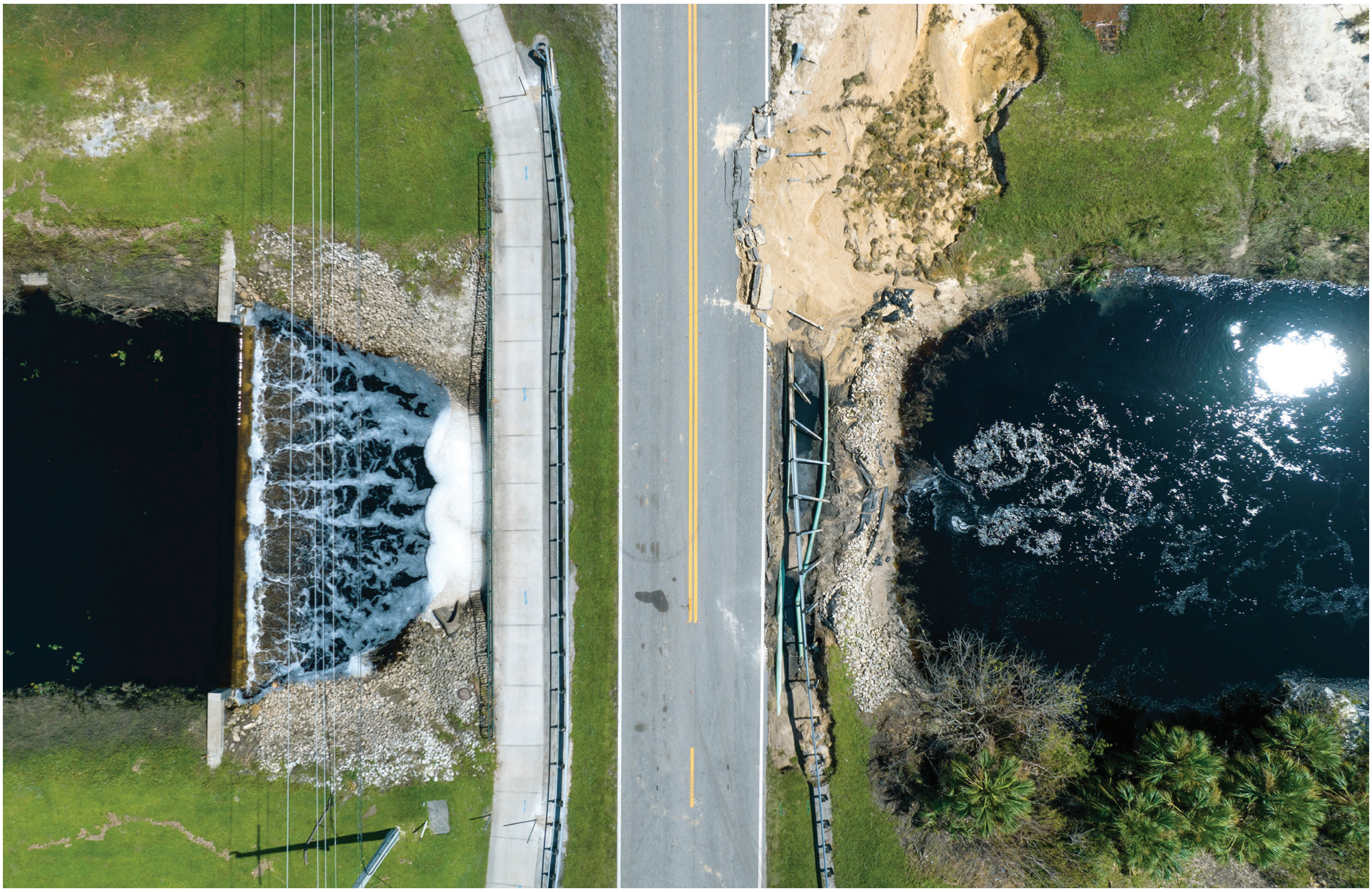

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The International Transport Forum

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ITF Roundtables

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Annex B lists the names and affiliations of the Roundtable participants.

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Key messages

Transport networks are vulnerable

Transport systems face multiple disruptions, from geopolitical tensions and climate change impacts to pandemics. Understanding these disruptions is crucial for strengthening their resilience.

Disruptions have spillover effects

Transport networks are interconnected, and transport disruptions in one part of the world can easily spread to other regions. Managing such spillover effects requires inter-regional co-operation.

Be systematic about resilience

The concept of transport resilience must be built into national-level policies, long-term plans, appraisal procedures, competition policies and transport indicators.

Main findings

The transport sector currently faces simultaneous disruptions related to geopolitics, climate change and energy security. This growing exposure to "poly-crises" is exacerbated by increased interconnections within transport systems. This is also the case for the linkages between the transport sector and other systems: disruptions related to energy, pandemics, cyber-attacks or supply chains can easily cascade to transport systems and across regions.

The severity of disruptions depends on the characteristics of the affected networks. Hub-and-spoke networks are more vulnerable to cascading disruptions than less centralised systems, for instance. In the case of container shipping, regional crises can quickly spill over to other regions: the Red Sea navigation crisis of 2023-24 disrupted shipping not only between Asia and Europe but also between Asia and North America, even though ships on this route do not transit the Red Sea.

Huge uncertainty exists where disruptions might occur in future. Despite progress in risks assessment, few governments currently use existing tools to identify potential risks. These tools include horizon scanning, vulnerability analysis of network characteristics, digital twins, and transport modelling.

Transport system resilience is the sector's capacity to deal with, adapt to and recover from severe and sudden shocks. An important distinction is between a system's robustness and its capacity to recover. Robustness determines the extent to which disruption reduces the functioning of the system. Recovery capacity determines the time needed to return to business as usual. Improving robustness can be considered a form of mitigation, whereas recovery capacity can be obtained through adaptation measures.

Policies to make transport systems more resilient need to define the balance between mitigation and adaptation measures. Which measures make most sense differs per transport system and the characteristics of the different transport networks.

Top recommendations

Incorporate resilience into transport policy and planning systematically

Resilience should be a core objective of transport policy. Resilient transport systems continue to function or recover quickly in case of disruptions, minimising the cost to society and the economy. Inoculating transport systems against breakdowns requires making the notion of resilience an integral part of transport policies, strategic planning, infrastructure appraisal, competition policies, and transport-related indicators.

Develop tools that help reduce uncertainty about future disruptions of transport systems

Analytical tools and indicators can help reduce uncertainty by detecting vulnerabilities in transport systems. Such tools should be employed by policies that aim to increase transport's resilience. The effectiveness of such tools, and the policies they inform, in turn, depends on the coherence and consistency of the information gathered on transport system performance. Policy makers should stimulate the development and deployment of methods such as horizon scanning, risk assessment and prediction of vulnerabilities via analysis of network characteristics, digital twins or transport modelling.

Develop guidance on which resilience measures for transport systems should be applied when and how

Guidance for policy makers on how to prepare for transport system disruptions should focus on best practices on robustness and recovery. One important aspect is the policy trade-off between proactive (mitigation) and reactive (adaptation) policies. Another is estimating costs of disruption, mitigation and adaptation in different circumstances. A third is how to embed concepts such as redundancy and adaptability in transport decision making. All of these help to determine when specific policy measures make most sense.

Improve global co-ordination mechanisms to deal with the impacts of transport system disruptions

Multilateral co-ordination makes national transport policies more effective. Many crises can cascade and have global impacts. Likewise, global transport companies can shift resources and capacities to other world regions. In both cases, national governments are limited in their ability to act alone effectively. Multilateral co-ordination also offers huge opportunities for governments to learn from each other how to deal with disruptions.

The resilience of transport systems

The transport sector currently faces simultaneous disruptions related to geopolitics, climate change and energy security. This report sets out the main disruptions to transport systems worldwide. It explores ways to reduce uncertainty resulting from these disruptions by assessing vulnerabilities, and the main mitigation and adaptation measures required to ensure transport systems function in times of crisis.

Transport systems consist of infrastructure, management, transport users, and the interaction between these three (Jenelius and Mattson, 2021). Technical and physical infrastructure include rails, roads, terminals, airports, ports, vehicles, signals and signs. Transport users can be travellers, companies who want goods to be moved and society in general. Transport managers are the actors responsible for planning, operating and maintaining the infrastructure and services under given regulations and budgets (Jenelius and Mattson, 2021). Policy makers in public administrations do not have full leverage over the transport system, as a considerable part of the transport operations is subject to market forces.

Transport systems exist on different spatial scales, from the local to the global; bring together different transport modes; and serve different functions (e.g. passengers or freight; business travel, commuting, other daily traffic, or tourism) that are often interconnected. Despite these interconnections, it makes sense to distinguish between separate transport systems, including urban transport systems and global freight transport systems.

Transport systems form part of a wider set of systems, for example supply chains and production systems. It is difficult to consider resilience of transport systems without taking account of the resilience of supply chains and production systems that transport is supposed to facilitate. Movements towards more resilience in critical supply chains, including more strategic autonomy of certain regions, will have an impact on transport systems.

Defining resilience

Transport system resilience refers to the system’s capacity to deal with, adapt to and recover from disruptions. In the engineering literature there is a tendency to focus on a system’s capacity to return to equilibrium, whereas the ecological literature has stressed the possibility of moving towards new equilibria (Holling, 1973; McDaniels et al., 2008; Matsson and Jenelius, 2015).

This report takes both approaches into account in discussing policy measures. Whereas the return to the previous equilibrium is possible in the short run, it is less easy to conceive in the medium and long run when disruptions like climate change will have fundamentally changed the conception of functions that can still be provided.

There are two important aspects to the resilience of transport systems:

1. **Robustness**. The robustness of a system determines the extent to which a deterioration of a system’s functions is due to the disruption. The more robust a system, the less the system functions are affected. Another term to describe this aspect is absorptive capacity. Transport systems are more robust or absorptive if they provide additional and alternative capacity (redundancy).

2. **Rapidity of recovery**. This is the time needed for a transport system to get back to the service level or level of operations before the disruption took place (time of recovery). A related concept is the adaptability of the transport system (Rehak et al., 2019).

These two aspects can be graphically expressed (see Figure 1) and are logically connected to two different types of policy tools:

1. **Mitigation measures** increase the robustness of the system. Mitigation is a pro-active tool, meaning measures are taken before the disruption takes place (*ex ante*).
2. **Adaptation measures** increase the rapidity of recovery. Adaptation is a reactive tool, meaning measures are taken after the disruption has taken place (*ex post*). The concepts generally associated with adaptive capacity are flexibility, agility, collaboration and communication.

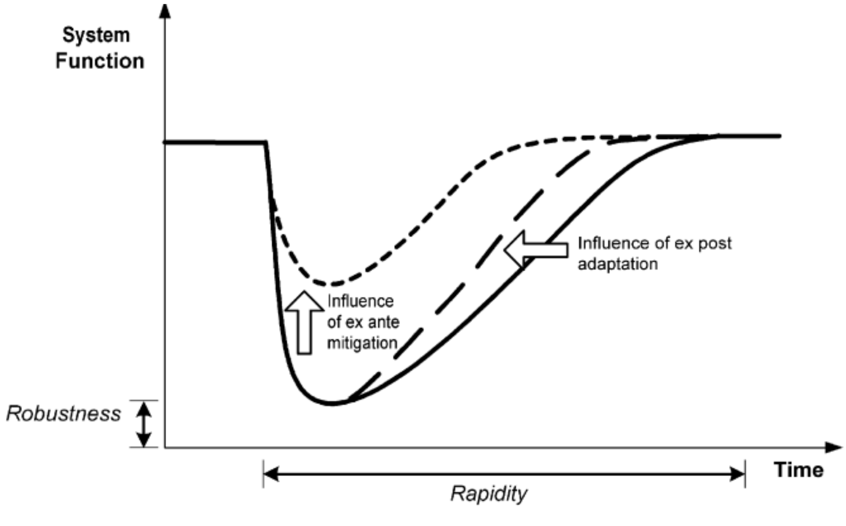
While these two tools can be clearly distinguished conceptually, in practice they can partly overlap. For example, adaptation measures can be prepared for in advance, and therefore also require a certain pro-activity to be effective.

Our description here evidently represents a simplification of reality. In practice, there are complex interactions between measures and their effects in the short-run and long-term. For example, it is possible that adaptation measures can be effective in the immediate aftermath of a disruption but can lead to new disruptions in the long run.

A related concept frequently used in discussions on resilience of transport systems is vulnerability. The vulnerability of a system can be considered the likeliness to suffer aggregate system impacts in case of disruption. The extent of system vulnerability depends on risk (the probability that a disruption will hit the transport system) and exposure (the service function impacts in case of disruption).

This report sets out the main disruptions to transport systems, ways to reduce uncertainty by assessing vulnerabilities, and main mitigation and adaptation measures to ensure transport system functions in case of disruptions.

Figure 1. Transport systems' preparedness for disruption



Source: McDaniels et al. (2008).

Classifying transport system disruptions

This report classifies transport system disruptions according to two types of causes. The first distinction is between internal or external causes:

1. **Internal disruptions** may originate from mistakes and accidents caused by staff or users, technical failures, components that break down, faulty constructions, overload and so on. They could also be intentional, such as labour market conflicts.
2. **External disruptions** may be related to natural phenomena including various degrees of adverse weather and natural disasters.

One specific long-term threat that lies between internal and external causes is climate change, which is partially a consequence of human activities in the transport sector.

The second distinction is between accidental or intentional causes:

1. **Accidental disruptions** strike the system mostly at random.
2. **Intentional disruptions** take place because one or more actors decide to cause the disruption.

Based on these two distinctions, it is possible to distinguish between four different kinds of disruption: internal accidental disruptions, internal intentional disruptions, external accidental disruptions, and external intentional disruptions (see Table 1).

While transport policy makers have considerable leverage over internal causes, this is much less the case for external causes. Intentional disruptions to systems will generally be concentrated where the transport system is most vulnerable, as this will increase the potential impact of the intended disruption. Intentional external disruptions are more difficult to predict with respect to frequency and location, compared to natural disruptions and internal technical and human failures, for which it may be possible to collect statistics.

Table 1. A typology of main disruptions according to their causes

Causes	Accidental	Intentional
Internal	Technical, operational, human failure	Strikes
External	Climate events, pandemics	Geopolitical tensions, terrorism, cyber-attacks

Source: Matsson and Jenelius (2015).

External disruptions to transport systems

This report focuses on external disruptions and describes four specific types of external disruption: climate events, pandemics, war and terrorism, and cyber-attacks. Many of these disruptions are interrelated, which means that disruptions in one system or domain can spill over to another system or domain, increasing the potential impacts of disruptions to interconnected systems.

Climate change

The transport sector already faces a large variety of extreme weather events, and these events will become more frequent and serious if climate change continue. Most of these extreme weather events have been well documented in reports of institutions such as the Intergovernmental Panel on Climate Change (IPCC). The IPCC also provides regular updates on the likely effects of climate change. Table 2 gives an overview of the four types of climate event that will likely be the most relevant for the transport sector: extreme heat, sea level rise, soil humidity and extreme storms.

Despite extensive data and knowledge, a large range of uncertainty persists about the likelihood of certain effects, due to the existence of tipping points beyond which certain ecosystems might collapse and which might have non-linear and unpredictable outcomes. Much will also depend on the extent to which greenhouse gas (GHG) emissions decrease in the coming years. There will also be large differences between world regions. For example, temperature rises in the Mediterranean region are predicted to be considerably higher than global average temperature rises due to climate change. As some regions will likely be more affected than others, adaptation policies will also differ (IPCC, 2023).

Land transport will face many different climate-change impacts. Extreme heat will deteriorate infrastructure such as roads, railways and bridges, but also machinery and equipment. Extreme heat will result in more wildfires that will disable transport access to affected areas. Sea-level rise and the increased risk of inundations will affect roads, rail lines and underground tunnels. In addition, rising sea levels could lead to the erosion of road and bridge supports. Changes in soil humidity due to extreme weather events including droughts or extreme precipitation could lead to landslides and increase the instability of bridges. Extreme storms could also damage roads and railways as well as lighting, power and communications infrastructure that could complicate transportation.

Other transport sectors, such as aviation and maritime transport, suffer from similar challenges, even if some weather events are more challenging than others. For example, seaports are particularly vulnerable to sea-level rise, resulting in higher tide and storm surges that could damage port infrastructure and lead to temporary closures (see Table 2). The thawing of the Arctic waters could offer alternative global maritime trade routes. While potentially economically beneficial, increased traffic through these pristine waters will likely have negative environmental impacts.

Table 2. Main climate impacts according to transport mode

	Land transport	Aviation	Maritime transport
Extreme heat	Deterioration of materials, asphalt rutting, rail buckling, intelligent transport systems (ITS) Thermal expansion of bridges and joints Damage to machinery and engines Wildfire and smoke risk Reduced construction work hours	Longer airport runway requirements	Less inland navigation at low water levels Obstacles to inter-oceanic passages (e.g. drought in the Panama Canal) Thawing of Arctic waters
Sea-level rise	Inundation of roads and rail lines Flooding of underground tunnels Erosion of road and bridge supports	Inundation of runways	Higher tide and storm surges Reduced clearance under bridges
Soil humidity	Subsidence of substrata Structural instability for bridges Increased landslide risk	Subsidence of substrata	Subsidence of substrata
Extreme storms	Damage to roads, railway superstructure, lighting, power, communications Traffic disruption from felled trees Storm debris	Damage to airport superstructure, lighting, power, communications Temporary closure of airports	Damage to port superstructure, lighting, power communications Temporary closures of ports Storm debris Loss of cargo, damages to ships, loss of life at sea, pollution, dangerous goods

Source: ITF (2016).

While the transport sector suffers from climate impacts, it is also a driver of climate change, as a large emitter of carbon dioxide (CO_2) and other GHGs. It is estimated that the transport sector is responsible for around one-quarter of total global GHG emissions, mainly because most of the sector's energy still comes from fossil fuels. In almost half of the world's countries, the transport sector constitutes the largest source of energy-related emissions. Moreover, transport emissions continue to rise in most countries (ITF, 2023b).

Pandemics

A pandemic is a widespread occurrence of an infectious disease over a wide range of countries at the same time. Around 60% of existing human infectious diseases, including Covid-19, are zoonotic – that is, transmitted from animals to humans. Zoonotic viruses cause no symptoms in the host animal, but for humans they can be deadly.

The main factor behind zoonotic diseases is humanity's relationship and interaction with nature. Viruses spill over to people because of the exploitation of the world's fauna, including via hunting and the global trade in wildlife. Human encroachment into other species' natural habitats, for instance through logging, mining cultivation or urban development, has increased contact with wild animals and heightened virus spill-over (Johnson et al., 2020).

As humans continue to invade unexplored wildlife areas, more zoonotic diseases are likely to jump the boundary between species and afflict human populations. At least 75% of the emerging infectious diseases are zoonotic. Of these, almost half are linked to changes in land use, principally for the production of meat, soy and palm oil (Keesing et al., 2010). Unless these practices change, there is a large likelihood that more pandemics will take place in the future.

Transport has often played a central role in the transmission of pandemics. The 1991 cholera epidemic in Peru is believed to have been introduced into three ports through ballast water from Bangladesh. The disease subsequently spread throughout Latin America, killing more than 10 000 people by 1994 (OECD, 2014). The increase in transport speeds and connectivity has spectacularly multiplied the diffusion of pandemics (Merk, 2020).

Another direct impact of pandemics is their impact on transport workers. Many of the people working in the transport sector, such as bus drivers, seafarers and port workers, were directly exposed to Covid-19 and suffered from high infection rates and related health effects. Due to the infectious nature of the virus, many transport users shifted from transport modes with high perceived risk of infection (e.g. public transport) to modes with lower perceived risk (e.g. such as individual cars) (ITF, 2023a).

Policies that reduce, control and regulate transport movements constitute an important way of containing pandemics' potentially huge lethal impacts. This was obvious from government responses during the Covid-19 pandemic. In this context, so-called Covid-19 impacts on transport are in fact the impacts of government responses, such as the closure of borders, lockdowns and quarantines. These responses resulted, in the short term, in very large decreases in transport movements, and related reductions in traffic congestion and transport-related emissions (ITF, 2021).

At the same time, lower passenger volumes made travelling off-peak feel less safe, which had significant impacts on women who continued to work during the pandemic (UN Women, 2020). Many cities addressed the connectivity challenge during the pandemic by promoting active transport modes and micromobility. They invested in pop-up infrastructure, widened footpaths, and partially closed streets to encourage walking and cycling. The local authorities that already had comprehensive active mobility plans in place were able to quickly roll out infrastructure during the pandemic (ITF, 2023).

While the levels of teleworking applied during the Covid-19 pandemic have not continued to the same extent in the post-pandemic world, hybrid working arrangements for office workers have become common in regions with industries and working cultures that could adapt. Fewer trips to the office can reduce environmental pollution and strains on the transport network. However, less commuting can also have inverse effects and lead to more non-work-related travel when more possibilities of teleworking means that more city-dwellers relocate to suburbs, prolonging occasional commutes and potentially increasing car dependence. In many cities, car traffic has returned to pre-pandemic levels and is rising further. The teleworking patterns emerging in the future could be a deciding factor in whether people adopt more car-centric lifestyles (ITF, 2023a).

Geopolitical conflict

Geopolitical tensions have important impacts on transport systems, depending on the intensity of the tension. Highly conflictual situations, such as interstate conflict and asynchronous warfare (e.g. terrorist acts), can lead to destruction of infrastructure and significantly impact mobility and connectivity. Such impacts are most severe in areas that are targeted, but often spill over to other regions and other domains, especially if transport systems are part of global supply chains. This can be illustrated by two recent geopolitical events: the war in Ukraine since 2022 and the crisis surrounding Red Sea navigation that started in November 2023.

The war in Ukraine

The war in Ukraine, which commenced in February 2022, has had huge impacts on the country's transport infrastructure, accessibility and connectivity. It also has wider repercussions for global transport networks, particularly rail transport, aviation and maritime transport.

Prior to February 2022, the main rail freight route between Asia and Europe was the Northern Corridor, or New Eurasia Land Bridge. Its rail link connects China and Europe via Kazakhstan, Russia and Belarus. The dominance of the Northern Corridor reflects the uniform track gauge and harmonised legal regime of the Organization for Co-operation of Railways (OSJD). When the war in Ukraine brought sanctions and uncertainty, transit on the corridor plummeted.

These disruptions persist and further intensify the problems created by fuel price increases, land-transport capacity constraints and port congestion, such as higher transport costs and delays. Moreover, insurance companies have begun to refuse coverage for shipments via the Northern Corridor (ITF, 2022d). As a result, transport via this corridor has come to a halt. Meanwhile, alternative rail corridors have not been able to absorb these freight flows.

Civil aviation activity in Ukraine ceased as soon as the country closed its airspace on 24 February 2022. As most Ukrainian airports have suffered damage, Ukrainian carriers have adapted to the closure of their home market by evacuating aircraft to airports outside Ukraine for lease to other airlines. Russia's airspace is now inaccessible for carriers from 36 countries, necessitating detours for planes that previously passed over its territory. This has led to significant increases in travel times for passengers on approximately 80% of the air routes connecting Asia and Europe. Longer flight times lead to increases in fuel consumption and associated CO_2 emissions.

Even if the war-related airspace closures prove temporary, they could spark long-lasting changes to the industry. Carriers quickly reconfigured their routes and networks in response to the hostilities; government sanctions may well outlast them. For example, Finnair, a hub airline based in Finland's capital that specialised in Europe-Asia flights before the war, shifted its offer towards Western destinations. Similarly, the increase in freight flights between Europe and hubs in the Middle East, at the expense of flights between Europe and Asia, could herald a permanent shift (ITF, 2022b).

The war has also resulted in the partial destruction of Ukraine's seaports, which export massive quantities of grain around the world. It also made navigation in the Black Sea a very risky undertaking. With many African and Asian countries dependent on grain from Ukraine, and limited transport options to get it there, food prices rose.

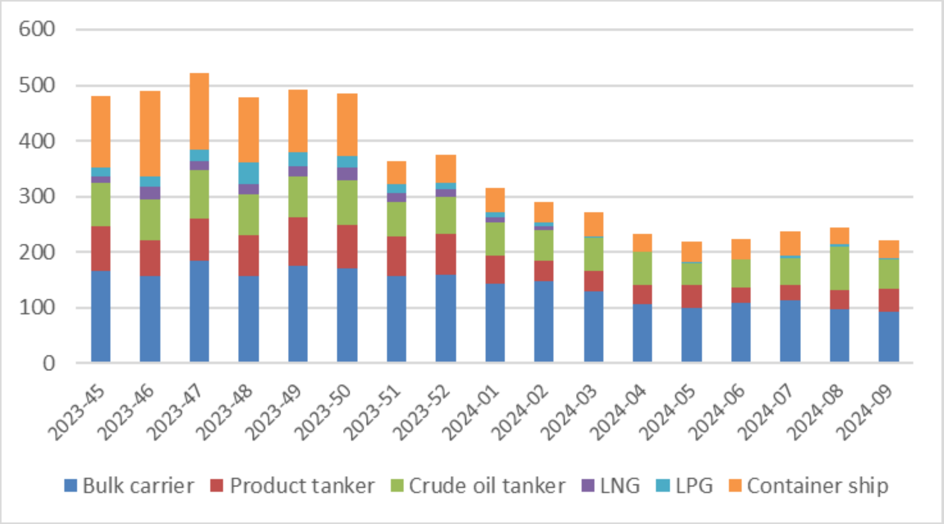
Although grain from Ukraine could potentially be exported via rail to other European ports and then by ship, there are various practical obstacles, including differences in rail gauges between countries. According to some calculations, exporting Ukrainian grain via foreign ports could add transport costs of USD 150 or more per tonne. This is triple the average intercontinental shipping cost. (ITF 2022a).

Navigation in the Red Sea area

Attacks by Houthi militia on ships in the Red Sea area since November 2023 have impacted maritime transport between Asia and Europe (ITF, 2024). In response to the Houthi attacks some shipping companies have instructed vessels to travel to Europe via the Cape of Good Hope route and avoid the Red Sea route.

Between 1 November 2023 and 28 February 2024, the number of transits via the Bab-el-Mandeb Strait dropped by around 55%. For containerships, one of the ship type most affected by the crisis in the Red Sea, there was a 75% decrease in transits over the same period (see Figure 2). The diversion via the Cape of Good Hope adds 8 500 nautical miles to a roundtrip between Asia and Europe; for a typical containership, this means an addition of approximately 10 days to the voyage. This increase in travel time translates into shipping delays, lower ship schedule reliability, more fuel consumption and additional shipping costs.

Figure 2. Number of ships transiting the Bab-el-Mandeb Strait, week 45 2023 to week 9 2024



Source: Lloyd's List.

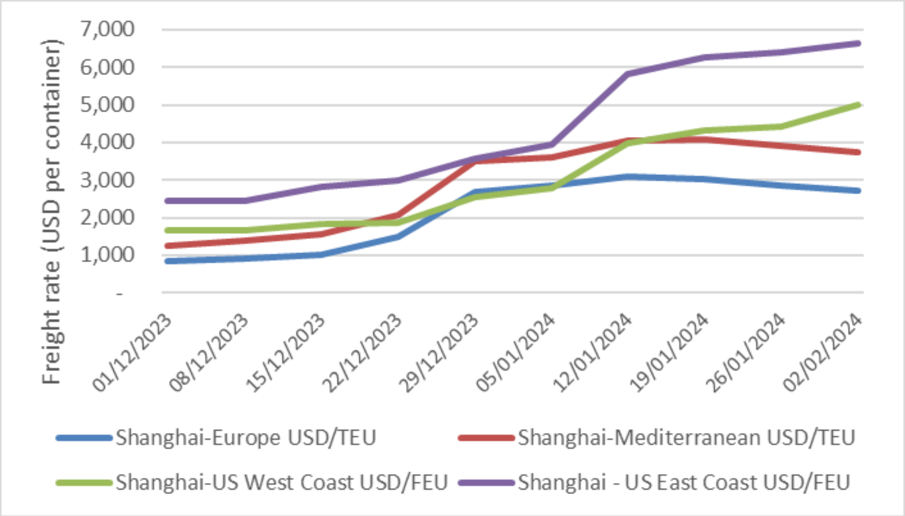
Container shipping companies offer weekly services to their customers. With the shipping distance increased because of re-routing via southern Africa, individual companies require more ship capacity to be able to offer the same level of service (assuming they do not change the speed at which their ships travel). In this situation, shipping companies would need to deploy 15 instead of 12 ships to be able to offer a weekly Far East–Europe service (considering the time it takes for a ship to get back to the point of departure).

The extra capacity needed for the Far East-Europe services appears to be coming from Pacific services (i.e. from Asia to the US west coast). The scheduled capacity for the first quarter of 2024 on Far East-Europe routes was 5% higher than for the first quarter of 2023, while on routes between the Far East and the United States, capacity was 16% lower. This data shows that regional disturbances on one shipping route (Far East-Europe) quickly cascade to other shipping routes, since the main container shipping companies are global operators that can shift their ship capacity from one to another shipping route, depending on the circumstances.

These disruptions are also reflected in developments in shipping rates. The container freight rate for the Far-East Europe route increased by USD 1 872 (representing an increase of 220%) between 1 December 2023 and 2 February 2024, while the rate for the Far East-Mediterranean route increased by USD 2 493 (or 198%) during the same period. As a result, rates for transporting a 20-foot container rose to USD 2 723 for a voyage between the Far East and Europe, and to USD 3 753 for a voyage between the Far East and the Mediterranean, according to the Shanghai Containerised Freight Index.

Rates have also risen substantially on other routes. For example, container transport rates between the Far East and the US West Coast stood at USD 5 005 on 2 February 2024, an increase of USD 3 359 (or 204%) from 1 December 2023. Rates for container transport between the Far East and the US East Coast stood at USD 6 652, an increase of USD 4 206 (or 172%). As Figure 3 shows, the rate increases on these routes have accelerated since mid-January, in comparison with rates for Far East-Europe and Far East-Mediterranean routes, which have slightly declined. This difference could be related to the shift in ship capacity from Far East-US routes to Far East-Europe routes, which created more scarcity on the former and less on the latter.

Figure 3. Container freight rates on selected trade routes



Source: Shanghai Containerised Freight Index.

The situation in the Red Sea has increased costs for shipping companies for both those with ships that continue to use the Red Sea and Suez Canal, and those that sail around the Cape of Good Hope instead. When comparing costs in the current situation with those prior to the disruption in the Red Sea, both scenarios (using the Suez Canal or the Cape of Good Hope route) need to be assessed (ITF, 2024).

This assessment considers various cost components: fuel costs, crew costs, canal fees, insurance costs, maritime security costs and other operating costs. Re-routing ships results in higher fuel costs, crew costs and other operational costs, but saves on Suez Canal tolls. Ships that continue to transit the Red Sea might have higher insurance and maritime security costs. The order of cost increases is set out in Table 3.

Table 3. Shipping cost increases due to Red Sea situation for median size container ship

Cost item	Via Suez Canal (USD)	Via Cape of Good Hope (USD)
Fuel costs		1 million
Charter costs		1 million
Container hire		0.3 million
Canal fees		–0.6 million
Insurance costs	Up to 1 million	
Maritime security	0.03 million	
Total additional costs per ship	**Up to 1 million**	**1.7 million**
Additional costs per 40-foot container	**Up to 160**	**272**

Notes: The data in this table assume a load factor of 80%; therefore, a 12 500 TEU ship would carry 5 000 40-foot equivalent units (FEUs). A total of 80% of the costs of the round trip are assigned to the westbound trip.
Sources: Personal communication with MDS Transmodal for calculation of Cape Good Hope scenario; ITF (2024) for data on Suez Canal scenario.

From these calculations it appears that there is a significant divergence between the costs for shipping companies and freight rates. The cost increases involved in rerouting a median-size container ship around the Cape of Good Hope represent an increase of around USD 300 per 40-ft import container, whereas the container freight rates on the Asia-Europe and Asia-North America routes have increased by around USD 1 800-4 200 per container.

Carriers have also applied a variety of surcharges, such as transit disruption surcharges, peak season surcharges and emergency contingency surcharges, ranging from hundreds to several thousands of dollars per transported container (ITF, 2024).

Crises such as the disruptions to Red Sea navigation or the Covid-19 pandemic frequently result in rate increases for transport services that are unaligned to the actual cost increases, risking escalation of disruption and inflation. This could be problematic. As the Group of Seven (G7) Transport Ministers have declared, it is important to increase transparency for transport users and to understand the drivers of increases in rates and surcharges related to disruptions (G7, 2024).

Cyber-attacks

The increased digitalisation of transport systems has increased the risk that cyber-attacks will create catastrophic disruptions. Digitalisation contributes to the efficiency of transport systems because it can facilitate smooth interfaces and procedures between different stakeholders. It can take the form of data exchange and processes in which information systems are linked. However, digital systems can be hacked by private individuals and organisations as a means of extortion, or by states as part of their efforts to destabilise their enemies. Considering their strategic importance, transport infrastructure or systems are evident targets for cyber-attacks (ITF, 2018).

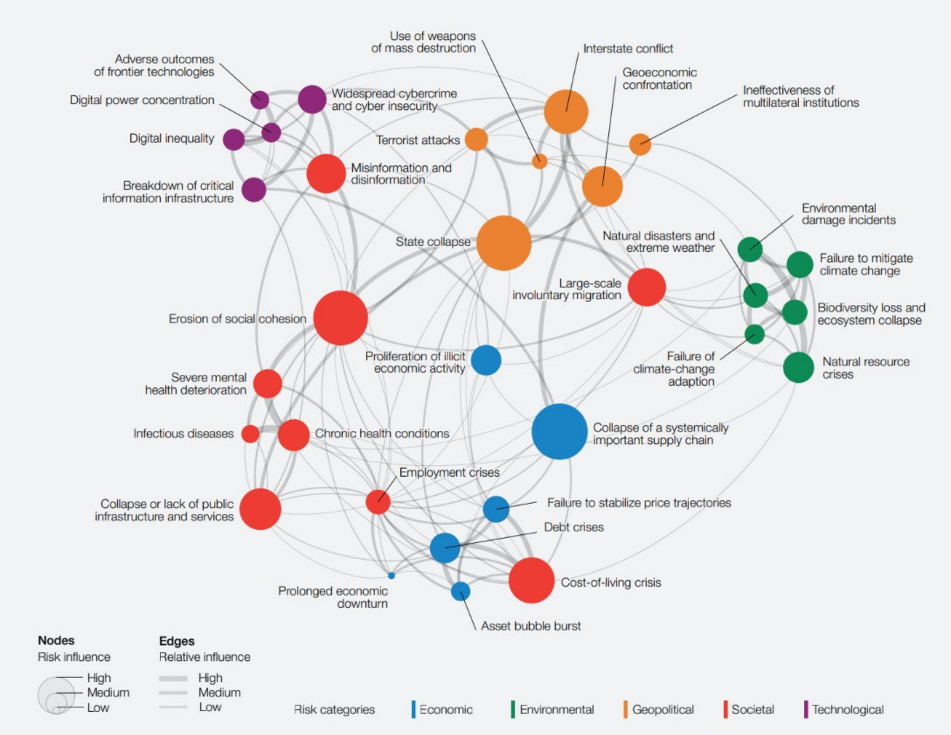
The impacts of cyber-attacks can be particularly significant when transport systems are highly integrated on a global scale, because it means that hacking a local information and communications technology (ICT) system can have enormous cascading effects. To take one example, the NotPetya cyber-attack was aimed at various Ukrainian targets, including a Ukrainian port terminal that was part of the global network of Maersk, one of the world’s largest shipping companies. The attack crippled the ICT network of the

Ukrainian terminal as well as the entire Maersk network consisting of more than 50 port terminals around the world and all ICT systems at Maersk headquarters. This failure of the whole computer network lasted for ten days, paralysed Maersk's shipping business and resulted in economic damage in the order of several billion dollars (Greenberg, 2019).

Interconnections and cascading effects

Transport systems contain many different parts and stakeholders that are interconnected. Transport systems themselves form part of a larger whole of interconnected systems related to food, energy, water and other commodities as well as industrial, financial and information systems (see Figure 4).

Figure 4. The interconnectedness of systems



Source: WEF (2023).

The increased interconnectedness between non-transport and transport systems means that shocks in the former can easily cascade to the latter. Furthermore, many of these systems are global, and while increased interconnectedness at a global scale has increased efficiency, it has also hugely increased the risks of disruptions, especially due to cascading effects.

Cascading effects are local disruptions spilling over to other places with the potential to generate global crises. Cascading is determined by the level of interconnectedness. Research on cascading effects between interconnected networks shows that, beyond a certain point, interconnections could lead to catastrophic cascading effects. Interconnections between networks can divert loads, with diverted load absorbed by the neighbouring network rather than amplified and returned, but only up to a critical point. Introducing too many interconnections after the critical point is detrimental, as this will let diverted load more easily return and with catastrophic effect (Brummitt et al., 2012).

The crucial question for different transport systems is whether it is possible to determine this critical tipping point beyond which more connectedness results in catastrophic cascading prevalence. There are various transport systems in which the level of interconnections seems to have set in motion cascading effects that have transformed local crises into global crises, as was the case in the containerised transport chain in 2020-21 (ITF, 2022).

Predicting transport system vulnerabilities

Policy makers seeking to increase the resilience of transport systems need to be able to assess current and future vulnerabilities. Such an assessment could be considered a “stress-test” of transport systems and could also help make policy actions more focused. Assessments of vulnerabilities can consist of different indicators: for example, on the performance of existing transport systems, recovery times in cases of disruption, and on the exposure of transport systems to disruptions. Exposure to disruptions can, in turn, be expressed by mapping network characteristics and modelling transport systems.

Measuring transport system performance

The resilience of a transport system cannot be discussed without establishing the baseline performance of the system in question. Baseline performance here refers to the performance of the system that would need to be maintained (via robustness of systems) or to be recovered in case of disruptions. So, improving the resilience of transport systems pre-supposes a sound set of transport system performance indicators (see e.g. ITF 2023c). However, in practice this is not the case, for a variety of reasons. These include a lack of available and transparent data, data bias in favour of certain stakeholders and a lack of policy relevance.

Transport system performance indicators are not neutral, as every stakeholder in the transport system has a set of indicators that he will find most important. For example, transport users will generally want the highest service quality for the lowest price, whereas transport managers care more about the return on their investments, so would prefer high asset utilisation and high tariffs and prices to recover their costs.

Selecting transport system indicators also raises the fundamental question what kind of performance the system tries to achieve, so it is linked to a wider discussion on which societal objectives governments want to promote. A transport system could be assessed by its function to support economic development and growth objectives, or essential needs of its population, or other objectives. As such, the choice of performance indicators might reflect choices on societal objectives, e.g. with respect to planetary boundaries. The use of performance indicators is based on assumptions that often remain implicit.

There is also a difference between infrastructure managers who want to make transport companies pay for the use of their infrastructure, and transport companies who will generally try to offload this to the taxpayer. Much also depends on the specific transport system. Delays or schedule reliability records, which are common in cargo transport, would be completely unacceptable in passenger transport. Some cargo (e.g. food that has an expiry date) is highly time sensitive. Time-related indicators are therefore considered more important in this context than for less time-sensitive cargo.

This means that governments need to have an adequate and balanced set of indicators on the performance of transport systems. These indicators should also be collected regularly, publicly available and be policy-relevant: in other words, designed in such a way that that it could be considered a benchmark for policy makers. An indicator’s positive development over time would then express something meaningful for the transport system, which is not always the case, as the example of maritime connectivity indicators shows.

The case of maritime connectivity indicators

Connectivity is widely considered one of the main strategic objectives of transport policy. The possibility to be connected rapidly and smoothly to as many places as possible has emerged as a priority for policy makers and has translated into strong interest in what connectivity means, how it could be increased, and how it could be measured.

Various studies have sought to capture the most important requirements for shippers when it comes to maritime transport services. Although much depends on the type of goods that are shipped, as well as distances and shipment size, there is some consensus on the priorities of shippers: low prices, reliable service and direct connectivity (ITF, 2022a).

If prices remain the same, shippers will always prefer a direct connection over cargo transport that includes one or more transshipments. The reason is that this reduces the risk that cargo gets delayed because of congestion or interconnection problems at the transshipment port, where cargo is transferred from one ship to another ship. Direct calls in many cases also lead to shorter transport times.

Despite the relevance of direct liner connectivity to shippers, no existing maritime indicator measures this connectivity. At best, direct connectivity forms part of a composite indicator that does not show direct connectivity scores. For example, the Liner Shipping Connectivity Index (LSCI) developed and disseminated by the United Nations Conference on Trade and Development amalgamates six different components (UNCTAD, n.d.):

1. the number of scheduled ship calls per week in the country
2. deployed annual capacity offered at the country in twenty-foot-equivalent units (TEU)
3. the number of regular liner shipping services from and to the country
4. the number of liner shipping companies that provide services from and to the country
5. the size of the largest ship (TEU capacity) deployed on services from and to the country
6. the number of countries connected to the country via direct liner shipping services.

Only one of these components – namely, the number of countries connected to the country via direct liner shipping services – refers to what could be considered a measure of direct liner connectivity. As the LSCI provides equal weight to each indicator, it only covers direct connectivity to a very limited extent. The ITF (2019) previously found that LSCI increases over time were mainly driven by one component: the spectacular increase in container ship size. Hoffmann and Hoffmann (2021) confirmed this finding.

To resolve these drawbacks – and those described in a more extensive critique of existing maritime connectivity indexes (Merk and Teodoro, forthcoming) – this report proposes an alternative indicator: the Maritime Trade Connectivity Indicator (MTCI). In essence, this indicator measures the maritime connectivity of a country as the share of its international trade volume (transported by ship) carried on direct liner connections with its trade partners. This generates a single value per country with a scale from 0 to 1 (0% to 100%), that is easy to compare over time and between countries. 1

The MTCI covers international containerised trade and therefore excludes intra-regional trade by sea. This specific coverage enables a focus on trade volumes that are most likely to be moved exclusively or predominantly via sea. For example, if intra-regional trade was included, the connectivity indicator would be subject to value changes related to modal shifts rather than changes in connectivity. Annex A outlines the methodology and data sources for the indicator.

According to the MTCI, in 2023 the Bahamas was the country with the highest maritime trade connectivity (see Table 4). In that year, it realised a score of 0.96, which means that 96% of the international trade volumes (transported by ship) from the Bahamas arrived at their destination via a direct liner connection (i.e. without transshipment). Other countries with very high MTCI scores in 2023 were the United States, Singapore, China, Germany, South Korea, Solomon Islands, the United Kingdom, Panama and the Dominican Republic.

The countries with the worst maritime trade connectivity – as defined by the MTCI – are those countries for which none (0%) of their international trade volumes (transported by ship) arrived at their destination via a direct liner connection. In 2023, this was the case for 29 countries, some of which are small island states with very small trade volumes. But the group also includes larger countries, such as Bulgaria, Cambodia, Finland, Georgia, Norway, Tunisia and Ukraine.

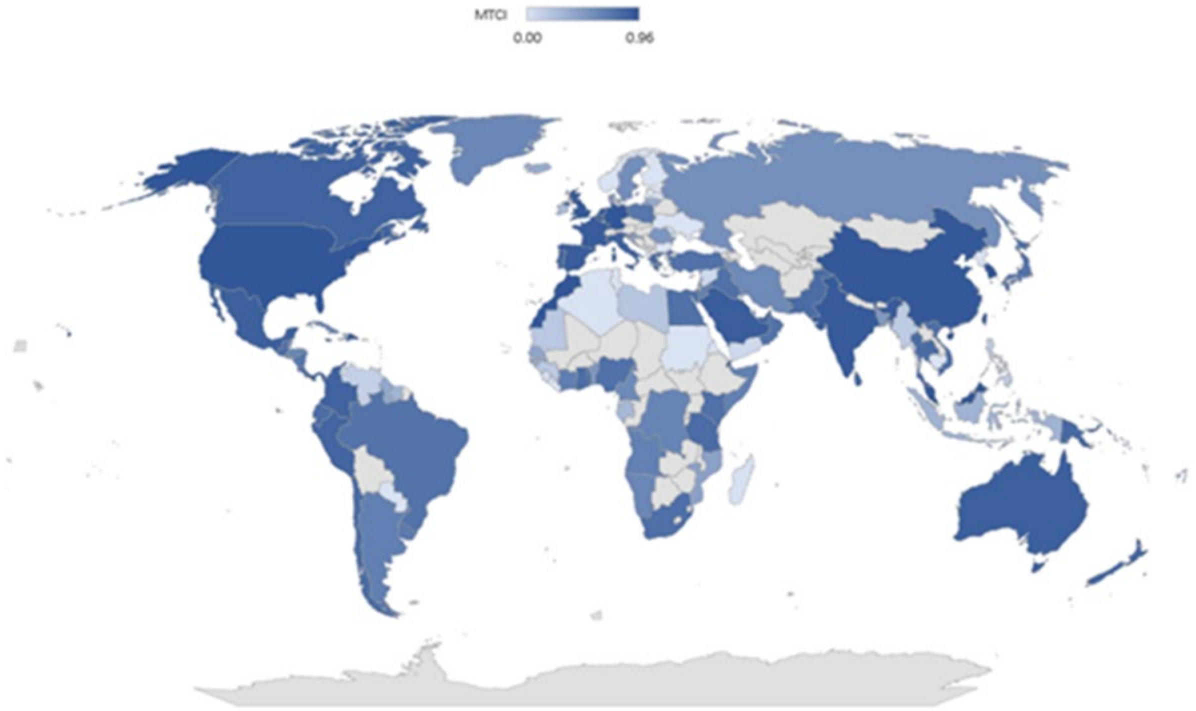
Note that the maritime trade connectivity indicator covers international trade: that is, trade between different world regions. Most of the countries with a zero-score on the MTCI have direct connections with main trade partners, but these are intra-regional and are therefore not considered in the MTCI. Figure 5 provides a graphic overview of the maritime trade connectivity scores of all countries.

Table 4. Countries with the highest maritime trade connectivity scores, 2023

Country	Maritime trade connectivity score
Bahamas	0.96
United States	0.94
Singapore	0.94
China	0.93
Germany	0.93
South Korea	0.93
Solomon Islands	0.91
United Kingdom	0.90
Panama	0.90
Dominican Republic	0.90

Note: For Maritime Trade Connectivity Indicator methodology and data sources see Annex A.

Figure 5. Maritime trade connectivity by country, Quarter 4 2023



Note: For the Maritime Trade Connectivity Indicator methodology and data sources see Annex A.

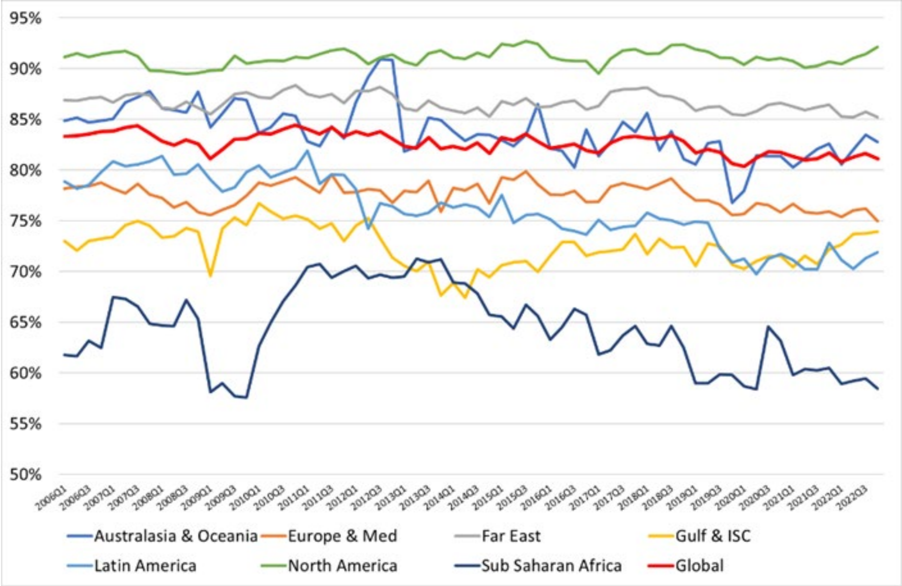
The database used to calculate the MTCI contains data from 2006 onwards, making it possible to compare how country scores have developed over time. Whereas in 2006 a total of 25 countries had a MTCI score of 0.90 or higher, this was the case for 17 countries in 2023, so the number of countries with very high maritime trade connectivity has declined since 2006, which suggests that the exporters in most countries have less access to direct maritime connections.

The country with the highest maritime trade connectivity indicator in 2006 was Belgium with a score of 0.98, followed by Italy (0.97), the United Kingdom (0.97), Spain (0.97), Germany (0.97), Costa Rica (0.96) and Jamaica (0.95). It is interesting to note how the top-ranked countries in 2006 were all European, which was much less the case in 2022. Not only did European countries show a relative decline (in terms of ranking) but they also witnessed an absolute decline (in terms of indicator values).

North America is the world region consisting of the countries with the highest MTCI score in 2023. It realised a score of 0.92, which means that 92% of the international trade volumes (transported by ship) of North American countries arrived at their destination via a direct liner connection (i.e. without transshipment). Other world regions with relatively high maritime trade connectivity scores in 2022 were Asia and Australasia.

The world region with the lowest maritime trade connectivity scores in 2022 was Sub-Saharan Africa (see Figure 6). The connectivity scores of North America and Asia were generally stable with only very minor changes from quarter to quarter. Sub-Saharan Africa is also the world region whose countries display the largest swings in maritime connectivity. Several world regions have witnessed a decline in maritime trade connectivity over the last decades. This is particularly the case for Latin America (-6 percentage points) and Sub-Saharan Africa (-4), and to a lesser extent for Europe and Mediterranean (-2). This matters, considering that connectivity is widely considered one of the main strategic objectives of transport policy.

Figure 6. Maritime Trade Connectivity scores by world region, 2006-2022, per quarter



Note: For the Maritime Trade Connectivity Indicator methodology and data sources see Annex A.

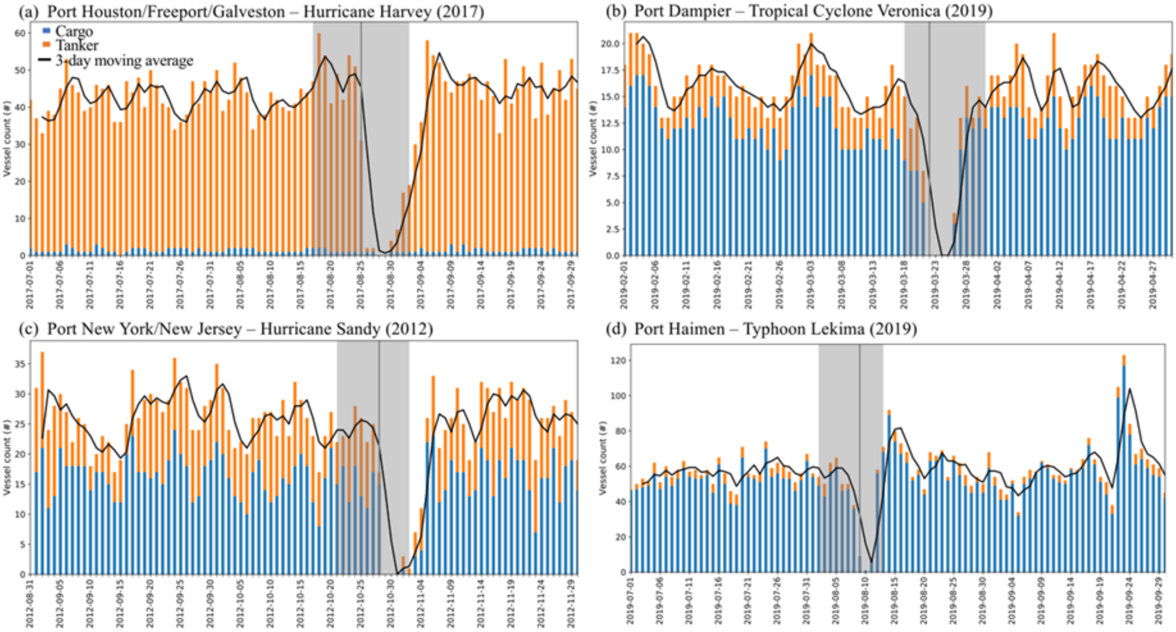
Measuring recovery time

The resilience of transport systems has been defined as the capacity to recover from disruptions. Therefore, an assessment of the resilience of transport systems could focus on this capacity. One way to measure this aspect of resilience could be to calculate the time it takes for an individual system to recover to its original level of transport services or operations. For example, an assessment of the vessel count in ports affected by hurricanes, typhoons and cyclones shows that recovery time in case of these disruptions is between one and three weeks (see Figure 7), depending on specific circumstances.

A related approach could be to calculate the costs required to achieve this recovery in services or operations. However, it should be noted that quite often full recovery is not actually realised. This seems to have been the case for US ports affected by supply chain disruptions during the Covid-19 pandemic. Average ship waiting times for ships waiting to enter these ports have not yet returned to pre-Covid levels but instead seem to have stabilised on a structurally higher level (so higher average waiting times for ships than before Covid-19).

Calculations of recovery times can also be carried out for disruptions that have already taken place. Such calculations can provide evidence of the extent to which specific transport systems have shown resilience, and therefore provide policy makers with an indication of which interventions helped and under which circumstances. However, these measurements are also limited, as they can only take place after disruptions have occurred. The following sections highlight approaches that could help to assess vulnerabilities before such disruptions take place.

Figure 7. Vessel traffic disruptions in ports affected by hurricanes, typhoons and cyclones



Note: Overview of port disruptions for four ports and events: (a) Port of Houston/Freeport/Galveston (United States) during Hurricane Harvey; (b) Port Dampier (Australia) during Tropical Cyclone Veronica; (c) Port New York/New Jersey (United States) during Hurricane Sandy; and (d) Port Shanghai (China) during Typhoon Lekima. The grey shading represents the formation and dissipation of the event, while the grey vertical line indicates the date on which the weather event made landfall.

Source: Verschuur, Koks and Hall (2020).

Mapping network characteristics

The process of mapping transport network characteristics is based on network theory. This academic discipline has classified networks and investigated how different types of networks react to disruptions. Network theory can help transport policy makers assess the extent to which actual transport systems resemble such schematised network types, and the implications for the vulnerability of these networks to disruptions.

Four main network types appear to be relevant for transport: 1) highly connected networks, 2) centrally connected networks, 3) circuit-like networks and 4) randomly connected networks. These four main network types are based on a classification of 17 network types that Zhang et al. (2015) identified as relevant to transport systems (see Table 5).

Various studies have shown that many existing transport systems resemble one or more of these network types. For example, in a general sense, many arterial roadway networks have a grid or ring shape; networks of towns often resemble small-world networks; and air systems and container shipping networks are commonly shaped as hub-and-spoke networks. In a specific sense, scale-free type characteristics exist in urban transit networks in Beijing (Wu et al. 2004) and the Boston subway system has a small-world network structure (Latora and Marchiori, 2002).

Research shows that highly connected networks, often found in urban street systems of larger cities, score highest on resilience. In contrast, centrally connected networks, such as aviation and container shipping networks, are the least resilient, but relatively most responsive to adaptation. Randomly connected networks, such as those found in urban transit networks and intercity roadways, are also not very resilient, but their structure provides some redundancy that compensates for this. Circuit-like connections are not the most resilient types of networks, but still relatively resilient (Zhang et al. 2015).

Such findings should not be used as evidence that certain transport systems (e.g. aviation networks) are destined to be less resilient, but rather to ensure that policy makers take these considerations into account when developing transport policies. For example, policy makers could, when designing and expanding transit systems, add new services to create loops. By doing so, they would convert a crossing path network to a central ring network, thereby creating a more resilient overall structure and providing riders with more transfer opportunities (Zhang et al. 2015).

Table 5. Transport networks and their preparedness for disruption

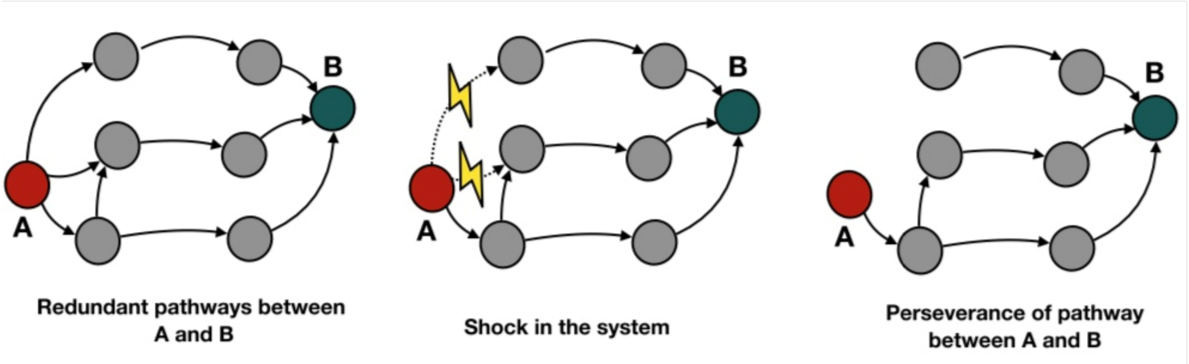
Type of network	Examples	Transport system	Extent of preparedness
Highly connected	Grid, matching pairs, complete grid, diamond	Urban street systems of larger cities	Highest preparedness
Centrally connected	Hub and spoke, double tree, diverging tails, crossing paths	Aviation networks Container shipping	Least prepared, but most responsive to adaptation
Circuit-like connections	Central ring, double U, converging tails	Underground transit Urban roadway system	Relatively prepared
Randomly connected	Random, scale-free, small world	Urban transit networks Intercity roadways	Less prepared, but provides some redundancy

Source: Zhang et al. (2015).

In line with the network-mapping approach, one could assess the characteristics of transport networks that could help to accelerate recovery in case of disruptions. For example, networks have higher rebound potential if they have in-built redundancy and modularity. These properties shield networks from huge impacts when transport links are broken (Kharazzi et al. 2020).

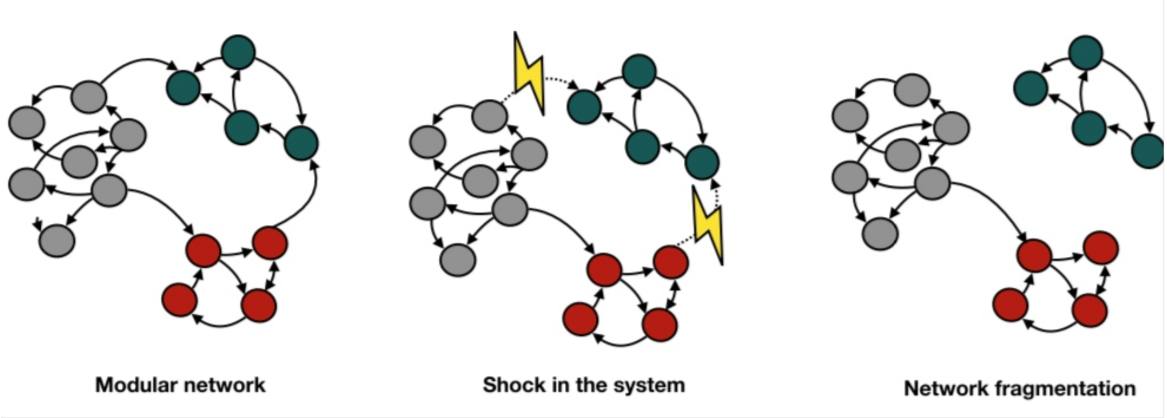
Redundancy refers to the replication of pathways, functions or components that provide transport systems with more alternatives to adapt to shocks. In case of disruptions, redundancy makes it possible for a transport system to continue its functions without failure (see Figure 8).

Figure 8. Schematic representation of a shock on a network with a lot of redundancy



Source: Kharrazi et al. (2020).

Figure 9. Schematic representation of impacts of a shock on a modular network



Source: Kharrazi et al. (2020).

Modularity is the property of a system whose components can be separated or integrated without any change within their properties or within those of the rest of the system. It is designed to measure the strength of the division of a network into modules. Systems with high modularity are better able to contain stress within a module without damaging other components (see Figure 9). For example, firebreaks in forest land management may break the spread of fire (Kharazzi et al., 2020).

Statistical indicators have been developed to operationalise these concepts and calculate values that could be compared over time and across sectors. In this way, policy makers could better understand the extent to which transport network preparedness develops over time.

Modelling transport systems

The second approach to assessing the vulnerabilities of transport systems is to model the potential impacts of disruptions on these systems. Such models could, for example, estimate the recovery time of any potential disruption that would incapacitate any combination of links and nodes, considering possible adaptations (e.g. route diversions, mode shifts or fluctuations in transport prices).

Certain models, such as general equilibrium models, could also model dynamic economic effects that would impact transport systems, such as firm location decisions in response to disruptions in transport systems. The crucial assumption here is that models react in a way that corresponds to reality.

Modelling of transport systems can be done on the micro level – for example at the level of infrastructure assets, such as bridges, terminals and ports (Neugebauer et al., 2024). Creating a digital model (digital twin) of the asset that is fed with information from sensors and other information could help to assess vulnerabilities in a timely way and report them to infrastructure managers for action. This type of process is already applied on bridges in Italy (ITF, 2021).

A digital twin has also been generated for container port terminals in Singapore that can be helpful in suggesting alternative combinations of quay and terminal equipment in case of disruptions such as a partial shutdown due to power loss (Zhou et al., 2021). Similar methods have been used to simulate the impacts of earthquakes, floodings and terrorist attacks. For example, researchers have simulated the effects of a bomb in the port, on hinterland access points or chemical storage areas in the port of Świnoujście, Poland (Nair et al., 2010).

Modelling of transport systems can also be carried out on the macro level. The ITF non-urban freight transport model assesses and provides scenario projections for freight flows around the globe. It is a network model that assigns freight flows of all major transport modes to specific routes, modes, and network links. Centroids, connected by network links, represent zones (countries or their administrative units) where goods are consumed or produced.

The most recent version of the ITF freight transport model integrates the (previously distinct) surface and international freight models. International and domestic freight flows are calibrated on data on national freight transport activity (in tonne-kilometres) as reported by ITF member countries. Reported data is also used to validate the route assignment of freight flows.

Trade projections in value terms stem from the OECD trade model and are converted into cargo weight (tonnes). These weight movements are then assigned to an intermodal freight network that develops over time in line with scenario settings. These define infrastructure availability, available services and related costs.

The current version of the model estimates freight transport activity for 19 commodities based on trade projections from the ENV-Linkages trade model produced by the OECD for all major transport modes, including sea, road, rail, air and inland waterways. The underlying network contains more than 8 000 centroids, where goods are consumed and produced. Several attributes describe each of the network's more than 150 000 links. These include length, capacity, travel time (including border crossing times), and travel costs per tonne-kilometre (ITF, 2023b).

Another approach to assessing the resilience of transport systems involves determining the factors relevant to system resilience in the different phases (including preparedness, adaptation during the disruption and recovery) and assessing – based on expert judgement – the extent to which an existing system scores well on these factors (Rehak et al., 2019).

Policy measures for resilient transport systems

Policy makers have a range of options available to them which can help increase transport system resilience. There are two main categories of policy measures to increase the resilience of transport systems to disruptions: mitigation and adaptation measures. This section describes the main goals and means of implementing these measures and concludes with a discussion of the relationship and possible trade-offs between mitigation and adaptation.

Mitigation measures

Mitigation measures focus on increasing the robustness of transport systems, so that disruptions are less likely and have less significant impacts. Mitigation measures are pro-active: they are conducted before disruptions take place. This report distinguishes between three types of measures (see Table 2):

1. **Avoid.** Measures to avoid disruptions reduce the probability that the disruption takes place.
2. **Coping capacity**. Measures to increase the capacity of the system to disruptions when they take place so that the system functions are minimally impacted.
3. **Redundancy**. Alternative capacity in case disruptions take place.

Table 6. A classification of main mitigation measures

Type of measure	What does it aim to do?	Examples of measures
Avoid	Mitigate disruptions (e.g. climate change) Avoid settlement in high-risk areas Produce networks that reduce the risk of cascading	Climate-change mitigation policies Land-use planning, relocation policies Strategic planning (hubs and minor hubs)
Coping capacity	Increase resistance of infrastructure to disruptions Protect critical infrastructure	Infrastructure investment (e.g. in drainage, permeable road surfaces, earthquake-proof construction, and increased pumping capacity in tunnels) Investment in elevated roads, runways, dikes, seawalls and bridges Prioritising maintenance of “critical networks”
Redundancy	Add links to create more alternative routes Provide buffers for crucial inputs (including electricity, workers and equipment)	Infrastructure investment planning Prioritising redundancy budgets for infrastructure managers

Measures to avoid disruptions

A key element in policies to avoid disruptions is to assess vulnerabilities of transport systems, along the lines that were indicated in the previous chapter. Several countries have invested in capacity to assess risks and vulnerabilities. For example, France has started a project to map vulnerabilities in its transport system, consisting of case studies of vulnerabilities in supply chains in cereals and chemicals, and on the vulnerability of the multi-modal transport systems in two selected areas in France.

Certain disruptions could be mitigated, particularly those caused by human behaviour. The prime example is climate change, which is primarily caused by human activity and could be mitigated by changing behaviour, and by phasing out activities or technologies that generate GHG emissions.

Transport policy makers have greater leverage over GHG emissions produced by the transport sector itself, and many countries are engaged in creating and implementing policies to decarbonise their transport sectors. This can take the form of strategies to avoid unnecessary transport, shift to cleaner transport modes, and improve the energy efficiency while reducing the carbon intensity of transport vehicles. The main mechanisms used to achieve these policies are standards, regulations and incentives, such as carbon pricing and subsidies for the development and roll-out of clean technologies.

However, the effectiveness of transport decarbonisation policies is dependent on policies in other domains. For example, energy policies determine the availability of renewable and clean energy sources. Transport decarbonisation is also embedded in broader climate policies that can vary in ambition and effectiveness.

Regardless of the policies governments put in place to avoid disruptions, such disruptions will always occur. Therefore, policy makers could ensure that these policies minimise the exposure risks of people and transport infrastructure assets. Similarly, even if governments implement ambitious climate change policies, emission trajectories are already locked in. This means that many catastrophic climate events will take place in the coming years.

In this context, policy makers could increase the disruption-preparedness of transport systems by avoiding human settlement – and the transport infrastructure that comes with it – in high-risk areas. Most coastal areas, river deltas and low-lying areas are likely to be flooded. Therefore, spatial planning of settlements will need to account for this disruption to reduce the risk that transport systems are exposed to catastrophic failure. Mechanisms that could help here include changes in land-use planning, and relocation policies, to make sure that no new settlements will be constructed in flood-prone areas. For example, county governments in the US state of Virginia buy houses and land when it comes for sale in areas where they do not want continued development (e.g. on flood plains).

To limit the possibilities of cascading effects that can turn small and local disruptions into large and catastrophic disruptions, policy makers could also reconsider the design of transport networks. A drive for ever greater efficiency has resulted in centralised network structures (e.g. hub-and-spoke networks) that are less prepared for disruptions because of the risk of cascading effects.

Policy makers could introduce more redundancy in transport networks, for example by introducing secondary or tertiary hubs that could take over functions in the case of the failure of main hubs. The disruption-preparedness of the design of transport networks could be integrated into infrastructure investment appraisal processes.

Measures to increase coping capacity

Transport systems can better cope with disruptions by improving the resistance of transport network infrastructure. Improvements can take various forms, depending on the specific challenges. For example, to better cope with the risks of flooding, transport infrastructures could be provided with better drainage facilities and permeable road surfaces. Tunnels could be made more resistant by improving their pumping capacity.

Governments could also prioritise investments in ecological urbanism and adaptive “soft” infrastructure measures. Examples of soft infrastructure measures include permeable surfaces and bioswales; preservation of natural water bodies, wetlands, natural reefs and mangroves in coastal areas (which act as barriers against storm surge), afforestation, and more ground drainage through wetlands and greenspace to ameliorate flash flooding. Various countries, such as South Korea, have removed elevated highways to preserve neglected waterways, or restored canals that were previously converted to motorways.

Another type of coping-capacity measure aims to better protect critical infrastructure. To limit the possible impacts of rising sea levels and extreme flooding, several countries have elevated roads, runways, dikes, seawalls and bridges. Many countries have also defined what they consider their critical infrastructure that needs to be protected and prioritised. Infrastructure maintenance policies are updated to reflect these priorities, with more frequent maintenance and repairs for critical infrastructure, to avoid system failure when disruptions occur (OECD, 2021).

Measures to create redundancy

Increasing redundancy in transport systems will generally increase their preparedness for disruptions. This could be done by adding links and nodes to create more alternative transport options that could be of great use in case of disruptions. This would require that infrastructure investment planning takes account of specific network vulnerabilities and guides investment decisions with the aim of increasing networks’ preparedness for disruptions.

Transport systems deliver their outcomes by a combination of “inputs”, such as workers, equipment, energy and often electricity. Disruptions can often have catastrophic effects when there is a lasting shortage of any of these production factors. Transport systems are better prepared for disruptions if strategic buffers are created (e.g. electricity storage) that could be used in case of disruptions.

Adaptation measures

Adaptation measures focus on the rapidity of the recovery when a disruption takes place. These are reactive measures. This report distinguishes between two types of adaptation measures (see Table 7):

1. **Response measures**. These are measures to deal with the immediate impacts of the disruption. This is a necessary step before recovery can take place.
2. **Recovery measures**. These are measures put in place to restore system functions.

Table 7. A classification of main adaptation measures

Type of measure	What does it focus on?	Examples of measures
Response	Planning, institutional and legal frameworks Training Optimising existing infrastructure	Contingency plans and timetables User communication plans Information systems for rescue workers Legal and contractual frameworks Support tools on which responses to prioritise Lane reversal and shoulder use (on roads)
Recovery	Clearing obstacles New transport equilibria New societal equilibria (e.g. teleworking, inventories, sourcing)	Plans and resources for clearing debris and conducting urgent repairs Relocation of roads, railways, runways and ports Policies on framework conditions (e.g. labour, trade facilitation, foreign direct investment)

Measures to improve response capacity

Plans and frameworks can increase the capacity to respond adequately in the case of disruptions. With better preparation, responsible actors will be more likely to be able to respond effectively. Policy makers could ensure that transport managers and operators have developed contingency plans and timetables, user communication plans and information systems for rescue services. This, in turn, will help ensure that procedures exist which can be followed to facilitate an adequate response.

Such contingency plans need to be specific for as many different situations as possible, as required measures might need to vary by scenario. For example, cities that introduced mandatory masking, physical distancing and frequent disinfection (among other measures) during the early phase of the Covid-19 pandemic helped manage the fear of infection among public transit passengers and performed best in terms of continuity of ridership (McKinsey and Company, 2021). Nevertheless, it will be impossible to foresee every disruption in advance, so organisations will always to a certain extent need to improvise and adapt to the situation at hand. In order for this to work, it needs to be clear which organisations have which roles and responsibilities in case of disruptions (PIARC, 2019). In other words, increased resilience of transport systems also requires adaptations in governance.

Legal and contractual frameworks could be designed that make disaster responses as smooth as possible. It is essential that transport staff receive relevant training to be able to respond to disruptions. Part of that training should involve developing decision support tools for transport staff that can help them to prioritise the appropriate actions to take in case of disruptions. In Japan, an important element in the policy approach is to enhance disaster awareness and skills, at the one hand by stimulating transport disaster management evaluation among board members of enterprises, on the other hand by training local authorities so that they can cope with disasters.

Governments have also deployed tools to make sure that workers at critical facilities or services will continue to perform their tasks. One specific strategy used by governments is to designate specific groups of workers as “essential” to improve the capabilities of transport nodes (including ports and airports) to respond to disruptions or abrupt changes in demand.

During the Covid-19 pandemic, for example, many transport workers were required to continue working despite the health dangers. Improving the safety of riders and essential transport workers was crucial for the survival of cities during the pandemic. Specific initiatives included off-board fare collection and back-door boarding, barriers, spacing, enhanced cleaning, personal protective equipment for staff, and mask mandates (UITP, 2020; 2021).

To help essential workers get to their workplaces, some transport authorities and operators also redeployed radial services and other lesser-used routes to suburb-based services (ITF, 2023a). In the maritime sector, crises such as pandemics could require facilitation of transport of seafarers to, and repatriation from, their vessels and appropriate access to shore leave, urgent medical care and welfare facilities.

Response capacity could be improved by optimising the infrastructure that continues to exist after a major disruption. For example, mechanisms such as lane reversal or shoulder use could help to maximise the use of roads, even in cases of disruption. Such emergency measures can be quickly implemented if procedures have been prepared and drilled in advance.

Measures to speed up recovery

The clearing of obstacles is one of the key measures for restoring transport system functions. This can take the form of clearing debris and urgent repairs of failing parts of infrastructure. This clearance of obstacles can be accelerated by preparation in advance via planning mechanisms and reservation and repositioning of resources for emergencies.

Recovery can also take the form of the emergence of new transport equilibria. This means that disruptions could lead to situations where decision makers decide against restoring a transport system to the state it was in before the disruption, choosing instead to “build back better” – that is, to recover along a pathway that makes more sense considering changed circumstances.

For example, when extreme weather events destroy infrastructure (e.g. roads, railways, bridges, ports and airports) that are highly exposed to these risks, governments could decide to recover transport system functions by locating such infrastructure assets in areas that are less exposed to climate risks. Such a policy response would reduce the likelihood of future disruptions and make the transport system better prepared for disruptions. It may be necessary to align regulations to support such policies.

Recovery measures could also take account of new societal equilibria. The increased acceptance of teleworking following Covid-19 has decreased the number of commuting trips but also increased commuting distances. The changed sourcing decisions of businesses following geopolitical tensions, such as the war in Ukraine and the related economic sanctions imposed on Russia, have changed international transport flows.

The vulnerability of supply chains to disruptions such as Covid-19 and related phenomena, such as port closures, fluctuations in shipping capacity and freight rates, have cast doubt on the sustainability of just-in-time business models and increased interest in inventory buffers. All of these tendencies might lead to new societal and economic equilibria that require different transport system characteristics. Any future policy package to recover from disruptions would need to take these new equilibria into account.

Whereas recovery measures provide the opportunity to "build back better" and use the adaptation to the disruption as an opportunity to be better prepared for future shocks, there is also the risk of maladaptation. As adaptation policies are based on imperfect information and designed under great uncertainty, they frequently fail and can actually worsen the situation; this is called maladaptation. In the case of maladaptation to climate change, this results in increasing rather than limiting the vulnerability to climate change. Poor planning is often the primary cause of maladaptation, but identifying maladaptation in advance is difficult (Schipper, 2020).

Policy trade-offs between mitigation and adaptation

There is a strong inter-relationship between mitigation and adaptation measures. Mitigation reduces the need for adaptation, as it decreases the likelihood of and exposure to disruptions. However, mitigation could also be more expensive than adaptation in certain circumstances. Transport policy makers face two important questions in this context: in which circumstances is mitigation more expensive? And when does mitigation or adaptation make most sense?

The exact form of the trade-off between mitigation and adaptation differs per transport sector and the design of the networks in those different sectors. For example, centrally connected (i.e. hub-and-spoke) networks are less robust, but most reactive to response actions. Therefore, in sectors where such network structures are common (including aviation and container shipping), disaster preparedness is most critical – unless policies can be implemented to better prepare such networks for disruption, for example by stimulating smaller ports and airports. To take a different example, certain mitigation measures (e.g. infrastructure relocation) could be too expensive until the disruption has already occurred, as in cases when infrastructure in a coastal area is flooded.

If transport policy makers are to make efficient decisions about the right mix of mitigation and adaptation measures, they need more insights into the costs of disruption and the costs of mitigation and adaptation options in case of a disruption. Such insights might differ according to local circumstances and the type of disruption. A tool to guide decision making in a variety of situations could help policy makers in finding the right balance between mitigation and adaptation measures.

International co-operation could focus on defining good policy practices for robustness and recovery and clarifying which measures have worked under which conditions. As part of this co-operation, policy makers could define a tool for incorporating disruption-related costs (i.e. the costs of disruption, mitigation and adaptation) into transport investment decision-making processes. An example of a tool that quantifies the costs of sudden shocks is the cost of disruption framework developed by the UK Department of Transport to quantify impacts of a disruption (Marshall-Clarke and Stewart, 2023).

Strategic planning

Resilient transport systems can only be realised if they become a priority in long-term strategic planning. This requires a clear articulation of strategic choices, for example with respect to the trade-offs between resilience and efficiency, and between mitigation and adaptation, and in relation to equity issues. Such a strategic vision should translate into identification of transport projects that contribute to increasing the resilience of transport systems.

Critical steps in this respect could include better framing of project proposals in light of broader policy objectives, identification of alternatives consistent with these broader framings, and improvements in the way projects are reviewed against broader policy objectives in the initial needs-case assessment. Adopting a strategic planning framework can improve outcomes by offering a co-ordinated and consistent approach to infrastructure investment (ITF, 2022c).

Transport appraisal processes

The need for infrastructure investment is assessed in appraisal processes, using techniques such as cost–benefit analysis (CBA). These traditional appraisal processes and techniques have changed significantly in recent decades, by incorporating analysis of wider economic benefits. For example, some investments in improved transport infrastructure can enable external benefits which improve the productivity of increased urban agglomeration. Indirect valuation techniques have also progressively broadened the scope of CBA to capture more impacts that are harder to express in monetary values.

Despite these changes, significant modification of appraisal practice might be required to ensure that resilience considerations are appropriately addressed. Although CBA can be well-equipped to address non-traditional goals, such as resilience, in practice resilience is either not included in CBA or resilience is under-valued because resilience aspects are not fully quantified or monetised.

The need for resilient transport policies has increased calls for changes to the way transport investments are reviewed and selected. Achieving this change requires enhancements to CBA and the use of complementary appraisal methods. Supplementary analyses, alongside CBA results, can greatly enhance the information available to decision makers, even where state-of-the-art CBA practice is applied. These could include risk assessments, vulnerability analysis and transport modelling to provide information on the resilience impacts of transport infrastructure projects (ITF, 2022c).

Institutional arrangements

Several countries have established specific bodies to co-ordinate efforts on the resilience of transport systems or supply chain resilience. For example, Transport Canada established a National Supply Chain Office in December 2023, to increase efficiency and resiliency across supply chains, including mitigating impacts from disruptions, by developing a National Supply Chain Strategy, supporting data sharing and fostering collaboration (Government of Canada, 2023).

In the United States, a Council on Supply Chain Resilience was inaugurated in November 2023 that will advance the long-term, government-wide strategy to build enduring supply chain resilience (The White House, 2023). The US Department of Transportation (DoT) has launched its Office of Multimodal Freight Infrastructure and Policy, responsible for maintaining and improving the condition and performance of the nation’s multimodal freight network via the development of the National Multimodal Freight Network and review of State Freight Plans (US DoT, n.d.).

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Annex A. Maritime Trade Connectivity Indicator methodology and dataset

The Maritime Trade Connectivity Indicator (MTCI) measures maritime connectivity of a country as the share of its international trade volume (transported by ship) carried on direct liner connections with its trade partners. This generates a single value per country that is easy to understand, with a scale from 0 to 1 (0% to 100%), and straightforward to compare over time and with other countries.

The MTCI covers international containerised trade and therefore excludes intra-regional trade by sea. This specific coverage enables a focus on trade volumes that are most likely to be moved exclusively or predominantly via sea. For example, if intra-regional trade was included, the connectivity indicator would be subject to value changes related to modal shifts rather than changes in connectivity.

The indicator is applied to seven world regions: Australasia and Oceania; Europe and the Mediterranean; the Far East; the Gulf and Indian Subcontinent; Latin America; North America; and Sub-Saharan Africa. Indicators are calculated quarterly, to allow for precise monitoring of developments over time.

Calculating the MTCI involves the following five steps:

1. Establishing if a direct container shipping connection has been offered in the relevant quarter for each possible country pair. If this is not the case for a specific country pair, it receives a score of zero. If direct connections have been offered for a country pair, the following information is identified: the name of the service, its TEU capacity and its frequency. This makes it possible to calculate the total TEU capacity offered per quarter for that country pair.
2. For the same country pair, the number of TEUs that are exported from country A to B are identified, along with the number of TEUs imported from country B to country A in that quarter. These two numbers are added to calculate the bilateral container trade volume.
3. The ratio of the TEU capacity offered for that country pair (see Step 1) is calculated, along with the bilateral container trade volume (see Step 2). This ratio represents the share of country A's international trade volume with country B (transported by ship) carried on direct liner connections. In the case that these ratios exceed 1.00 (i.e. when more direct ship capacity is available than there is demand for that capacity) a value of 1.00 will be assigned, to indicate that 100% of the bilateral trade volume was carried on direct liner connections. This can be considered the **bilateral maritime trade connectivity score** between country A and country B.
4. The country score is calculated by aggregating all the bilateral maritime trade connectivity scores for that country. When the ratios from the country-to-country level to the country level are aggregated, the country-to-country ratios are multiplied by the share of the international container trade volumes that each country pair represents. In other words, the **MTCI for a country** represents the aggregation of the weighted bilateral MTCIs relevant to that country.

5. A similar process of aggregation is applied to arrive at **MTCIs at the regional and global level**. Country scores are weighted according to their shares of total international container trade volumes.

The MTCI is calculated using two different data sources: the MDS Transmodal World Cargo Database (WCD) and the MDS Transmodal Containership Databank.

The WCD is used to calculate bilateral containerised trade volume (see Step 2 in the five-step approach described above). It contains containerised cargo volumes from 1996 to the present for around 250 countries and territories.

The WCD is generated by gathering quarterly trade data (in tonnes) from the major economies of the world, covering 95% of unitised world trade. These include the 28 individual European Union member countries, Argentina, Australia, Brazil, Canada, Chile, China, Chinese Taipei, Hong Kong, India, Indonesia, Japan, Mexico, Norway, the Philippines, Russia, South Africa, South Korea, Switzerland, Turkey, Thailand and the United States,

For trade between other countries, trade data from the United Nations is used, which boosts the global coverage of unitised world trade to 99.9%. Using various lookup tables based on commodity, volume and the origin and destination countries, the WCD tonnage data is translated into unitised tonnes and then into loaded TEU, carried by container ships.

The MDS Transmodal Containership Databank is used to assess the capacity scheduled to be offered for any given country (see Step 1 in the five-step approach described above). It contains operational details of the world container carrying fleet and 30 fields of information for every vessel, including operator, service, route, TEU, service frequency, port rotation and much more.

The MDS Transmodal Containership Databank, which in its current format has been produced since 2006, is mainly used by MDS Transmodal for its consultancy services and by UNCTAD to produce (in collaboration with MDS Transmodal) the Liner Shipping Connectivity Index (LSCI) and by the World Bank to produce the Logistics Performance Index (LPI).

Annex B. List of Roundtable participants

Elise MILLER-HOOKS (Chair), George Mason University, United States

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International
Transport Forum

Transport System Resilience

The transport sector currently faces a number of disruptions related to geopolitics, climate change and energy security. Transport system resilience refers to the sector's capacity to deal with, adapt to and recover from such disruptions. This report sets out the main disruptions to transport systems worldwide. It explores ways to reduce uncertainty by assessing vulnerabilities, and the main mitigation and adaptation measures required to ensure transport systems function in times of crisis.

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