Policy paper

Transport Network Resilience

Transport networks constitute the backbone of modern economies, ensuring the efficient, sustainable, secure and safe movement of people and goods. However, increasing disruptions from extreme weather, geopolitical tensions, pandemics and other hazards highlight the need to bolster the resilience of transport networks.

This paper summarises ITF's position on transport resilience – based on its 2024 report – and sets out the priority areas in which it aims to advance together with authorities.

Key takeaways

- Transport networks are essential for economic growth, trade and labour markets. They support key societal functions, such as defence, education and health care. However, increasingly frequent disruptions such as extreme weather events, geopolitical tensions and pandemics have exposed the vulnerabilities of transport networks, resulting in shocks with costs to society in the billions of US dollars.
- These vulnerabilities highlight the need for policy makers to focus on the resilience of transport networks, in other words, to increase the capability of all relevant stakeholders – both public and private – to prevent, respond and adapt to disruptions.
- Policy makers can improve the resilience of transport networks via three strategies: better analytical tools, more strategic policy design and co-ordinated policy development. It is in these areas that the ITF intends to provide practical guidance for policy makers.
- This paper provides insights to foster fruitful dialogue between ITF member countries and transport stakeholders – including via the ITF Summit and the ITF Transport Resilience Working Group.

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Boxes

Relevance of transport network resilience

Transport networks constitute the backbone of modern economies, ensuring the efficient, sustainable, secure and safe movement of people and goods. However, increasing disruptions from extreme weather, geopolitical tensions, pandemics and other hazards highlight the need to bolster the resilience of transport networks (see Box 1 for a formal definition of resilience). This paper summarises ITF's position on transport resilience – based on its 2024 report – and sets out the priority areas in which it aims to advance together with authorities.

Box 1. Defining resilience in the context of transport networks

The resilience of transport networks is hereby defined as the capability of transport networks to prevent, respond, and adapt to disruptions:

- **Prevention** refers to actions that ensure that disruptions do not happen or only have a minimal impact on transport networks. In other words, prevention reduces the vulnerability of the network and absorbs the effects of disruptive events. Prevention is closely related to robustness. The more robust a network, the less the network functions are affected by shocks. Robust transport networks provide redundancy in the form of additional and alternative capacity that can be used in case of disruptions and thus ensure a certain level of operation regardless of disruption. Such alternative capacity makes it possible to cope with disruptions when they occur.
- **Response** refers to the rapidity at which a network can recover and provide sufficient service levels. Response takes place after a disruption occurs and impacts the network.
- **Adaptation** refers to restoring or regenerating the network in a way that it can better deal with the disruptive events.

Resilient transport networks safeguard from a range of disruptions (see Box 2). The frequency, intensity and unpredictability of these disruptions to transport networks are likely to increase, making resilience increasingly important. For example, current rare extreme sea level events (with a one in hundred years occurrence) are projected to occur at least annually in more than half of all tide gauge locations by 2100.[1] Hence, resilience is now one of the main policy objectives within transport and mobility, interlinked with other policy goals, such as connectivity, efficiency, sustainability and accessibility.

Resilience can help to guarantee essential transport network functions, such as reliability and predictability, that are essential to global supply chains, economic growth and national welfare. However, improving the resilience of transport networks is highly ambitious considering the complexity, uncertainty and interconnectedness of the unprecedented disruptions facing transport networks.

[1] IPCC (2023), Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34

Box 2. Categories and causes of disruptions to transport networks

A wide variety of disruptions impact transport networks. One can distinguish between internal and external disruptions to transport systems, and between accidental and intentional causes of disruptions:

- **Internal disruptions** – which originate from within transport systems – can stem from mistakes and accidents caused by staff or users, technical failures, components that break down, faulty constructions, overload, etc. They could also be intentional, such as labour market conflicts.
- **External disruptions** may be related to natural phenomena (including extreme weather events and natural hazards), geopolitical tensions, terrorism, and pandemics.
- **Accidental disruptions** strike the system mostly at random, whereas **intentional disruptions** take place because one or more actors decide to cause the disruption, such as with geopolitical conflicts or cyber-attacks.

Transport policy makers have considerable leverage over internal causes, much less so for external causes. Intentional disruptions to transport systems generally target the system's most vulnerable components, as doing so can increase the impact of the disruption.

A further distinction can be made between **short-term** disruptions (such as sudden shocks and acute hazards) and more **long-term** disruptions (such as a rise in temperatures or sea levels). Resilience covers both types of disruption. But these time horizons remain somewhat uncertain, for example, because we do not know how fast climate change is happening and exactly what effects it will have.

Transport resilience is one of the ITF's priorities and the guiding theme of the upcoming annual Summits in 2025, 2026 and 2027. The ITF has also established a Working Group on Resilience of Transport Networks to Critical Events. Via these mechanisms, the ITF will try to advance the policy discussions related to transport resilience, in particular with regards to practical guidance for policy makers.

This guidance covers three areas set out below in this paper: analytical tools, policy design and policy implementation.

Analytical tools

Policy makers operate in a context of deep uncertainty, especially when it comes to long-term perspectives. Policy makers' ability to design more resilient transport networks could be improved if at least part of the uncertainty could be reduced. To achieve such a reduction in uncertainty, they can leverage more and better data and apply analytical tools, particularly in three areas: the impacts of disruptions, vulnerabilities of transport networks, and interdependencies.

The **impacts of disruptions** of transport networks can be economic, social or environmental, and are severe for society as a whole. Transport often constitutes the most vulnerable part of the supply chain. In the short term, disrupted transport networks can have immediate effects on users, workers and operators, and long-term effects in terms of supply chains, economy and ecosystems (Box 3). Users need transport services to go to work, school, family, and hospitals. Important societal functions, such as defence, education, and healthcare, can therefore be paralysed without well-functioning transport networks. These impacts can have huge implications. For example, a massive disruption in transport networks occurred when the NotPetya cyber-attack targeted various Ukrainian installations, 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, along with all ICT systems at Maersk headquarters. This failure of the entire computer network lasted for ten days, paralysed Maersk's shipping business and resulted in economic damage in the order of several billion dollars[2].

Box 3. Assessing impacts from disruptions to transport networks

Assessing the impacts from disruptions to transport networks provides policy makers with information to learn and increase their resilience. Such impact assessments can take the form of helpful tools not only to identify the extent to which networks are prepared for and able to recover from disruptions, but also to generate useful indications on the effects of policy, operational and regulatory measures put in place, and the potential to increase their effectiveness in the future. Impact assessments can also help to quantify the monetary impact of disruptions, which is information that could be fed into cost-benefit analyses of future transport projects.

Disruptions to transport networks have impacts on transport users, shippers, workers and operators. These impacts are not systematically monitored, nor necessarily assessed with comparable methodologies. The impacts of disruptions to transport networks vary depending on regional conditions, infrastructure capabilities, and service demands.

In passenger transport, disparities may exist between regions, considering differences in the resilience outlook for urban as compared to rural transport networks. Impacts of disruptions to freight transport networks will be different for economic sectors according to their dependence on reliable and just-in-time transport. Whilst there are several methodologies for assessing impacts, it is not always clear which ones to use in which situations.

The resilience of transport networks is related to their **vulnerability**. Rigorous *ex ante* assessment of vulnerabilities of transport networks would help policy makers deal with disruptions, and design and implement adequate and timely policy measures. Considering the variety of approaches, policy makers might benefit from simple tools or frameworks for identifying vulnerabilities and the weakest links in and between transport networks (Box 4). Such a tool could help reduce costs associated with disruptions. In addition, policy makers could benefit from access to a wide range of tools for horizon scanning, to reduce uncertainty about possible future developments.

[2] ITF (2024), Transport System Resilience: Summary and Conclusions, ITF Roundtable Reports, No. 194, OECD Publishing, Paris.

Box 4. Tools to detect vulnerabilities in transport networks

The vulnerability of a network can be considered as its propensity or predisposition to be adversely affected by disruptions. The extent of network vulnerability depends on sensitivity (the susceptibility to adverse effects in case of exposure) and capacity (the ability to cope with exposure and adapt to the impacts). High resilience results in low vulnerability, and conversely, high vulnerability stems from low resilience.

A first step in detecting vulnerabilities could consist of an initial inventory of past events that have taken place in past decades, to understand the disruptions and impacts that could be specific to the context of the transport network, for example because of certain geographic characteristics. This could form the basis of a more elaborate analysis on potential future risks. For example, this could help to detect vulnerabilities of freight flows or the failure of certain bridges in the road network.

Despite progress on predicting risks, huge uncertainty persists on future disruptions and the vulnerability of transport networks. Governments could use existing tools to improve how they understand and predict potential risks, but few governments currently tale advantage of these. Such tools include horizon scanning, risk assessments and predictions of vulnerabilities via analysis of network characteristics, digital twins, or transport modelling.

Technological innovation and advancement of digitalisation have resulted in better tools to detect the vulnerability of transport assets – e.g. using digital twins, drones and robotics to detect cracks in bridges. Such digital real-time monitoring of infrastructure assets is applied by the Italian highway operator Autostrada per l'Italia[3]. Decision-making on transport policies and investments stand to benefit from such tools for assessing the impacts of disruptions to transport systems and from indicators to assess the resilience of transport networks.

Transport networks are vulnerable because of their **interdependencies**, both within transport networks and with other networks, such as energy, financial and communication networks. Interdependencies can result in cascading effects where a crisis in an area – sometimes not strictly related to transport – or region spills over to other areas or regions, resulting in polycrises, sometimes on a global scale.

Transport networks are key to ensuring the reliability of supply chains for food, energy, commodities and manufactured products. Transport networks are also critical for the provision of disaster relief, humanitarian aid, as well as transport of military cargo. Furthermore, they benefit people by facilitating access to employment, education, healthcare and other services. In short, they ensure that economies can continue to function. While goods can be stored as a precautionary measure to guarantee delivery, people cannot. Being prepared for disruptions will therefore have different implications for the transport of freight and people. The essential role of transport for economies means that transport disruptions imply huge systemic risks.

Policy makers could benefit from knowledge sharing, awareness raising and capacity building on the interdependencies of the transport sectors, and the systemic risks that these imply (Box 5).

[3] ITF (2021), Data-driven Transport Infrastructure Maintenance, International Transport Forum Policy Papers, No. 95, OECD Publishing, Paris.

Box 5. Interdependencies, cascading effects and systemic risks

Transport networks are increasingly interconnected on a global scale. This interconnectedness has improved efficiency and provided possibilities for re-routing, but it has also hugely heightened the risks of disruptions, especially because of what is known as cascading effects. Cascading effects are local disruptions that spill over to other places, with the potential to generate global crises. The likelihood and severity of cascading is determined by the level of interconnectedness. Research on cascading effects between interconnected networks shows that, **beyond a certain point, interconnections can lead to catastrophic cascading effects**. Several interconnected sectors are already subject to regulations aimed at limiting cascading effects. In the financial sector, this has taken the form of policies to separate retail and investment banking, higher capital and liquidity buffers and intensified risk management.

The crucial question for different transport systems is whether this critical point, beyond which more connectedness results in catastrophic cascading frequency determined ex-ante. There are various transport systems where the level of interconnections seems to have set in motion cascading effects that turned local crises into global crises, as was the case in 2020-2021 when US port congestion, in combination with a Covid19-related demand surge for containerised goods, resulted in disruption of containerised transport chains throughout the world.

Strategic policy design

Policies aiming to increase the resilience of transport systems need to define the mix of prevention and adaptation measures. **Prevention** measures focus on avoiding disruptions, increasing the capacity to cope with disruptions and providing alternative capacity in case disruptions take place.
Adaptation measures focus on dealing with changed circumstances after an event, in such a way that the system is better able to deal with disruptions.

To some extent, there is a policy trade-off between proactive (prevention) and reactive (adaptation) policies. Which measures make most sense differs according to transport systems and the characteristics of the different transport networks. These different characteristics determine the costs of inaction, prevention and adaptation. Insight into these costs can help to determine which type of policy measures (proactive, reactive or a mix) make the most sense in given circumstances (Box 6).

However, resilience is one of many objectives of transport policies with which it interacts.
These interactions can engender synergies or antagonisms:

- **Transport policy objectives can run counter to resilience**. Growing connectivity makes infrastructures, systems and interfaces more vulnerable to disruptions coming from elsewhere. High efficiency and cost pressures often reduce the redundancy (including alternative transport routes) that can be useful in case of shocks. Digitalisation, automation, AI and global seamlessness with a growing number of open interfaces can increase cybersecurity risks.
- On the other hand, **policies that foster resilience could create synergies with other policy objectives**. For instance, construction materials for road infrastructure can be selected based on both their durability under extreme weather conditions and their long-term performance characteristics. Similarly, resilient rail infrastructure supports the development of multi-modal transport systems, which contribute to operational efficiency and continuity of service under a variety of conditions. Resilient roads support industrial trade – and thus competitiveness and

economic goals – and support the movement of military equipment and relief goods – advancing security and humanitarian objectives.

Box 6. Policy trade-offs between prevention and adaptation

There is a strong inter-relation between prevention and adaptation measures. Prevention reduces the need for adaptation as it decreases the likelihood and exposure to disruptions, but prevention can prove more expensive than adaptation in certain circumstances. Transport policy makers face the following two questions: In which circumstances is prevention more expensive, and when does prevention or adaptation make most sense?

The exact form of the trade-off between prevention and adaptation differs per transport sector and the design of the networks in those different sectors. For example, centrally connected networks (hub-and-spoke) as in aviation or container shipping are less robust, so most dependent on disaster preparedness, that is the capability to quickly respond and adapt when disruptions occur. Relevant examples of prevention measures could include developing smaller ports and airports. On the other hand, certain prevention measures, such as relocation, could be too expensive until the disruption has occurred, for example when infrastructure in a coastal area is flooded.

If transport policy makers are to make informed decisions with regards to the right mix of prevention and adaptation measures, they would need more insight into the costs of disruption and the costs of prevention and adaptation options in case of a disruption. Such insight might differ according to local circumstances and the type of disruption. Applying tools, such as real option analysis to consider the opportunities to make future decisions based on how uncertainties unfold, could guide decision making in a variety of situations.

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 in the decision-making processes, for example with respect to policy choices between resilience and efficiency, between prevention and adaptation, and in relation to equity issues. Such a strategic vision should translate into identifying transport projects that contribute to increasing the resilience of transport systems. Adopting a strategic planning framework can improve outcomes by offering a co-ordinated, cross-sectoral and consistent approach to infrastructure investment.

Box 7. Policy synergies of dual infrastructure use

The perceived rise in geopolitical tensions has increased the interest in dual use of transport infrastructure. Dual use refers to transport infrastructure that could be used for both civilian and military purposes. Transport networks are essential for moving military cargo and soldiers, but existing networks and infrastructure are not necessarily appropriate for military use. This raises the question of what types of transport infrastructure can be used for both civilian and military purposes, and what the implications are for transport planning, in light of the current geopolitical context.

Financial mechanisms could be designed to include private sector actors who benefit from resilient transport networks. Such mechanisms could be the fruit of collaboration between various actors, such as the transport and logistics industry, multilateral development banks, and the insurance industry. This could help to incorporate resilience into transport investment frameworks, for example in climate adaptation funds and resilience bonds. Resilience should not only be taken into account in the initial design and construction phases of transport infrastructure projects, but also during operation and maintenance.

Procurement procedures would also need to reflect resilience considerations, by taking into account both short-term and long-term risks and uncertainties. When it comes to climate adaptation, it is not uncommon for decisions to be made based on short-term rather than on long-term benefits. Valuation and financing models need to be developed to encourage this long-term perspective-taking.

A way to internalise resilience into financial mechanisms is to incorporate it into cost-benefit analyses. Current appraisal processes might fully or partly ignore resilience considerations because resilience cannot be appropriately valued and quantified (Box 8).

Box 8. Resilience in cost-benefit analyses

The net benefit of building more resilient infrastructure in low- and middle-income countries amounts to US 4.2 trillion, according to the World Bank, with USD 4 in benefit for each USD 1 invested. If countries were to continue business as usual by building low-resilience infrastructure assets over the next decade, the costs of inaction would amount to USD 1 trillion.[4] These aggregate numbers demonstrate the logic of investing in resilient infrastructure and networks. In order to ensure resilient infrastructure investment, similar quantifications need to take place when the project is developed and during project appraisal.

The need for infrastructure investment is assessed in appraisal processes, using techniques like cost-benefit analysis (CBA). Resilience implies making investments for situations that might not happen soon or frequently. Most CBAs currently do not incorporate this uncertainty on frequency, probability and extent of impact. Some experts argue that CBA is far less well-equipped to address non-traditional goals, like resilience, which are either not included in CBA or under-valued because they are difficult to fully quantify or monetise, considering the uncertainty of most disruptive events. However, these traditional appraisal processes and techniques have changed significantly in recent decades, namely by incorporating analysis of the wider economic benefits, such as the positive externalities on productivity of increased urban agglomeration, which specific investments in improved transport infrastructure can enable. Indirect valuation techniques have progressively broadened the scope of cost–benefit analysis (CBA) to increasingly capture impacts that are difficult to quantify in monetary terms. Despite these changes, significant modification of appraisal practices is required to ensure that resilience considerations are appropriately addressed. Traditional “mobility-based” CBA appraisals do not give due weight to the effects of transport infrastructure choices on health, environmental impacts, or risks of systemic failure.

The pressing need for resilient transport policies has increased calls for changes to the way transport investments are reviewed and selected. This 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 that can provide information on the resilience impacts of transport infrastructure projects.

[4] Hallegatte, S., Rentschler, J., Rozenberg, J. (2019), Lifelines: The Resilient Infrastructure Opportunity, World Bank, Washington DC, http://hdl.handle.net/10986/31805.

Coordinated policy development

The challenges to global supply chains are highly complex in nature, which means they require harmonised, integrated and complementary policy approaches that address all parts of the supply chains. In this approach, all relevant elements of the transport network need to be considered – including at the regional and supranational levels – that may have an impact on global chains. Yet, existing policy development mechanisms are fragmented, imperfect and under pressure.

Growing geopolitical tensions also impede the emergence of global collaboration, yet there is a need for mechanisms that could help resolve disruptions despite geopolitical adversity. This raises the question of what such collaborative mechanisms and procedures could look like, and how they might be inspired by successful multilateral initiatives in the transport sector, such as the framework for global air traffic safety. In addition, global governance mechanisms could include common and harmonised approaches, sharing of best practices, and collaboration along supply chains.

Because the transport system is a network that extends across local, regional and national geographical and administrative boundaries, there is a growing need to foster transboundary multi-level collaborations. Essential questions that would need to be answered in this respect include: which tasks need to be carried out, in which priority, by whom, together with whom? Clarity on this is essential because it can secure effective disaster management (Box 9). Cross-jurisdictional collaboration requires the development of a common vision, building relationships and long-term trust. For example, Japan has implemented the “Five-year Acceleration Measures for Disaster Prevention and Mitigation and National Land Resilience” which includes the development of disaster prevention infrastructure and projects which focus on addressing ageing infrastructure through preventive maintenance shifts, covering both national and local infrastructure, complemented by training programmes to support local governments in their maintenance efforts[5].

Another important aspect is advancing cooperation with industry stakeholders, for example to achieve more resilient supply chains and based on existing trade relations. Potential levers and mechanisms for collaboration with the private sector could include public-private partnerships for resilience strategies, and stress testing and crisis simulations with industry stakeholders.

[5] OECD (2024), Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters, OECD Publishing, Paris, https://doi.org/10.1787/54d26e88-en.

Box 9. Planning for effective disaster management

Good planning can increase the capacity to adequately respond to disruptions. The better prepared they are, the more likely the responsible actors will be able to respond effectively. Policy makers could make sure that transport managers and operators develop contingency plans and timetables, user communication plans and information systems for rescue forces, allowing for the application of preexisting procedures that improve response.

Legal and contractual frameworks could be designed to 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 involves developing decision support tools for prioritising responses. Distinctions could be made according to the type and intensity of the disaster, the type of transport network and the type of country. In addition, it is essential to foster mechanisms of cooperation with the private sector, such as insurance companies and logistics operators, considering their key roles in disaster management.

Transport resilience policies take place in a context of contention. This touches on the political economy reform: how to make sure that desired resilience and adaptation measures within the field of transport are acceptable to the involved public and stakeholders (Box 10).

Box 10. Enhancing the acceptability of resilience measures

Knowledge sharing and awareness raising are vital in order to improve the social acceptability of resilience measures for transport networks. Public and private support for resilience measures can be enhanced by raising awareness on the role transport networks play in supporting national functions such as defence, emergency response, healthcare, education, and the economy. The ITF Transport Resilience Working Group is working on an overview of measures that governments have put in place to improve the acceptability of adaptation measures within the field of transport.

The role of the International Transport Forum

The International Transport Forum can add value in this area, considering its convening power of Transport ministers, and international organisations, such as specialised bodies of the United Nations (UNCTAD, IMO, ICAO), regional UN offices (ESCAP, ESCWA, ECE, ECA, ECLAC), European Union, African Union, G7, G20, and transport sectoral organisations. The ITF holds a unique position at the intersection of policy makers, science and private sector, in all modes of transport. As such, it is well placed for exchange and knowledge transfer on good practices relevant to policy makers. As the international organisation covering all transport modes, the ITF is also in a good position to reach out to organisations covering other sectors and areas, including on climate change (UNFCCC), energy (IEA), disaster management (UNDRR) and finance (multi-lateral development banks).

The ITF can promote the resilience of transport networks at two levels. The ITF Working Group on Transport Network Resilience has planned a series of deliverables that could be helpful for policy makers (Box 11). These deliverables could be included and developed in upcoming ITF Summits.

Box 11. Overview of activities of the ITF Working Group on Transport Network Resilience

Analytical tools:

- An overview of approaches to assess the impacts from disruptions to transport networks
- A framework tool to detect vulnerabilities of transport networks
- Mapping the interdependencies of transport networks and systemic risks
- Best practices on horizon scanning

Policy design:

- Policy guidance on the prevention-adaptation trade-off
- Assessment of potential dual transport infrastructure use
- Guidelines on incorporating resilience in cost-benefit analyses

Policy implementation:

- Checklist for disaster management in transport
- Overview of best practices for the acceptability of transport resilience measures