions, and improve future decision-making. This feedback loop is essential for continuous improvement and for strengthening the resilience of logistics networks over time.

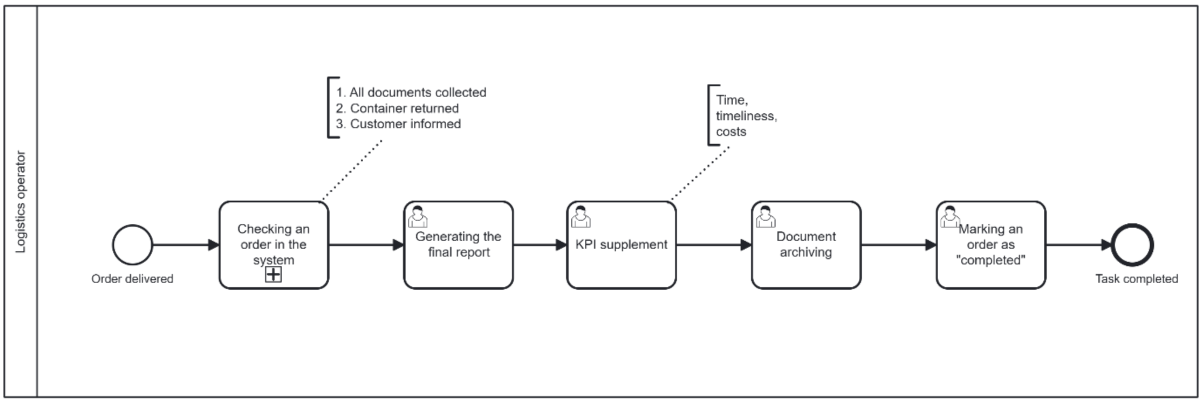

Figure 24: Closure of the order Process 1.6.

10.2 Logistics process disrupted – crisis

The Figure 25 Figure 26 illustrate a logistics process under disruption conditions, representing a crisis scenario (Process 10.2) within the SARIL framework. The disruption is triggered by a port strike, which significantly impacts the planned transport execution and introduces additional complexity into the logistics chain.

The process begins with the identification of a potential disruption through external information sources, including market signals, shipowners, and terminal operators. Based on this information, a decision is made to suspend or modify the original transport plan. A key decision point determines whether the strike will take place and how long it is expected to last, introducing uncertainty into the process. Once the disruption is confirmed, a crisis management phase is initiated. This includes analysing the current situation, assessing its impact, and informing the customer about expected delays. The process then branches depending on the duration and severity of the disruption. For short-term disruptions, operations may be temporarily paused, while for longer disruptions, alternative solutions must be developed. The disruption leads to the cancellation of planned transport activities, such as train bookings, and requires the reorganisation of cargo handling operations. This includes identifying alternative unloading options, re-planning inland transport, and coordinating new collection strategies. Decision points are introduced to determine whether cargo can be transported using alternative modes (e.g. rail or road), resulting in dynamic reconfiguration of the logistics network.

The process also involves extensive communication and coordination between multiple stakeholders, including terminals (e.g. Hamburg, Bremerhaven), carriers, and customers. New transport orders may need to be issued, and cargo flows redirected to alternative terminals or routes. The process concludes with forwarding updated scheduling information to the customer, reflecting the adjusted logistics plan.

From the SARIL perspective, this disrupted process highlights the transition from a linear, predictable workflow to a highly dynamic and decision-intensive system. The number of decision points, alternative paths, and stakeholder interactions increases significantly, reflecting the complexity introduced by disruptions. Key resilience aspects such as flexibility, adaptability, visibility, and collaboration become critical for maintaining operational continuity.

This scenario demonstrates how disruptions propagate through the logistics chain and require continuous monitoring, rapid decision-making, and the ability to reconfigure transport operations in real time. It also highlights the limitations of traditional, static planning approaches and underlines the need for advanced decision-support tools, such as those developed in SARIL, to effectively manage crisis situations.

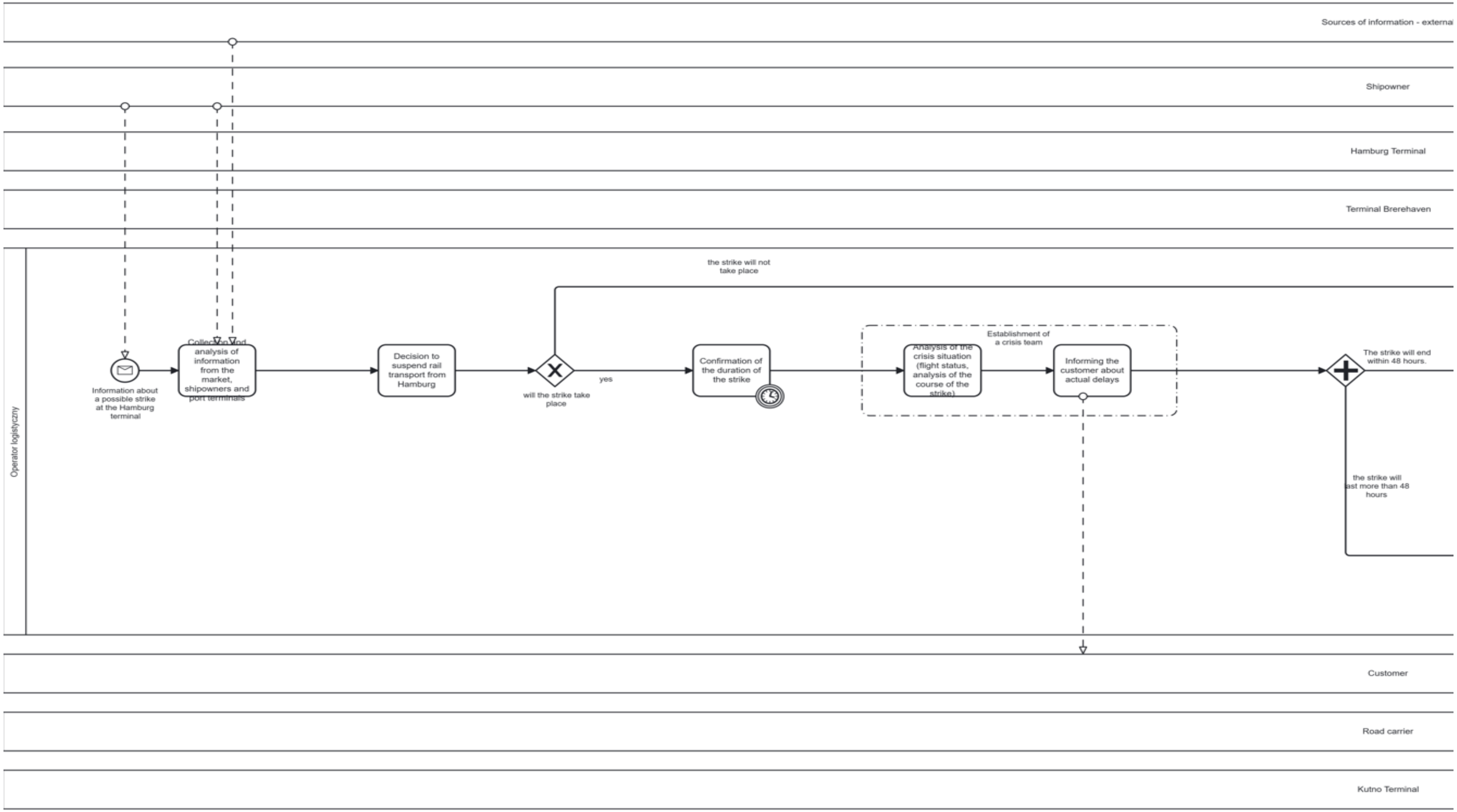

Figure 25: Logistics process disrupted - crisis - strike in port (1/2). Source: Own elaboration

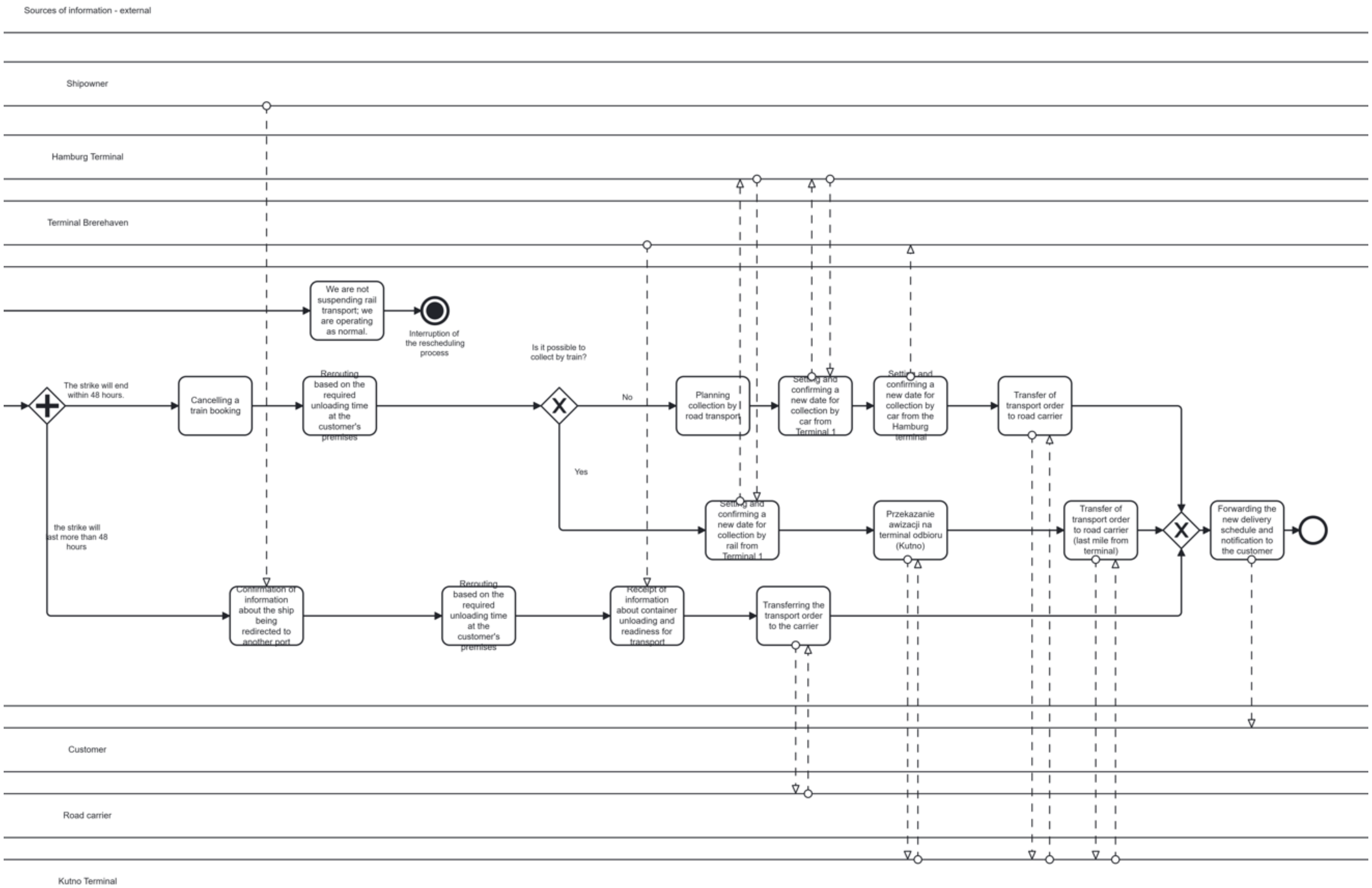

Figure 26 Logistics process disrupted - crisis - strike in port (2/2). Source: Own elaboration

10.3 Logistics process disrupted – crisis with support of SARIL tools

The figure illustrates a disrupted logistics process under crisis conditions enhanced with SARIL tools (Process 10.3). Building upon the disruption scenario presented in Process 10.2, this version integrates advanced digital solutions that support decision-making, improve information flow, and increase the overall resilience of the logistics network.

As in the previous scenario, the process is triggered by the identification of a disruption, such as a port strike. However, in this case, the detection and analysis phase is supported by SARIL tools, such as the Disruption Information Interface (DII), which enables more structured and timely access to relevant information from multiple sources. This improves situational awareness and reduces uncertainty in the early stages of disruption management. During the crisis assessment phase, SARIL tools facilitate a more systematic evaluation of the disruption, supporting the analysis of its causes, expected duration, and potential impact. This enables more informed and faster decision-making, including the communication of reliable delay estimates to the customer.

A key enhancement introduced by SARIL tools is the support for dynamic re-planning of transport operations. For example, tools such as ASTROIT provide decision support in evaluating alternative transport options, including adjustments to unloading times, modal shifts, and rerouting strategies. This allows for the optimisation of logistics flows under disrupted conditions, taking into account multiple criteria such as time, cost, and environmental impact.

The process also benefits from improved data integration and interoperability, reducing reliance on fragmented communication channels and enabling a more coordinated approach among stakeholders. Information regarding container handling, transport orders, and alternative routing is processed more efficiently, supporting seamless interaction between terminals, carriers, and logistics operators. As a result, the reconfiguration of the logistics chain becomes more structured and less reactive compared to the non-supported scenario. Decision points are still present, but they are supported by data-driven insights, reducing ambiguity and enabling more robust selection of alternative solutions.

From the SARIL perspective, this enhanced process demonstrates how digital tools contribute to key resilience factors, including visibility, flexibility, collaboration, and recovery capacity. The integration of real-time data, predictive capabilities, and decision-support functionalities transforms the crisis management process from a reactive and fragmented approach into a proactive and coordinated system. Ultimately, this scenario highlights the transition towards “resilience by design”, where disruptions are not only managed more effectively but are also anticipated and mitigated through advanced analytical and digital capabilities.

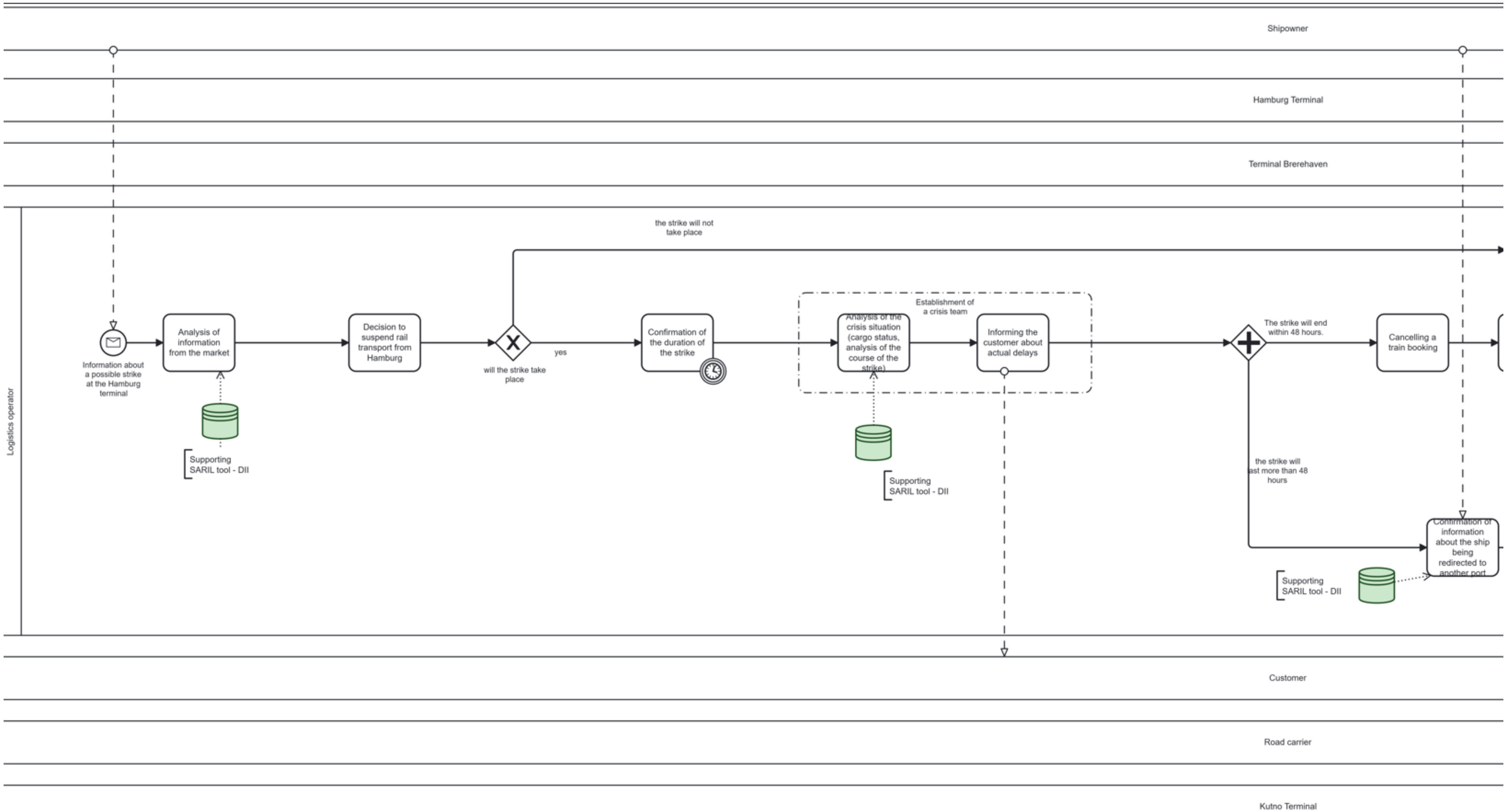

Figure 27: Logistics process disrupted - crisis with support of SARIL tools (1/2). Source: Own elaboration

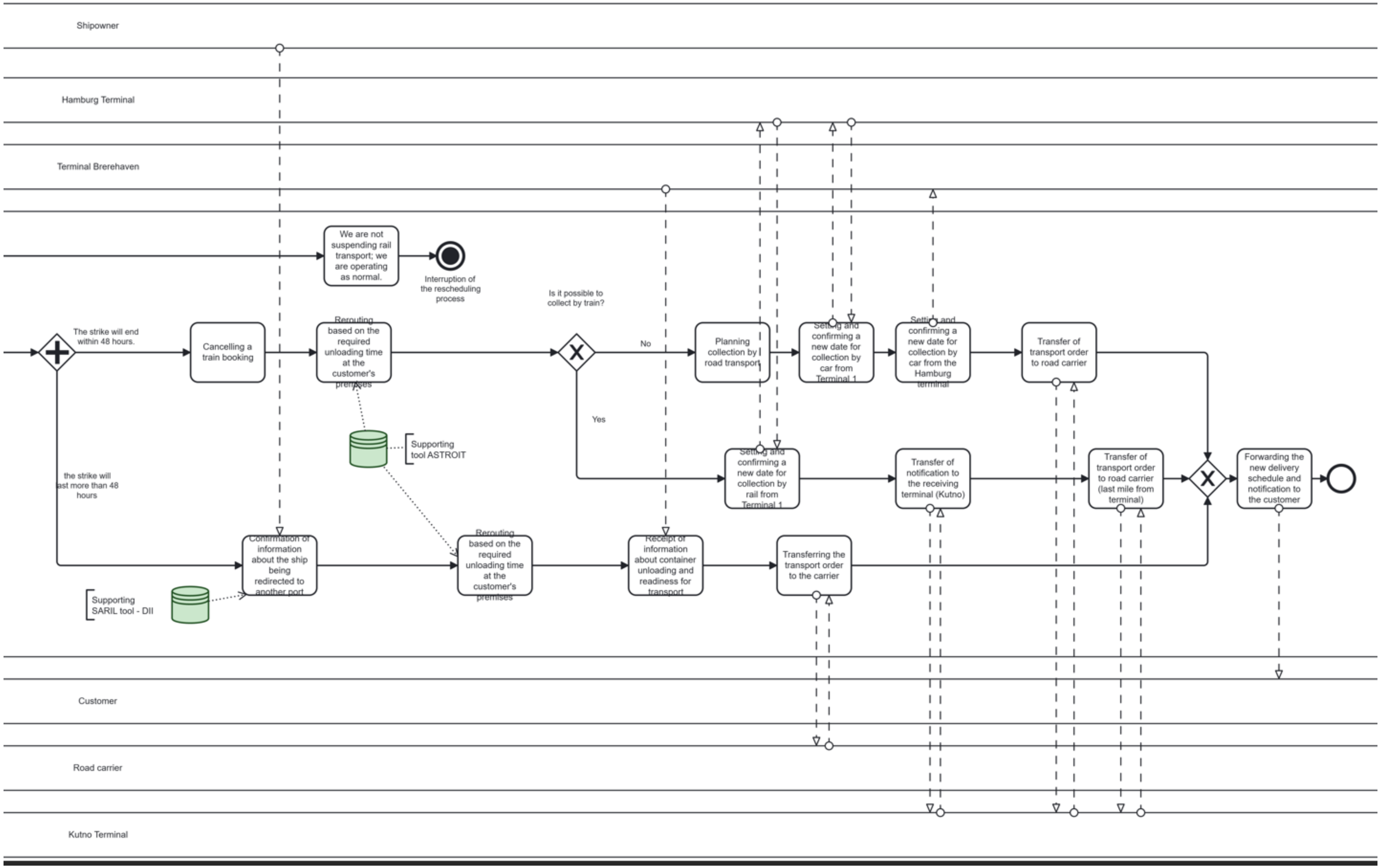

Figure 28 Logistics process disrupted - crisis with support of SARIL tools (2/2). Source: Own elaboration

11 Appendix 3

This appendix presents the detailed service proposals for supplementing the TEN-T with structured maritime freight services, as summarised in Section 6.6. It contains the proposed regional hub ports, the full descriptions and justifications for each backbone "highway" route group, and the proposed spoke (first/last mile) service connections. The conceptual framework and policy rationale are provided in Sections 3.2 and 6.6 above.

11.1 Proposed Regional Hub Ports

Based on existing TEN-T core port status, cargo volumes, hinterland connections, and geographic positioning, the following ports are proposed as maritime freight hubs in a pan-European hub-and-spoke network:

Table 10: Proposed regional hub ports for the pan-European maritime hub-and-spoke network. Source: SARIL analysis based on TEN-T core port data.

Sea Region	Hub Port	TEN-T Status	Strategic Role
North Sea	Rotterdam	Core	Continental gateway; primary hub for Northern Europe distribution
North Sea	Zeebrugge/Antwerp	Core	Complementary Benelux hub; strong RoRo tradition
North Sea	Gothenburg	Core	Scandinavian gateway; Stora Enso RoRo experience
Baltic	Travemünde/Lübeck	Core	Baltic–North Sea connector; Germany's RoRo hub
Baltic	Gdynia/Gdańsk	Core	Eastern Baltic gateway; growing Polish trade
Baltic	Helsinki	Core	Finland gateway; connection to arctic logistics
W. Med	Barcelona	Core	Western Mediterranean hub; Iberian and N. Africa gateway
W. Med	Genoa/Savona	Core	Italian gateway; Rhine-Alpine corridor endpoint
C. Med	Civitavecchia/Naples	Core	Central Italian hub; connects to Tyrrhenian islands
E. Med	Piraeus	Core	Eastern Mediterranean hub; island and Adriatic connector
Adriatic	Trieste/Koper	Core	Adriatic gateway; Central Europe rail connection
Atlantic	Sines/Lisbon	Core	Atlantic Iberian hub; connection to deep-sea
Norway	Bergen area	Comp./EEA	West Norway regional hub (as per Logistics 2030)
Irish Sea	Dublin	Core	Ireland gateway; post-Brexit direct continental links

11.2 Proposed Backbone "Highway" Services

The following new or significantly upgraded regular maritime freight services are proposed as the backbone of the European Maritime Space. These are the "motorways" connecting hub ports at high frequency. Each route group is described below with its corridor, justification and strategic role.

11.2.1 Route Group A: North Sea–Baltic Connector

Corridor: Rotterdam/Zeebrugge – Gothenburg – Travemünde/Lübeck – Gdynia.

This service would create a continuous loop linking the Benelux with Scandinavia and the Eastern Baltic, operating with multiple departures per week in each direction using appropriately sized RoRo vessels. It builds on the existing DFDS/CLdN Zeebrugge–Gothenburg service but extends it into a full loop with Baltic coverage.

Justification: The service connects the three busiest short sea shipping regions (North Sea, Kattegat, Baltic) into one continuous corridor. It parallels the heavily congested E45/E47 road corridors through Denmark and northern Germany, and serves major automotive, forestry and consumer goods flows between Scandinavia, Germany and Poland. It provides an alternative to the bottleneck of road/rail transit across the Fehmarn Belt and Danish straits, and links four TEN-T core ports already handling significant RoRo volumes.

11.2.2 Route Group B: North Sea–Atlantic Connector

Corridor: Rotterdam/Zeebrugge – Dublin – Bilbao/Sines.

This extends the existing Benelux–Ireland services southward along the Atlantic coast to Iberia, creating a bypass of the congested Channel and land routes through France. Post-Brexit, direct Ireland–Continent services have already grown substantially; this formalises and extends them.

Justification: The service creates a direct Atlantic corridor bypassing the congested Channel crossing and French motorway network entirely. Post-Brexit, Dublin requires reliable EU-direct freight links that avoid UK land-bridge transit. Sines is Europe's deepest natural harbour and Portugal's gateway, currently underserved by unitised freight connections northward. Bilbao serves Spain's industrial north (automotive, steel), which currently relies almost entirely on road freight to northern Europe.

11.2.3 Route Group C: Western Mediterranean Loop

Corridor: Barcelona – Genoa – Civitavecchia – Barcelona.

A high-frequency (daily or near-daily) RoRo loop connecting the major Western Mediterranean industrial centres. This would serve the automotive, FMCG, and general cargo flows between Spain, Southern France (via Barcelona hinterland), and Italy that currently use trucks through Southern France.

Justification: The western Mediterranean loop fills the most significant gap in existing services: there is no high-frequency unitised freight circuit connecting Europe's three largest western Mediterranean economies (Spain, France/Italy, central Italy). Existing Grimaldi services run only 3–4 times per week — below the threshold for time-sensitive supply chains. The service provides a sea alternative to the congested A7/E80 coastal motorway corridor along the Riviera. All three ports are intra-EU, so no customs barriers would apply, enabling the fastest possible modal shift. Each port serves a major industrial hinterland (Catalonia, Lombardy/Piedmont, Lazio/central Italy).

11.2.4 Route Group D: Adriatic–Eastern Mediterranean

Corridor: Trieste/Koper – Piraeus – (Limassol).

A regular RoRo service connecting the Adriatic corridor endpoint to Greece and potentially Cyprus, creating the missing eastern Mediterranean freight link. The recent sale of DFDS's Cappadocia Seaways to Salamis Lines for a Greece–Cyprus–Israel route signals market interest.

Justification: The service creates an Adriatic–Eastern Mediterranean spine that currently does not exist for unitised freight. Trieste/Koper are the natural gateway for central European cargo (Austria, southern Germany, Czech Republic, Hungary) heading to the eastern Mediterranean. Piraeus is already a major container transhipment hub but lacks regular RoRo connections northward into the EU. Extension to Limassol would connect Cyprus, which is almost entirely dependent on ad-hoc shipping. The service also provides a geopolitical resilience corridor — an alternative to Suez-dependent routing for EU–Eastern Mediterranean trade.

11.2.5 Route Group E: Cross-Mediterranean Connector

Corridor: Barcelona – Civitavecchia – Piraeus.

This is the critical missing east–west Mediterranean link for unitised freight, potentially serving as a "southern TEN-T corridor" at sea, paralleling the Mediterranean land corridor.

Justification: This would be the only proposed east–west cross-Mediterranean unitised freight link — currently no such service exists. Routing south of Sicily and around the Peloponnese, it would connect three major EU economies across the full width of the Mediterranean. It provides redundancy: if Alpine crossings are disrupted (weather, infrastructure failure), cargo from Spain to Greece/Eastern Mediterranean can bypass land entirely. The service supports EU cohesion by linking peripheral southern economies directly rather than routing everything through northern European hubs. It complements Group C (western Mediterranean loop) and Group D (Adriatic–Eastern Mediterranean) by connecting them.

11.2.6 Route Group F: Norway–Continent Direct

Corridor: Rotterdam – Bergen area – Trondheim – (Bodø/Tromsø).

As proposed in the Logistics 2030 study, direct high-frequency services from the Rotterdam region to Norwegian West Coast destinations, bypassing the current South-East Norway land consolidation. The spoke component would use autonomous/electric vessels (ASKO model) for local distribution.

Justification: Norway's connection to continental Europe is the weakest link in the existing network — current services run only 1–2 times per week to Ghent and are largely limited to the Oslo region. Northern Norway (Trondheim, Bodø) has virtually no direct freight shipping to the continent, forcing all goods onto the fragile E6 road corridor — over 2,000 km of exposed mountain and coastal road. The "Motorways of the Sea 2030" concept specifically identifies the Norwegian coast as the prime candidate for autonomous vessel deployment (Yara Birkeland precedent, ASKO drones). Norway's seafood, energy and aquaculture exports are time-sensitive and high-value — exactly the cargo that benefits most from reliable, frequent maritime service. Climate resilience is a factor: Storm Hans (2023) demonstrated how a single weather event can sever Norway's road links for days.

11.2.7 Route Group G: Baltic–Mediterranean Bypass

Corridor: Gothenburg – Zeebrugge – Sines – Barcelona – Genoa.

A long-distance backbone service providing a complete maritime alternative to the Scandinavian–Mediterranean land corridor, offering resilience when Alpine crossings or Central European routes are disrupted (as SARIL highlights with examples like Storm Hans).

Justification: This "long loop" provides a Baltic-to-Mediterranean bypass that avoids all Alpine road/rail crossings entirely. It offers strategic resilience: if the Brenner, Gotthard or Fréjus corridors are disrupted, cargo can still move between Scandinavia and the Mediterranean. It connects five hub ports across four sea basins in a single scheduled rotation. While operating at lower frequency (1–2 departures per week), it would serve as a consolidation service for less time-critical but high-volume cargo (forestry products, building materials, machinery). It demonstrates the full potential of the hub-and-spoke concept — cargo from any spoke port in Scandinavia can reach any Mediterranean spoke port via two hub transfers.

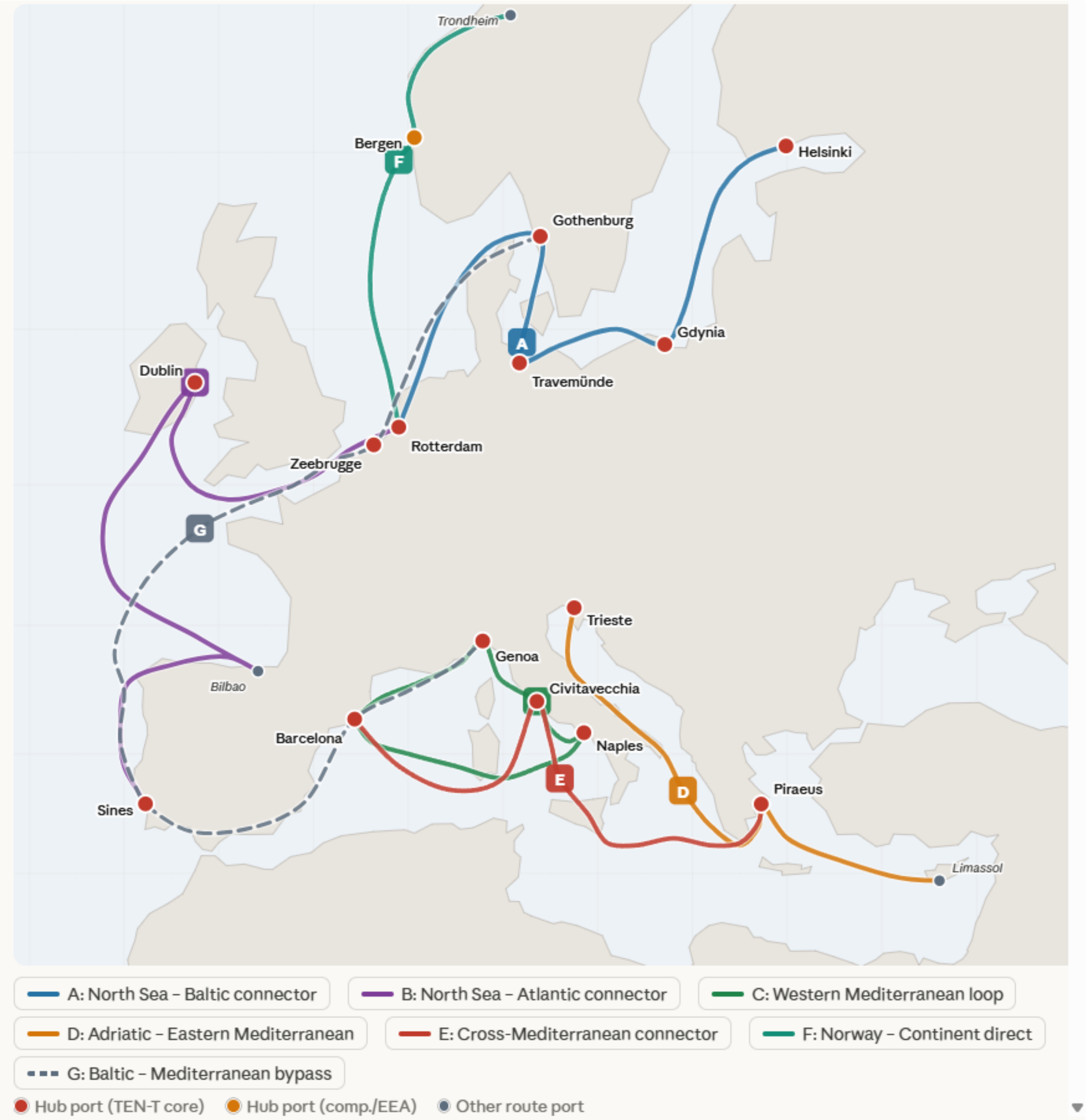

Figure 29: Suggested main TEN-T maritime extensions. Source: SARIL analysis.

11.3 Proposed Spoke Services (First/Last Mile)

From each hub port, spoke services using smaller vessels (potentially autonomous) would connect to the following categories of destinations:

Urban distribution hubs in coastal cities (Bergen city centre, Oslo, Stockholm inner port, Naples, Palermo, etc.), enabling waterborne last-mile delivery with small electric vehicles.

Island connections: Regular freight services to Corsica, Sardinia, Sicily, Greek islands, Balearics, Canaries, and Baltic islands from their respective hubs.

Rural/industrial ports: Connections to smaller comprehensive-network ports serving local industry (fish export ports in Norway, agricultural export ports, etc.).

Inland waterway connections: From coastal hubs to Rhine, Danube, and other inland waterway ports, creating true sea–inland multimodal chains.

These spoke services are designed to extend the reach of the backbone hub-and-spoke network into areas currently underserved by maritime freight, and to provide the fine-grained connectivity that supports both territorial cohesion and resilience at the local level.