International Transport Forum

SIPA
Sustainable Infrastructure Programme in Asia

Enhancing freight transport resilience through analytical frameworks

Applications to Central and Southeast Asia

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The Sustainable Infrastructure Programme in Asia

This paper is part of the Sustainable Infrastructure Programme in Asia (SIPA), funded by the German International Climate Initiative (IKI) and led by the OECD. SIPA aims to support countries in Central and Southeast Asia in their transition towards energy, transport and industry systems aligned with the Paris Agreement and Sustainable Development Goals.

The ITF leads the transport component of the SIPA programme (SIPA-T). The SIPA-T project helps decision makers in Central and Southeast Asia by identifying policy pathways for enhancing the efficiency and sustainability of regional transport networks. Project outputs include two regional studies that explore opportunities to improve the connectivity, sustainability, and resilience of freight transport systems in Central and Southeast Asia.

This paper is the third in a series of four ITF expert working papers that collectively provide the methodological foundation for the two SIPA-T regional freight transport studies. The full series includes the following papers:

1. *Enhancing freight transport connectivity through analytical frameworks* (Ruth Banomyong)
2. *Enhancing freight transport decarbonisation through analytical frameworks* (Alan McKinnon)
3. *Enhancing freight transport resilience through analytical frameworks* (Jasper Verschuur)
4. *Evaluating the relationships between connectivity, decarbonisation and resilience in freight transport* (Alan McKinnon)

Access these papers, more information, and other SIPA-T project deliverables:

https://www.itf-oecd.org/sustainable-infrastructure-programme-asia-transport

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Summary

Freight transportation systems are prone to a variety of external shocks (geopolitical conflict, labour strikes, natural disasters) that can disrupt the operations of the system. These impacts can cause revenue losses and wider economic losses in the case of large-scale disruptions. As such, ensuring that freight transport systems are resilient to these shocks is essential. While the resilience of freight transport systems has gained considerable political traction, there are large knowledge gaps in how to incorporate resilience into freight transport planning and policymaking.

This paper aims to develop a methodology to evaluate the resilience of freight transport systems in general and then apply the methodology to the regional freight transport networks of Central Asia and Southeast Asia. The paper proposes an overarching framework that captures the risk and resilience considerations for freight transport networks, followed by a set of practical approaches to evaluate freight transport resilience. It ends with future recommendations to improve regional freight resilience in the two regions.

A disruptive event associated with a type of risk can cause disturbance to the normal operational level of a freight transport system. Risks to the regional transport network can be classified in terms of (i) whether it affects demand or transport facilitation and (ii) whether the risk is sudden or longer-term.

Examples of such risks are major shifts in freight demand due to geopolitical conflict, gradual reallocation of economic activity, climate extremes, or spikes in transport costs. Based on a survey involving actors in the freight and logistics sector in Central Asia, the respondents identified geopolitical conflict, climate extremes and political instability as key risks for the country's freight transport sector. In Southeast Asia, the respondents identified climate extremes as the key risk for regional freight transport, followed by geopolitical conflict, sudden demand changes and domestic instability. These results are well aligned with recent challenges faced by freight transport systems in both regions.

Resilience extends the concept of risk and measures as the ability to cope with, recover from, and adapt to external shocks to the freight transport network. Freight transport resilience can be contextualised depending on the spatial scale and actors considered. We can define freight transport resilience on different interconnected levels:

- Physical infrastructure resilience: focuses on certain infrastructure segments (e.g. roads, railways, inland waterways) or nodes (e.g. ports, stations) and their service reliability.
- Network resilience: focuses on the regional transport network as a whole and the ability to cope with shocks to one or more physical infrastructure segments or nodes.
- User/operator resilience: focuses on the operators and users (e.g. freight forwarders) of the freight transport network and their ability to cope with operational shocks.
- Organisational resilience: the ability of the managing organisation to prepare for and cope with shocks and incorporate these considerations into long-term investment planning.

In this paper, we distinguish between (i) quantitative and (ii) qualitative approaches to measure resilience. Quantitative approaches are model-based approaches to quantify resilience indicators for the transport network, often termed "criticality analysis". These approaches can be distinguished based on the availability of data on freight transport networks only (network-based approaches), whether a dynamic

freight model is used (freight model approach), and whether detailed information on the risks to infrastructure components is available (risk-agnostic or risk-informed).

Qualitative approaches complement the quantitative approaches, providing insights into the organisational practices surrounding freight resilience and policy. Examples of this are storyline approaches, which provide an analysis of what-if scenarios and are often designed in co-creation with stakeholders. Qualitative approaches using surveys provide information on the resilience policies and practises in place that determine organisational capacity to cope and deal with shocks.

In the two regions, resilience recommendations have been developed based on the survey results and a literature review focused on the regional freight transport systems.

For Central Asia, the three resilience priorities identified are:

1. Embed resilience in national and cross-border policy. A stronger top-down policy push is required to mainstream resilience in national freight plans and project planning and prioritisation. For Central Asia, it is increasingly important that resilience planning takes place on a bi- or multilateral level, given that the major freight corridors span across borders.
2. Improve network redundancies. Existing network robustness and redundancies are still insufficient from a resilience perspective, making the system particularly prone to risks that can affect the system as a whole (e.g. conflict and pandemics). Network redundancy should be enhanced together with planned infrastructure expansion projects, including improved opportunities for modal substitution.
3. Technology for emergency preparedness and response. There are currently limited emergency preparedness and response mechanisms to deal with shocks to the regional freight network. The use of advanced technologies to monitor freight flows can benefit this objective, as well as a great emphasis on improving the capability to respond rapidly to shocks. Scenario and storyline exercises with regional stakeholders can help to identify where major shortcomings lie and what interventions have the greatest potential for impact.

For Southeast Asia, the three resilience priorities identified are:

1. Embed resilience in policy: While existing national plans and project prioritisation exist, they do not provide enough guidance on how to improve resilience and make sure resilience is prioritised in project selection and appraisal.
2. Improve resilience through multi-modal freight transport: Approaches to diversify flows and embed redundancies in the freight network are underdeveloped and should be prioritised in the future. The regional freight network of Southeast Asia includes a variety of modes with the potential for modal substitution.
3. Mainstream resilience into new infrastructure expansions or upgrades: Given that Southeast Asia is one of the most climate-vulnerable regions, it is essential to mainstream climate resilience in new infrastructure developments, as well as within asset management cycles. To do this, it is important to (i) have a clear understanding of how climate change may affect input parameters for infrastructure design and (ii) understand which transport segments require the most urgent adaptation efforts through criticality analysis.

Introduction

Freight transportation systems are prone to a variety of shocks that can disrupt their operations. For instance, geopolitical conflict can force the reallocation of freight flows, labour strikes can shut down transport nodes (e.g. ports, border crossings), and landslides and flood events can damage road and rail infrastructure. These impacts can cause revenue losses, but in case of large-scale disruptions, there will be wider economic losses to those sectors that depend on freight flows. Preparing and responding to these shocks is imperative to avoid such economic losses. Alongside policy objectives to improve freight connectivity, ensuring that freight transport systems are resilient, which reflects the ability to cope, recover and adapt to shocks, is critical. However, while the resilience of freight transport systems has received considerable attention, knowledge on the resilience of freight transport systems is underdeveloped, including how to incorporate resilience into freight transport planning and policymaking.

This paper aims to develop a methodology to evaluate the resilience of freight transport systems in general and then apply the methodology to the regional freight transport networks of Central Asia and Southeast Asia. The paper proposes an overarching framework that captures risk and resilience considerations for freight transport networks. It approaches freight resilience on separate yet interconnected levels, including the asset level, the network level, the user/operator level and the organisation level. This is followed by a set of practical approaches to evaluate freight transport resilience. Moreover, based on the results of a regional survey, existing risk and resilience policies for Central Asia and Southeast Asia are discussed, as well as recommendations to improve regional freight resilience in the future.

Regional setting

Central Asia

Central Asia is facing unique challenges in their regional freight transport network. During the COVID-19 pandemic, regional trade to and from the region collapsed (ITF, 2022; UNESCAP, 2023). Yet road and rail transport corridors through Central Asia and Russia were increasingly utilised as alternative transit routes between China and Europe as a result of the disrupted maritime transport networks in China. However, the war in Ukraine has led to severe disruptions on this continental freight corridor, known as the Northern Corridor, including reduced capacity, uncertainty, and higher insurance premiums (ITF, 2022). As a result, trade has been rerouted on alternative corridors, such as the Middle Corridor (via the Caspian Sea) and the South Corridor (via Kazakhstan-Turkmenistan-Iran), but these corridors are underdeveloped and cannot yet cope with major transport flow increases (ITF, 2022)

The loss of connectivity in Central Asia has had major implications for the region's trade and economic performance. In addition, new infrastructure investments are being made to develop the transport corridors to the south, including port connections from Kazakhstan and Turkmenistan to Azerbaijan and Iran, and by land, through the creation of a railway line between Uzbekistan, Afghanistan and Pakistan (Levystone, 2022). Container flows through the Middle Corridor could increase by a factor of seven by 2040 or even an order magnitude more if continuous developments take (EBRD, 2023). All the above underline that, at present, the freight corridor system is starting to become more efficient in handling an increasing amount of freight, as well as diversifying trade flows. However, the current freight capacity is insufficient to cope with sudden shifts in freight flows because of the Russian invasion of Ukraine.

At the same time, the region is exposed to other types of shocks due to climate-related extremes. The most prominent climate-related extremes in Central Asia are flooding, extreme temperatures (both high and low) and landslides. Generally, two types of flooding occur in Central Asia: flash floods (due to high-intensity rainfall) and river flooding (due to excessive rain or snowmelt causing riverbanks to overflow) (ADB, 2023). These climate extremes can cause damage to the region's transport infrastructure. For instance, according to a global risk analysis of road and rail infrastructure, the hazard-related risk to Tajikistan's road and rail infrastructure is equivalent to 0.3% of the country's Gross Domestic Product (Koks et al., 2019). Wang et al. evaluated the river flood and earthquake risk to transport infrastructure within Belt and Road corridors (Wang et al., 2021). They found that the China-Central Asia-West Asia Economic Corridor has a risk of USD 40 million per year, with the largest risk (in absolute terms) related to transport infrastructure in Uzbekistan. Caleca et al. (2021) assessed the exposure of road and rail infrastructure in Central Asia to landslides. They concluded that the landslide risk to roads ranges between USD 21 million in Turkmenistan and 682 million USD in Tajikistan, while the risk to rail assets ranges from USD 4 million in Turkmenistan to USD 324 million in the Kyrgyz Republic.

More generally, transport infrastructure density in the region is relatively sparse, with improvements needed in both infrastructure connectivity and quality. Much of the regional trade is allocated on major transport corridors, with few connections between rural areas and urban areas. As such, the resilience of the transport system is anticipated to be relatively low, particularly if disruptions occur to infrastructure within one of the major freight transport corridors.

Southeast Asia

Southeast Asia has faced similar challenges associated with the COVID-19 pandemic, particularly in terms of seaport reliability due to shifting demand (Verschuur et al., 2023a). However, in many Southeast Asian countries, trade, and hence freight demand, has been relatively constant given the increasing demand for food, medical supplies and manufacturing goods from Southeast Asian countries during the pandemic (Kimura and Zen, 2023).

Going forward, on a macro-level, two large shifts are likely to occur, which may affect future freight flows. First, given some of the expected diversion of production away from China and towards Southeast Asia, international freight demand is expected to grow. On the other hand, geo-fragmentation, which may divide countries into international trading blocs, may hamper trade and economic growth in Asia more than the global average (Aiyar et al., 2023). Model simulations performed by the IMF show that Southeast Asian countries would be among the biggest losers if geo-fragmentation persists and non-friendly trading blocs impose additional trade (Aiyar et al., 2023). For countries in Southeast Asia, this loss can be explained by reduced access to export markets and the splintering of production networks that span both Southeast Asia and the rest of the world.

Southeast Asia is one of the most climate-exposed regions in the world. Extreme events such as landslides, cyclone-induced wind and flooding, and river flooding cause frequent disruptions to transport services and the reliability of the transport network overall. A global natural hazard risk analysis of road and rail infrastructure by Koks et al. (2019) found that Vietnam, Myanmar, the Philippines, Indonesia and Laos are among the top 10 most at-risk countries in terms of their risk per kilometre of infrastructure. On top of that, a study by Verschuur et al. (2023) found that ports in the Philippines and Vietnam are particularly prone to cyclone wind speeds, whereas ports in the rest of Southeast Asia are more prone to flooding. This puts a large share of maritime trade at risk of disruption during extreme events, such as major cyclones. Similarly, Vietnam and Indonesia score in the top 15 countries with the most road infrastructure exposed to landslides (Emberson et al., 2020).

Compared to Central Asia, the freight transport network in Southeast Asia is more developed, with higher-quality roads, ports and trade facilitation measures. A key observation of the regional transport network is the high density of transport infrastructure in densely populated areas (e.g. coastal Vietnam and Thailand) but limited connectivity between countries (e.g. between Myanmar and its neighbours, between Vietnam and Cambodia). Disruptions to major transport hubs can hinder interregional trade. Similarly, cross-border rail transport is underdeveloped in Southeast Asia (Morgan et al., 2015) with most of the interregional trade being road-based or maritime. However, as in Central Asia, new corridors are being developed, including improved connectivity between China and Vietnam with future plans for corridors extending all the way to Singapore (via Thailand and Laos) (UNESCAP, 2023).

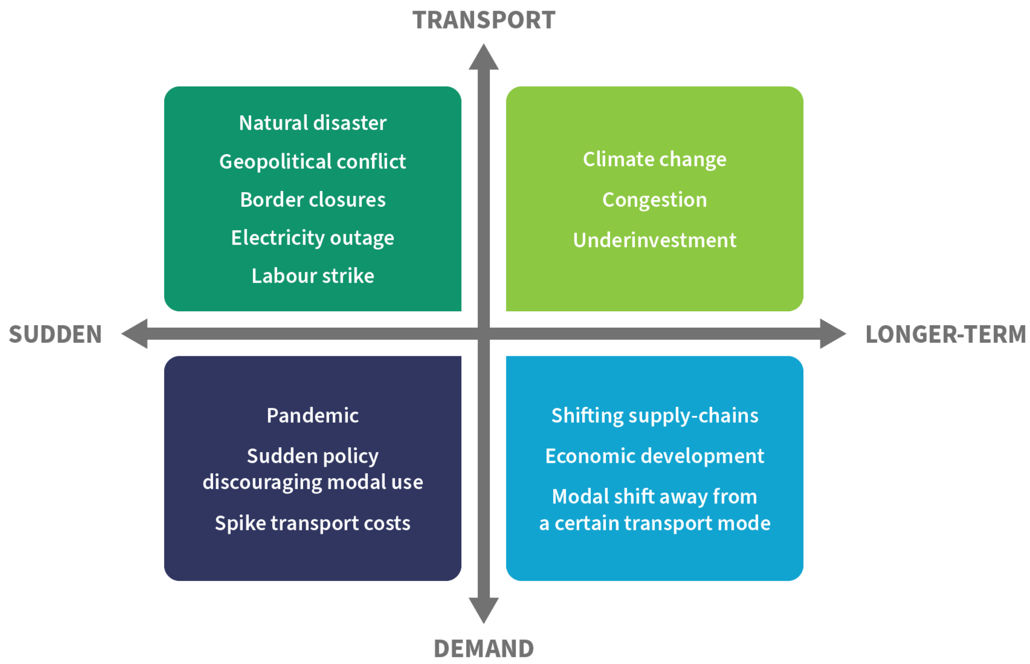
While the transport network is more advanced in Southeast Asia, limited interregional connectivity can limit the resilience of the transport network. However, in Southeast Asia, disruptions to road transport can partly be buffered by the presence of maritime transport as an alternative for interregional trade, though at the cost of significant additional travel time. There is potential for improved inland water transport on the Mekong River, which can connect countries alongside roads and expand rail connections, potentially allowing for freight diversification across modes.

Risk and resilience in freight transport

Overview of risks

A disruptive event, associated with a type of risk, can cause a short-term or long-term disturbance to the normal operational levels of a system, such as the normal level of freight traffic operations in the case of freight transport systems (Henry et al., 2021; Meyer et al., 2019). The risks to regional freight transport networks can be classified in terms of (i) whether it affects demand or transport operations and (ii) whether the risk is sudden or longer-term. Examples of such risks are major shifts in freight demand due to geopolitical conflict, gradual reallocation of economic activity, climate extremes affecting transport systems, closure of border crossings, or spikes in transport costs (e.g. fuel prices, insurance premiums). The categories of risks are highlighted in Figure 1.

Figure 1. Classification of disruptive events that create risks for freight transport systems



Each risk can further be classified in terms of its likelihood of occurrence and the impact across different scales:

- Likelihood of occurrence: The likelihood that some of these risks could materialise, expressed in terms of probability.
- Impacts across different scales: The impacts that could materialise from a given risk, in terms of monetary (or non-monetary) impact as well as the spatial scale of the impacts (local, regional or national). For some risks, different types of impacts could be associated with different levels of severity. In terms of spatial scale, one can distinguish between localised risks, which is an isolated

event affecting a small region or specific mode, and large-scale risks, which can affect the entire freight transport system across a country or region.

To understand the types of risk and how they can impact freight infrastructure, risks can be visualised by means of a risk matrix (Elmonstri, 2014). Risk matrices are a "mechanism to characterise and rank process risks that are identified through a multifunctional review (e.g. hazard analysis, audits, or incident investigation)" (Markowski and Mannan, 2008). A risk matrix classifies the different types of risk in terms of their probability of occurrence and the associated impact. While other risk management tools exist, risk matrices are commonly adopted and recommended in the ISO codes (ISO 31010 Risk Management). An example of a generic risk matrix is shown in Figure 2.

Figure 2. Example of a generic risk matrix

		Risks		
		Significant	Moderate	Low
Frequency	High	High	High	Moderate
	Medium	High	Moderate	Low
	Low	Moderate	Low	Low

Elements of resilience

Resilience is defined as the ability to cope with, recover from, and adapt to external shocks to the freight transport network. Resilience thus extends the concept of risk (which captures the occurrence of shocks) and measures also how one can cope, recover, and adapt to the impact. A widely used framework to capture these features is the "4Rs" framework proposed by Bruneau et al. (2003) and further elaborated upon by Tierney and Bruneau (2007). Within this framework, resilience is characterised by four dimensions: robustness, redundancy, resourcefulness and rapidity. Robustness captures the absorptive ability of a freight transport network, while redundancy characterises the degree of substitutability of certain parts of the network if disrupted (given alternative paths, spare capacity, and so on). Resourcefulness, on the other hand, is determined by the availability of materials, workers, and resources to restore the system's operational functionality, while rapidity determines the speed with which a system can recover after a disturbance.

Given the definition above, freight transport resilience can be contextualised depending on the spatial scale and actors considered. We can define freight transport resilience on different interconnected levels:

- Physical infrastructure resilience: focuses on certain infrastructure segments (e.g. roads, railways, inland waterways) or nodes (e.g. ports, stations) and the service reliability on the segment or node alone, without considering the rest of the network. Indicators for measuring this level of resilience could be the flow of goods or passengers, or average travel speed.
- Network resilience: focuses on the regional transport network as a whole and the ability to cope with shocks to one or more physical infrastructure segments or nodes. The service reliability indicators could be the number of passengers or freight that is facilitated by the network, or the

total travel time or cost. Network resilience is mainly driven by capacity constraints in the system, utilisation rates, and redundancy in the system.

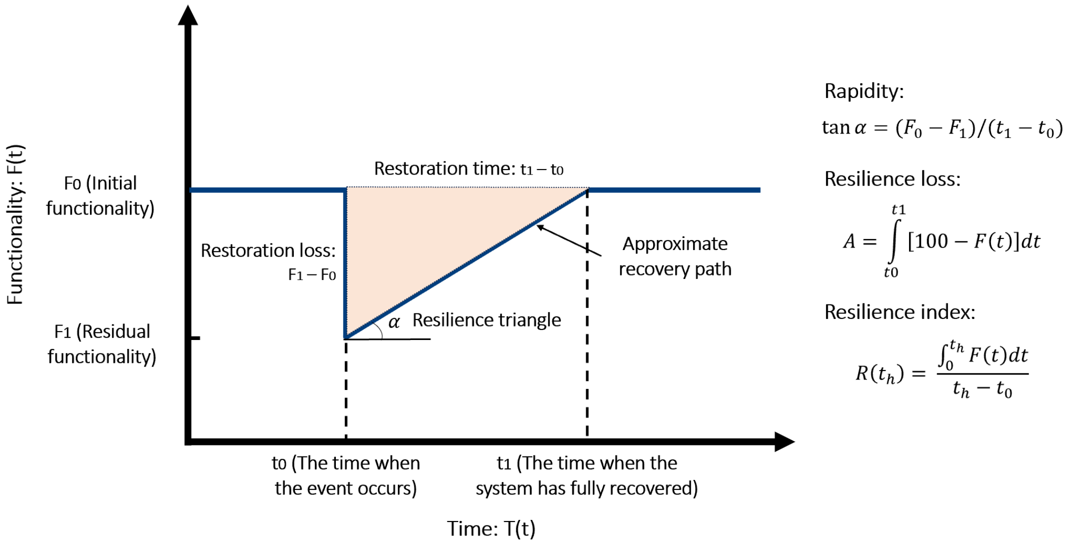
- User/operator resilience: focuses on the operators and users of the freight network (e.g. freight forwarders) and their ability to cope with shocks. This is closely linked with network resilience; users are constrained by the resilience of the network. Service reliability indicators might include the revenue derived, goods moved, or number of delays.
- Organisational resilience: the ability of the managing organisation to prepare and cope with shocks and incorporate these considerations into long-term investment planning and emergency response strategies. Indicators could be related to the repair or restoration time after shocks or the number of users informed. Organisational resilience is more qualitative than the other dimensions. In the case of cross-border transport corridors, organisational resilience could also be related to cross-border co-operation across the freight corridors.

The resilience on an infrastructure or network level is often simplified as a triangle, called the "Resilience Triangle" (Bruneau et al., 2003), as shown in Figure 3. The initial reduction of functionality is determined by the robustness and redundancy of the system, while the slope of the recovery path is the speed of recovery (or rapidity). However, many relevant resilience indicators exist to measure the functionality of the freight transport system. A review by Poulin and Kane (2021) classifies typical resilience indicators into seven broad types:

- Magnitude-based: system performance at a specific milestone or point in time. For instance, the peak congestion or minimal freight flow on a network.
- Duration-based: The duration between two milestones. For instance, the time required to restore freight flows to pre-event levels.
- Integral-based: Incorporate both time and performance and capture the cumulative impacts. It can be quantified as the integral of the resilience triangle, which represents the total loss in functionality. This might be quantified by the total freight flow disrupted or lost or the total revenue losses.
- Rate-based: The speed with which the system performance changes over time. For instance, the failure rate from pre-event functionality to peak drop or the rapidity of the recovery.
- Threshold-based: The functionality of the system with respect to some critical performance threshold. For instance, the duration of the period where congestion reaches a certain limit or the period during which a rail or port terminal must work above operational capacity.
- Ensemble: A weighted or unweighted combination of different resilience metrics captured in an ensemble or multidimensional resilience metric.

While the recovery of the system within the "Resilience Triangle" definition is often described as the time required for the system functionality to reach its pre-event state, within the context of freight transport systems, a piece of transport infrastructure may not return to its pre-event functionality. This could be because restoration efforts are incomplete (e.g. emergency repair works only have taken place, not full asset recovery), or it may be restored to an improved condition (e.g. a new asphalt layer is added to a road). For instance, with much of the transport infrastructure in Ukraine damaged because of the Russian invasion, rebuilding provides a window of opportunity to make overdue investments to improve the system as a whole (e.g. enhancing pavement quality, making rail compatible with the European rail network). This is referred to as the post-event system adjustment (which could be equal to the pre-event system state, or higher or lower).

Figure 3. Overview of system resilience



Note: The graph on the left traces the traditional resilience curve with different components, which are often conceptualised as a resilience triangle. The indicators on the right are several commonly used resilience indicators derived from the curve.

Source: Sun et al. (2020).

In addition, modal reassignment could occur within the freight system. For example, a shock to road transport can cause a modal shift toward rail, which may persist after the road transport has recovered from the shock. This is particularly important in freight transport, given the relatively high switching costs involved. Major shocks to ports have led to the rerouting of goods to alternative ports, and diverted flows do not always return to the original port (Chang, 2000; Verschuur et al., 2020). As such, shocks can have long-term negative repercussions but also provide a window of opportunity to switch to an alternative equilibrium.

Empirical insights into freight resilience

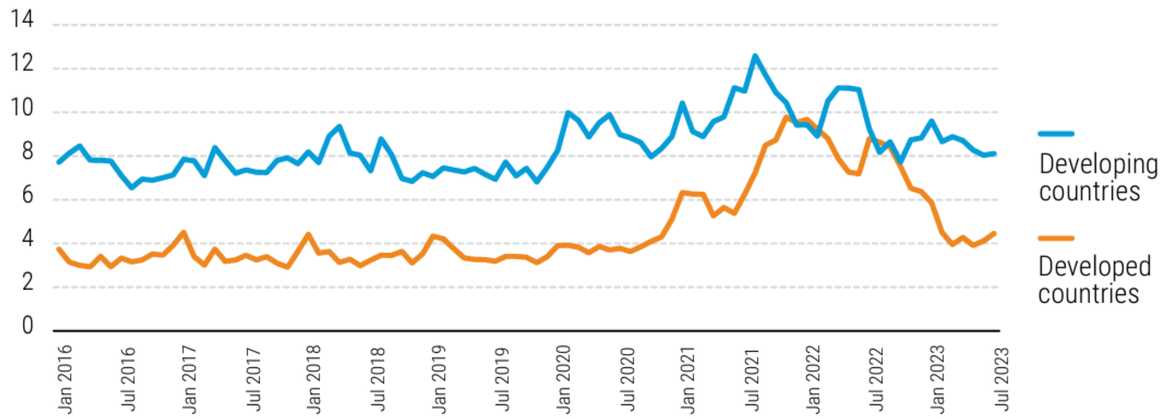
In most cases, empirical data is used to construct resilience curves, in particular on an infrastructure or system level. One example is the impact of COVID-19 on container waiting times in global ports. COVID-19 impacted shipping logistics in different ways, including causing shifts in demand and disrupting logistics operations within a port, hinterland and maritime logistics chains (Notteboom et al., 2021). This had a severe impact on congestion at ports, as demonstrated by the increased average waiting time of container ships at ports shown in Figure 4. Another example is the resilience curves created for several ports during past extreme events in Verschuur et al. (2020). These curves clearly demonstrate the different elements of the resilience triangle described above, including the onset of the shock, the recovery and the post-shock adjustment (e.g. temporary increases to "catch-up" lost activity).

However, it remains challenging to prescribe these curves for new or modelled extreme events, therefore in most cases, simplified assumptions are adopted (e.g. so-called "restoration curves" for infrastructure).

Despite it being known that restoration curves may vary widely across countries or even infrastructure within countries, in model-based studies, these nuances are often ignored, and a single restoration curve is adopted (often from the USA due to the availability of data).

COVID-19 exemplified the importance of resilience for the macro-logistics network, which captures the interplay between logistics processes, infrastructure networks and system management. Shocks to the macro-logistics network are absorbed by the different sub-systems and actors involved in these systems, such as transport operators, carriers, and freight forwarders. While overall macro-logistics performance has increased over time, with lower costs to ship goods internationally and faster transit times, the macro-logistics chain is typically less able to cope with unexpected shocks, in particular when they affect multiple parts of the chain at once. However, this may differ from one macro-logistics system to the other. For instance, the relative impacts were more severe in developed countries compared to the developing countries (see Figure 4). While ports and logistics chains in developed countries are more efficient (indicated by lower long-term average waiting times), they are considered less resilient when it comes to unexpected major disruptions such as the COVID-19 pandemic.

Figure 4. Average waiting times of container ships in ports from January 2016 to July 2023



Note: The waiting time is estimated based on the time between when a vessel first enters an anchorage associated with a port group (or a port, if an anchorage shape has not been detected) and when it first enters a berth within the port.

Source: UNCTAD (2023) with data provided by Clarksons Research.

Risk and resilience in Central and Southeast Asia

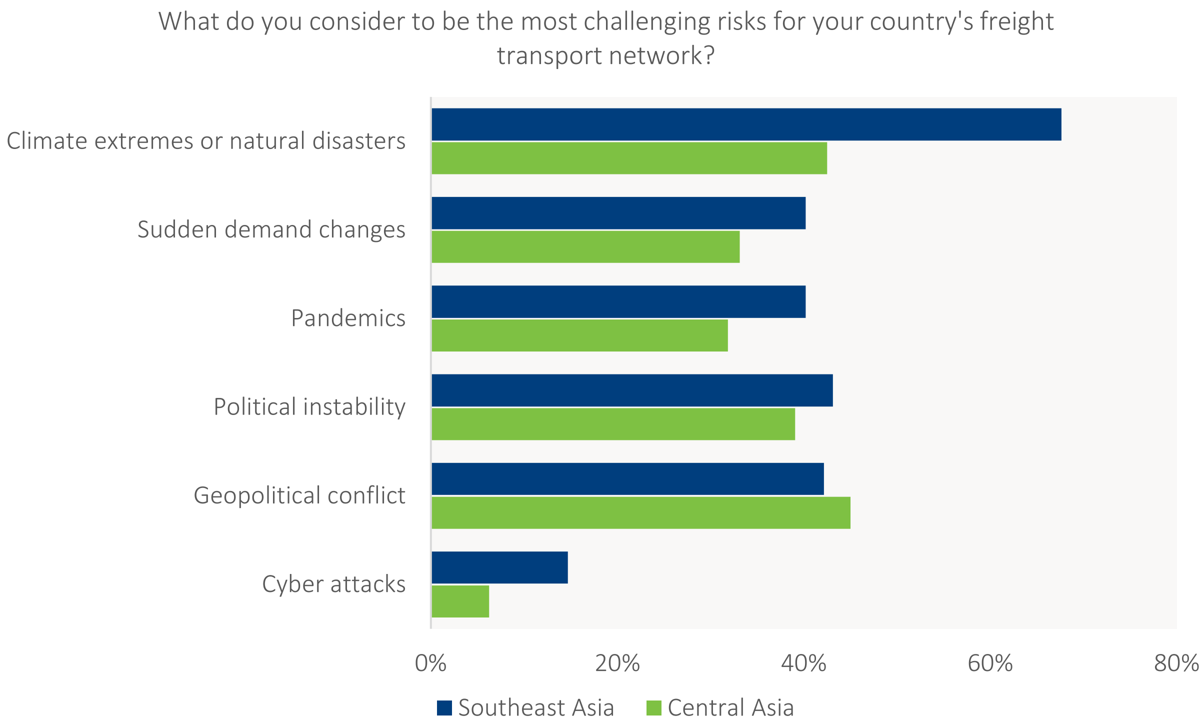
In 2023-2024, the ITF distributed a survey to various actors involved in the freight and logistics sector in Central Asia and Southeast Asia, asking about (i) major risks to their regional freight transport networks, (ii) existing resilience practises, and (iii) suggested future resilience policies.

For Central Asia, the respondents identified geopolitical conflict, climate extremes and political instability as key risks for the regional freight transport sector, followed by sudden demand shifts and pandemics. Cyberattacks were not frequently mentioned. In Southeast Asia, the respondents identified climate extremes as the key risk for regional freight transport, followed by sudden demand changes, pandemics, and domestic instability. These risks are well aligned with some of the key risks identified based on a literature review. The results for the Central and Southeast Asia risk questions are presented in Figure 5.

Based on the ITF survey, around half the respondents in Southeast Asia are moderately concerned about risks to their regional freight, given a lack of resilient infrastructure. In Central Asia, however, most respondents indicated that they are highly concerned about the lack of freight resilience given the risks faced in the region.

These results illustrate that the two regions have different priorities in terms of the risks that policy makers should prepare for, with climate extremes and sudden demand changes being more prevalent in Southeast Asia and geopolitical conflict, pandemic and political instability being a more prevalent risk in Central Asia. This is well aligned with some of the recent challenges that each region’s freight transport systems have faced. Stakeholders in Central Asia are generally more concerned about the resilience of their freight systems compared to Southeast Asia, which may be reflective of the fact that Southeast Asian freight transport has higher levels of resilience embedded in the network compared to Central Asia.

Figure 5. Result of the survey question on main risk challenges for Central and Southeast Asia



Evaluating freight resilience

Quantifying resilience ex-ante is an ambiguous task and depends on the definition of resilience, the scope, and the data available. Here, we will discuss practical approaches to measuring resilience, given the information available within the freight modelling context. These approaches should not be seen as all-encompassing, as they capture only part of the resilience definition.

Measuring resilience can involve both quantitative and qualitative approaches. Quantitative approaches are model-based approaches to quantify resilience indicators for the transport network, such as network-level resilience. These resilience indicators could indicate something about the network as a whole or about the relative importance of specific assets within a network. The latter approach is often referred to as "criticality analysis", which focuses on quantifying the relative criticality of specific assets with respect to one another.

We can distinguish between three types of quantitative criticality analysis to quantify the resilience of a freight transport network: (i) risk-agnostic network-based approaches, (ii) risk-agnostic freight model approaches, and (iii) risk-informed freight model approaches. This classification, including the type of information that is needed for each analysis, is illustrated in Figure 6.

- Risk-agnostic network-based approaches: No risk information is available, and network-based resilience indicators are used to compare network components with each other. The resilience indicators are derived from the transport network only, without a dynamic freight model component.
- Risk-agnostic freight model approaches: No risk information is available, and network-based resilience indicators are used to compare network components with each other. The resilience indicators are derived from a dynamic freight model, which can simulate the allocation of freight flows on the network during normal conditions and under disruption scenarios.
- Risk-informed freight model approaches: Risk information is available, and network-based resilience indicators are combined with risk information to compare network components with each other. Information from a freight model is available.

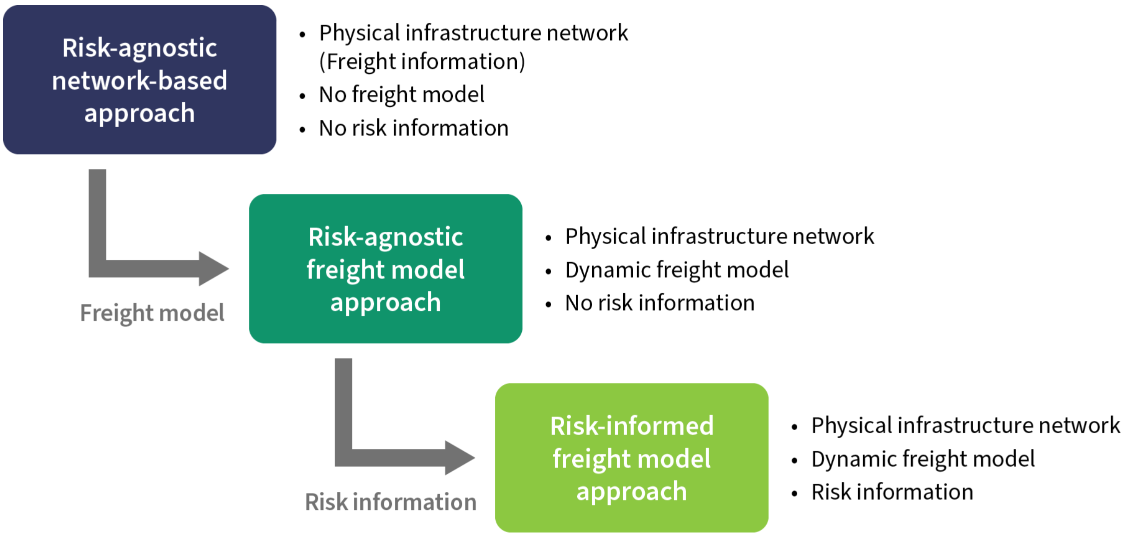
Some methodologies could be classified as a combination or variation of these three main approaches, for example, risk information combined with the output of a static freight model that does not enable dynamic rerouting. Such approaches will not be discussed further in this section.

Qualitative approaches complement the quantitative approaches and go beyond the network or model-based analysis, providing insights into the organisational practises surrounding freight resilience and policy. The two approaches we will highlight are:

- What-if/storyline approaches: Analysis of "what-if" scenarios, including the response of the system to these scenarios. This can be fed into a freight model or used within a "serious game" setting to discuss the operational and policy response to the scenarios. This exercise is often designed in co-creation with stakeholders.
- Qualitative approaches using surveys: Provides additional information on the resilience policies and practises in place that determine the organisational capacity to cope and deal with shocks.

Each approach is described in detail below, followed by an overview of key considerations when selecting the appropriate resilience approach for a given application.

Figure 6. Quantitative approaches for resilience analysis of freight transport networks



Risk-agnostic network-based approaches

Network- or graph-based approaches to measuring transport resilience originate in graph theory, an area of research within mathematics (Jafino et al., 2020; Sun et al., 2020). Here, transport networks can be represented as complex graphs consisting of nodes and edges. The network could be represented as an unweighted graph (i.e. a binary connection) or a weighted graph with the weights representing some characteristic of the edges, such as the freight volume or number of vehicles traversing the edge. The weights can be derived from observed or estimated freight data, depending on the application.

Over the years, many network metrics have been developed that are used as proximate indicators to represent the resilience of transport networks. Some metrics consist of basic counts of the graph's nodes and edges (i.e. local network metrics), while others relate to the entire network (i.e. topological or network-wide metrics). A common type of topological metrics is known as percolation methods, which were originally involved the removal of network elements to showcase phase transitions in networks (Koks et al., 2023a). When used in freight transport modelling applications, percolation methods involve the incremental removal of network elements to evaluate how disruptions affect the overall connectivity or network service, either because certain flows have to be diverted or certain flows cannot take place any more.

Examples of common local network metrics are:

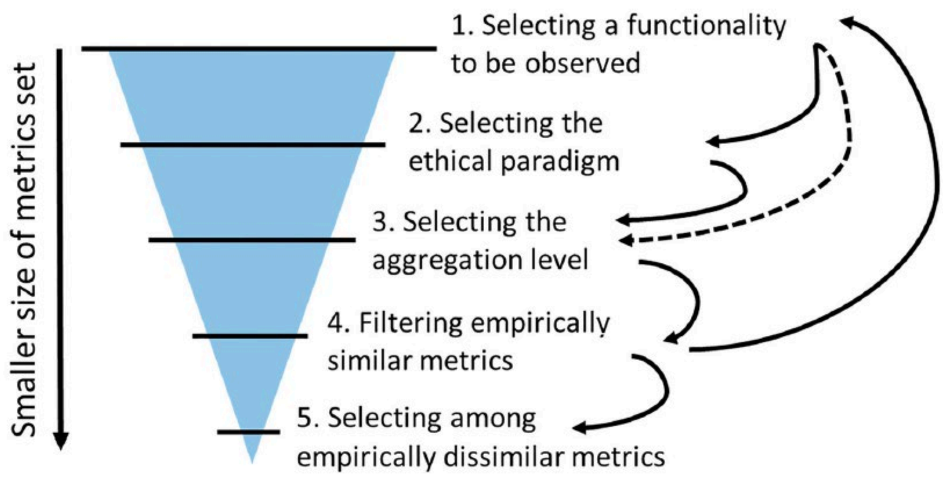
- Betweenness centrality: captures the frequency that a transport segment appears in the shortest paths between any two combinations of nodes in the network.
- Traffic flow: measures the freight flows or other activity passing through nodes or edges.

Examples of common topological or network-wide metrics are:

- K-connectivity: captures the reduction in the number of shortest paths between two nodes due to the removal of a transport segment.
- Minimum link cut centrality: captures the frequency of a link's appearance in the minimum cut set between two nodes. The minimum cut set is the minimum set of links that must be removed simultaneously to disconnect two nodes.
- Change in accessibility: measures the decrease in topological accessibility due to the removal of an element.
- Change in travel time/cost/distance: measures the total increase in travel time, cost, and distance among all node pairs due to disruption of an edge. Link weights representing travel time, cost or geographic distance are needed to calculate the corresponding indicators.
- Size of the largest connected component of a network: captures the size of the largest connected component (LCC), which is the largest sub-network of a graph when it is disintegrated into multiple sub-graphs.
- Average or maximum shortest path length in the LCC: The average of the maximum shortest path length between any two nodes in the LCC of a network.

A few observations can be made based on these metrics. First, while the absolute values of these metrics are less informative if they are normalised within a network (e.g. regional service areas) or across networks, insightful comparisons can be made. Second, different metrics serve different purposes. While some are highly correlated, others have little correlation, as shown in the work of Jafino et al. (2020), who derived cross-correlations of 17 relevant network indicators for a transport network in Bangladesh. It is therefore recommended to review the sensitivity of the results across metrics used or to use a network metric that serves a particular purpose. The same authors propose a set of guidelines on how to select criticality metrics (see Figure 7). This involves choosing the policy objective (either minimising travel cost or maximising accessibility), the equity considerations (whether utilitarian or egalitarian) and the level of aggregation (whether network or local).

Figure 7. Five-step guideline to select network metrics for criticality analysis



Source: Jafino et al. (2020).

These metrics are all considered risk-agnostic, as they do not include information on the level of disruption risk faced by the network elements. Hence, a comparison is based purely on the importance or criticality of the network elements to each other and to the functioning of the network. In other words, this type of approach tries to identify critical elements within the transport network without differentiating whether the removal (due to disruptions) of these elements is more or less likely to occur, how long it takes to restore these elements, and whether certain flows between nodes are more prevalent than others. Moreover, the freight transport characteristics of the network are largely ignored (e.g. capacity, rerouting ability).

Risk-agnostic freight model approaches

Risk-agnostic freight modelling approaches to quantify resilience add a dynamic element to the network-based approaches by using a freight transport model while still applying metrics that originate from graph theory.

The main difference compared to network-based approaches is that a freight model is used to quantify logistics or transport-relevant impact metrics, compared to purely network-based impact metrics. Moreover, the freight model commonly captures information on the origin and destination of flows, infrastructure capacities, time and cost elements, and other transport and logistics constraints, all of which are absent from static network-based approaches**.** Common metrics used to measure the resulting cost for users as a result of these node or link removals are the total additional travel time, logistics costs, and the value of trade disrupted.

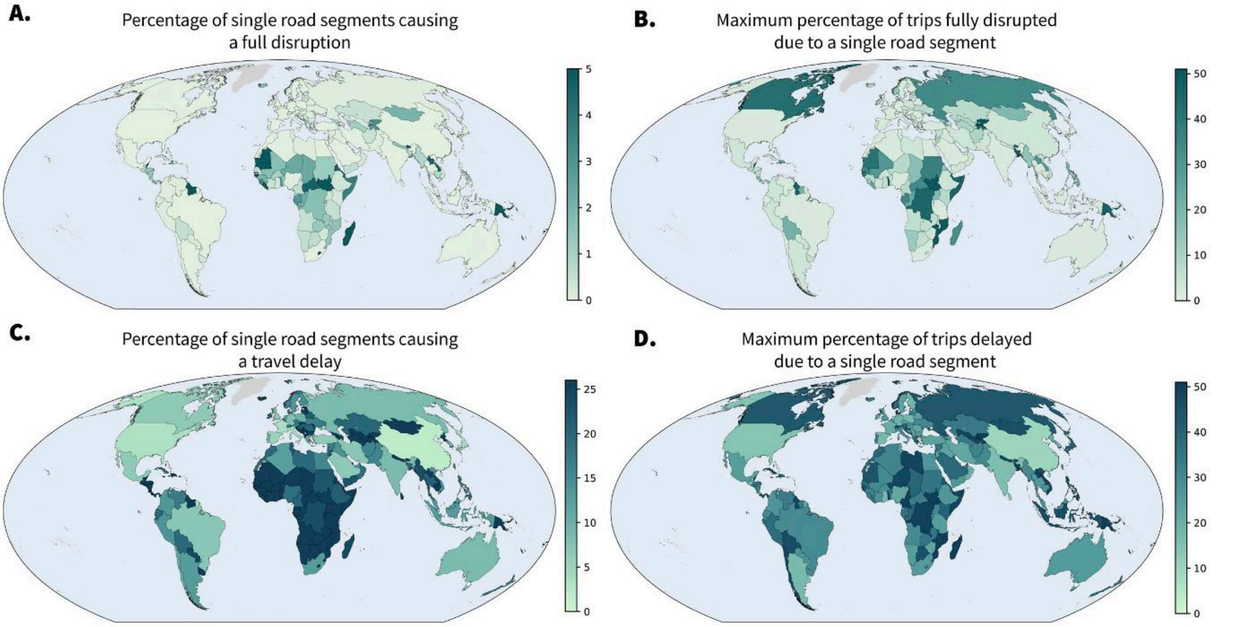
By measuring the impacts of network removal strategies, percolation methods allow quantification of the resilience of individual transport assets as well as the transport network as a whole; transport systems with more redundancy will be less affected by the removal of network elements and experience fewer user losses. There are different node and link removal strategies that can be incorporated into percolation approaches, all of which serve different purposes. Three commonly used categories of removal strategies are:

- <u>Targeted attack</u>: This is considered the simplest network removal strategy. With this strategy, a single edge is removed from the network at a time, after which flows are reallocated within the network. Targeted attacks resemble local disruptive events (e.g. landslides, road closures) and measure the criticality of the transport segment to the network as a whole. This approach helps compare and contrast segments to identify their relative importance.
- <u>Local attack</u>: The second network removal approach estimates the impact of local attacks, which affect multiple transport segments within a defined area. Similar to targeted attacks, the impacts after reallocating the flows are evaluated, but in this case, multiple transport elements are removed from the network. Local attacks represent events that affect wider spatial areas simultaneously, such as earthquakes, large flood events, man-made disasters, or electricity outages. Instead of comparing individual transport segments to one another, local attacks measure the importance of a cluster of transport segments in the functionality of the overall network. There are no universal rules for determining the size of the disrupted area.
- <u>Random attack</u>: The third network removal strategy considers the removal of multiple network elements but in a randomised fashion. The number of elements to be removed at the time has to be decided, and often, an incremental strategy is adopted (e.g. at first, 1% of the network is removed, then an additional 1%, and so on) until a certain level of service or user impact is

reached. Random attacks resemble extreme events that may happen at multiple places simultaneously but have limited spatial correlation (e.g. a storm or multiple traffic accidents).

For example, Koks et al. (2023a) applied a percolation method following the three network removal approaches described above for the global road transport network using a simplified origin-destination flow allocation method. Figure 8 presents the results of the targeted attack strategy (in this case, single road removal). Figure 8.A shows that for countries in Sub-Saharan Africa, Laos, Guyana, Suriname, and Papua New Guinea, there are multiple single road segments that, if disrupted, can cause the full interruption of network flows. Figure 8.B indicates the maximum percentage of trips disrupted because of a single road segment. Figure 8.C and Figure 8.D illustrate how the removal of road segments can create travel delays. To summarise the results, while travel delays resulting from road segment closures are common across countries, full disruptions are more likely to occur in emerging economies due to lower network redundancies.

Figure 8. Results of the global road criticality analysis



Note: Figure A shows the percentage of road segments causing full disruption between at least two parts of the country. Figure B shows the maximum percentage of trips fully disrupted due to the removal of a single road segment within a country. Figure C shows the percentage of road segments that create a travel delay between at least two parts of the country. Figure D shows the maximum percentage of trips delayed due to the closure of a single road segment within a country.

Source: Koks et al. (2023a).

Risk-informed freight-model approaches

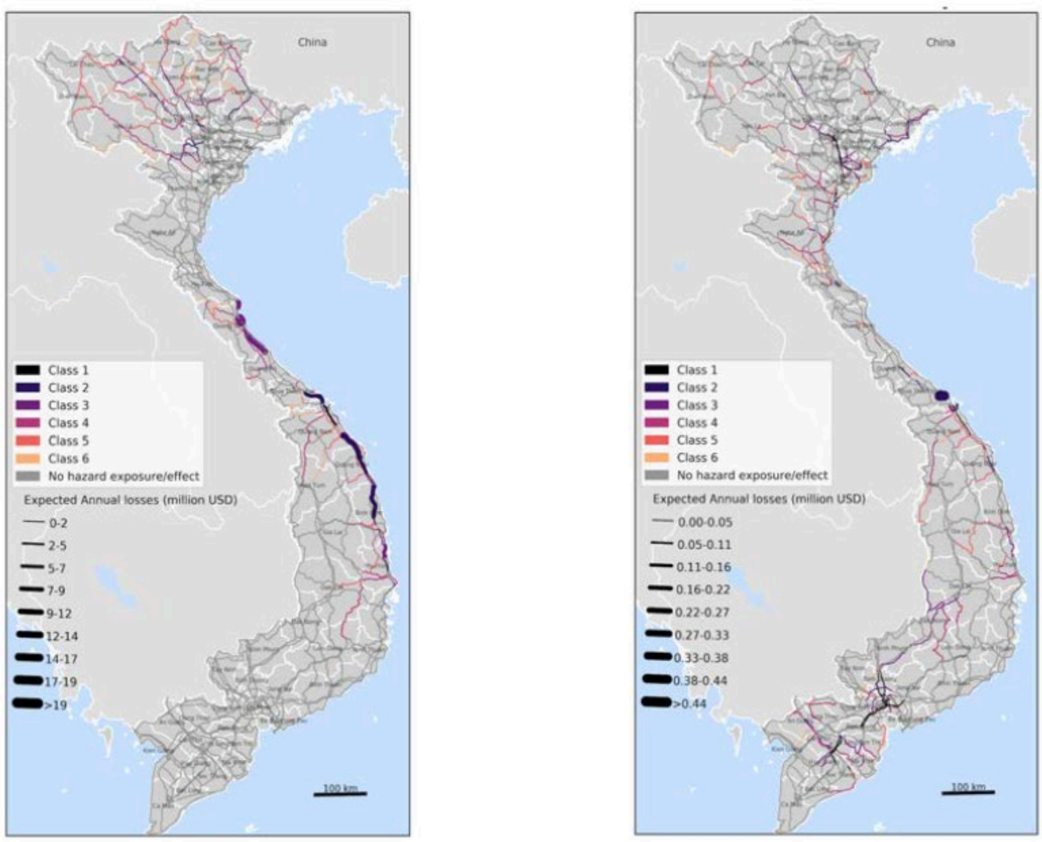
The risk-agnostic approaches described above do not specify the cause of a disruption and how likely the disruption is to occur. However, if this information is available, a risk-informed model approach can be adopted. In other words, underlying risk data is introduced to perform risk-informed network removal strategies based on the probability of disruption. This allows quantifying the criticality of different transport elements, or the network as a whole, similar to the previous approaches, but in this case, from a risk perspective. The approaches described previously are still used and often form the input to risk-informed analyses. There are two primary categories of risk-informed analysis:

- Asset-based analysis: Here, the output from any of the aforementioned methods is adopted (quantifying the user impact per transport segment) and combined with additional information on the likelihood of a particular disruption happening. This could, for instance, be the probability of a road experiencing flooding, a segment of rail experiencing extreme heat causing buckling, a port experiencing high winds causing closure, or a segment of a river experiencing low water levels which impede vessel movements. The criticality metric adopted is then the combination of the user cost or impact metric and the likelihood of occurrence. The latter could be in a more binary fashion (e.g. the likelihood of occurrence is once every two years) or in a more risk-based fashion. Risk-based approaches compute the integral over a set of events with different likelihoods of occurrences and their resulting impacts (e.g. a one-in-two-year event causes a three-day disruption, a one-in-five-year event causes a ten-day disruption, etc.). Such criticality analysis thereby allows the prioritisation of investments to improve the resilience of particular transport segments given the risk under consideration.

- Event-based analysis: While criticality analyses are useful for comparing segments within a network, they are less informative for quantifying the resilience of the network as a whole against disruptive events. This is because (i) the resulting metrics across transport segments are non-additive, and (ii) segments that do not appear critical within a targeted removal strategy may become critical during simultaneous network disruptions. Therefore, to capture the resilience of the transport system, a series of realistic (risk-informed) simultaneous disruptions should be implemented, and their impacts should be quantified. This could, for instance, be simultaneous port disruptions during a single cyclone or earthquake, a large-scale drought affecting multiple segments of an inland water network, or a flood affecting multiple roads. It goes without saying that performing event-based approaches is data intensive and, therefore, inherently difficult. However, they do allow for deriving impact metrics that are more relevant for national decision makers (e.g. the total system loss that can be expected once every few years) and enable logistics services to develop informed resilience strategies (e.g. the need for certain inventories or warehouses, or route and mode diversification strategies).

An example of a risk-informed asset-level analysis is shown in Figure 9 for the Vietnam national road network, based on Oh et al. (2019). Here, the authors developed a national freight transport model, which allocates transport flows on the national road network. Then, the authors performed a targeted attack percolation method, with the total system loss defined as the total rerouting costs and macroeconomic loss due to industry production disrupted by freight unable to reach its destination. The total economic loss is then combined with the likelihood of road segments being affected by landslides and river flooding (and typhoon winds and flash floods). This example highlights how when using a risk-informed criticality approach, the most critical links can vary substantially based on the type of risk considered. Hence, resilience approaches could be targeted for specific risks across the transport network.

Figure 9. Results of the national transport criticality analysis of Vietnam



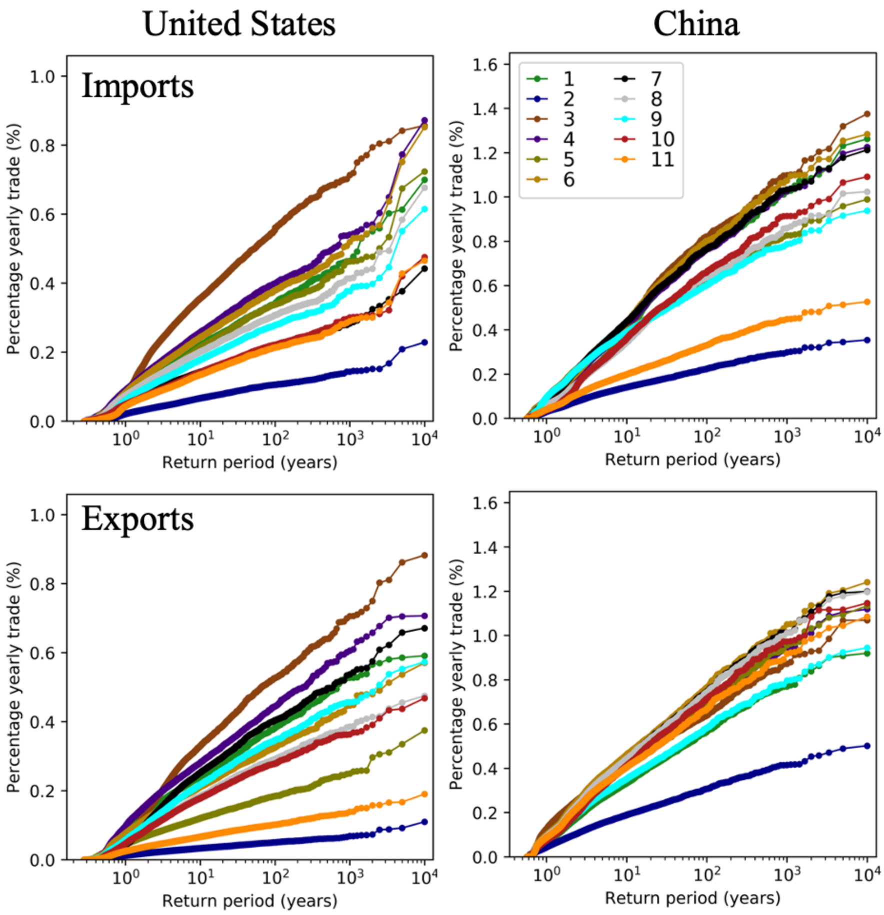
A. Landslide susceptibility maximum risks **B. River flooding maximum risks**

Note: The result combines information on the modelled freight flows on the network (in USD per year) and combines this with the likelihood and intensity of landslides (A) and river flooding (B). In this example, the criticality of a road is represented by expected annual losses due to disruption.

Source: Oh et al. (2019).

An example of an event-based approach is the quantification of trade flows at-risk disruption as a result of hurricane events affecting one or multiple ports simultaneously. Based on 10 000 years of synthetic hurricane event data (Bloemendaal et al., 2020a,b) an estimate of the amount of maritime trade flowing through each port and a relationship between hurricane wind speeds and the resulting port downtime, Verschuur et al. (2021b) quantified the likelihood of trade being affected at the country level. Figure 10, for instance, shows the results for the United States and China, with the y-axis representing the percentage of annual trade affected during a single hurricane, the x-axis representing the likelihood of occurrence, and the colours indicating 11 different economic sectors. The results demonstrate that for both countries, between 1.0% and 1.5% of annual imports and exports could be affected due to a single hurricane event.

Figure 10. The percentage of annual trade that could be disrupted by a hurricane or typhoon



Note: The top row presents the disruption of USA/China imports, and the bottom row presents the exports. The return period refers to the inverse of the annual exceedance probability (a 100-year return period has a 0.01 probability of occurrence every single year). The colours indicate the different economic sectors affected.

Source: Verschuur et al. (2021b).

What-if/storyline approaches

What-if scenario approaches, or storyline approaches, are qualitative complements to the asset-based or event-based analyses described above. However, instead of an exhaustive exploration of all network vulnerabilities, a small number of extreme scenarios or storylines are adopted, the impact of which can be modelled within a transport model or by means of a "serious game" (i.e. a hypothetical setting where a scenario will be acted out with relevant actors involved) (Shepherd, 2016; van den Hurk et al., 2023). Storyline approaches are emerging as a powerful complement to traditional approaches that investigate the impacts or resilience of a system for four reasons. First, decision makers may be more interested in a small subset of extreme conditions that surpass a tolerable threshold of service disruptions. Second, many types of risks are hard to quantify and may therefore be ignored in a risk-based approach. Third, there are often a multitude of related impacts to a system that are hard to capture in a single modelling framework, and finally, a set of storylines allows decision makers to construct emergency response strategies for specific case studies and communicate them more easily. Storyline approaches could still be informed by risk modelling but often are less prescriptive and more explorative (Koks et al., 2023b).

Storylines are particularly relevant for disruptive scenarios that have a low probability of occurrence and major potential impacts. Examples of such disruptive events for freight transport networks are a global pandemic, geopolitical conflict (which leads to the closure of major transport routes), terrorist attacks, or other unexpected events (e.g. the blockage of a major maritime chokepoint, a river becoming unnavigable). These kinds of events can impact freight transport systems in diverse ways, including the closure of key nodes, trade restrictions between countries, or rising transport costs, all of which are hard to explore using traditional modelling tools. For instance, following the Arab Spring in 2011, port activity in multiple countries was affected (e.g. Libya, Syria, Yemen) (UNCTAD, 2022). More recently, the Russian invasion of Ukraine in February 2022 disrupted maritime transport across Black Sea ports, resulted in embargos on Russian commodities, raised the logistics costs of transport routes through Russia, and forced the rerouting of rail freight between China and Europe, among other factors (UNCTAD, 2022). Therefore, a storyline approach is helpful for understanding the resilience of a country or regional transport network to such events and is often performed in close collaboration with the decision makers involved to brainstorm realistic scenarios.

Qualitative approaches

The approaches to quantifying resilience discussed thus far largely refer to the structural properties of transport networks within countries or regions. They do not necessarily reflect the softer or intangible elements that shape the resilience of freight transport networks. For instance, quantitative modelling frameworks often do not explicitly capture the elements that determine the amount of time needed to restore a freight transport service after a disruption, how transport systems cope with disruptions in the first place, and how decision makers are planning and preparing for various risks. These intangible elements are intrinsically linked to the wider governance of transport systems and how resilience is embedded within them.

Generally speaking, there is limited evidence pertaining to differences in transport resilience governance between countries. Institutional and policy levers that can shape the resilience of transport services include (Chow and Hall, 2023):

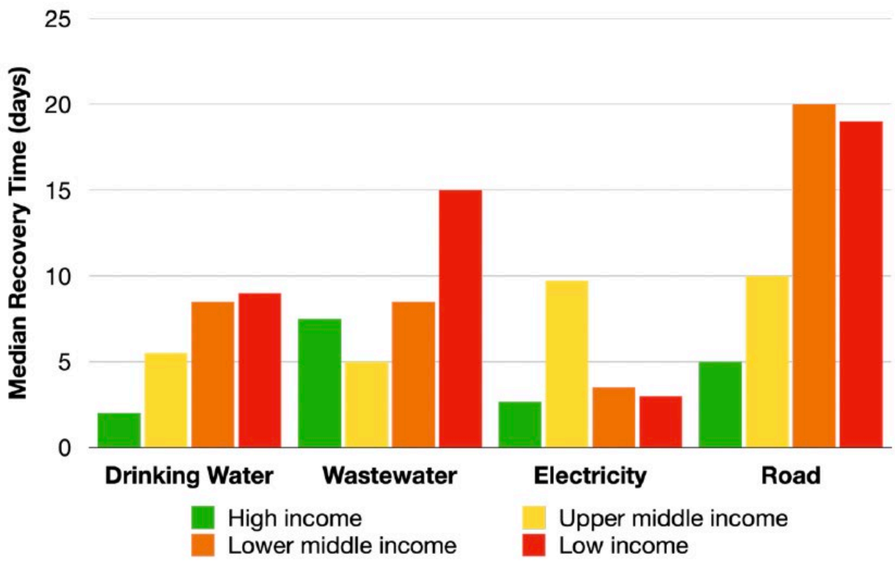
- The presence of national resilience policies, strategies or plans.
- Quality of freight transport services.
- Technical capacity.
- The inclusion of resilience conditions in the transport design cycle.
- The presence of technical standards.
- Disaster preparedness and response planning.
- Financial instruments to fund resilience projects and cope with extreme events.
- Government effectiveness (e.g. corruption, stability).

These intangible or softer resilience factors should be considered, or at least acknowledged, when comparing countries to avoid purely focusing on network redundancy measures. In addition, softer factors can help countries to improve the resilience of their freight transport system without improving the spatial configuration of the transport network.

Alternative approaches, such as surveys, interviews, or case studies, can provide in-depth information for which quantitative information is not available. For instance, the recent “Global Infrastructure Resilience Survey” gauged the most important factors behind infrastructure resilience across 86 countries (Chow and Hall, 2023). The respondents identified resilience policies, disaster preparedness, and financing as the three most important factors, although they varied across country groups (as classified by their income status). For instance, while institutional stability and technical capacity are important in low- and lower-middle-income countries, they are considered less important in high-income countries, which identify maintenance and standards as being more important.

The survey also identified that the main resilience management challenge is the lack of resilience policies, and in particular, guidelines and policies that are routinely improved and consistently applied. Similarly, the transport sector was identified as the most frequently impacted by climate hazards in high and upper-middle-income countries compared to other sectors. High- and middle-income countries reported the loss of service capacity during impacts was most pronounced in the transport sector. Moreover, compared to other sectors, the median recovery time of transport disruptions was consistently high: approximately 5 days in high-income countries, 10 days in upper-middle-income countries, and nearly 20 days in lower-middle and low-income countries (Figure 11).

Figure 11. Reported median recovery time of infrastructure services due to a significant hazard, split by infrastructure sector and income group



Source: Chow and Hall (2023).

Key considerations

The previous sections above have outlined various practical approaches to quantify freight resilience, either in a quantitative or qualitative manner. The following considerations should be kept in mind when approaching the question of which method to apply in practice:

- Choice of approach. the type of approach is a normative decision and depends on the objective of the study and the information at hand. Without detailed information on network flows, graph-based criticality analyses are often the only alternative. If flow information is available or a transport model has been developed, either risk-agnostic or risk-informed approaches could be taken. As mentioned, the risk-agnostic approach can be seen as an initial step in performing a risk-informed approach. Storyline/What-if scenario approaches often serve a different purpose and can complement other approaches.

- Unimodal versus multi-modal. The above approaches have been mainly discussed within the context of a single transport mode. However, similar approaches could be developed for multi-modal transport networks, although is less common in the literature. The limited evidence available has indicated that multi-modal transport systems can be more resilient than unimodal ones due to the ability to reroute goods across modes or routes. However, setting up multi-modal transport models is more challenging, given the demand for additional data. In addition, the ability to reroute goods across modes may be constrained in practice for several reasons, particularly in the short term due to contracts, capacity, or other factors.

- Macro-logistics and behavioural considerations. Most approaches to evaluate the criticality of transport networks do not consider the logistical processes involved in freight transport and evaluate criticality based only on network properties (graph-based models) and capacity constraints (transport models). There is still a limited understanding of network behaviour following disruptive events, particularly within macro-logistics, and how this behaviour might influence the resilience of the system. For instance, after port disruptions, liner companies may not always be able to reroute goods to alternative ports, given existing contracts, horizontal integration within logistics chains, and other constraints (e.g. depth constraints of channels, port infrastructure constraints). Similarly, models that consider the recovery of networks must typically make assumptions about how the time needed to restore transport services and which assets are prioritised for recovery. In other words, more empirical data is required to better integrate behavioural factors into model-based approaches.

- Calibration. Most quantitative resilience approaches are difficult to calibrate due to a lack of empirical data. For instance, freight models are often calibrated using annual data at certain nodes or edges. There have been very limited efforts to calibrate such freight models during extreme events. Moreover, users may prefer different objectives during extreme events (e.g. loss aversion) compared to normal conditions (e.g. where they minimise costs or travel time).

Enhancing freight resilience in Central and Southeast Asia

Strategies to improve regional freight resilience in Central Asia

The ITF survey questionnaire included a variety of questions regarding regional freight resilience in both regions. For Central Asia, 380 survey respondents indicated their current resilience practices and policies (see Annex A, Figure A1). Despite a mix of options selected, the most common current resilience policies include (i) incorporating resilience into national freight plans and project prioritisation, (ii) the diversification of transport routes and modes, (iii) improving routine infrastructure asset monitoring and maintenance, (iv) risk monitoring and modelling, and (v) incorporating resilience into project design and implementation. In other words, existing resilience practises are comprised of a combination of organisational resilience (top-down policies, risk modelling) with network-based approaches (route and mode diversification) as well as asset-level resilience (routine maintenance). On the other hand, policies related to emergency preparedness and management remain limited.

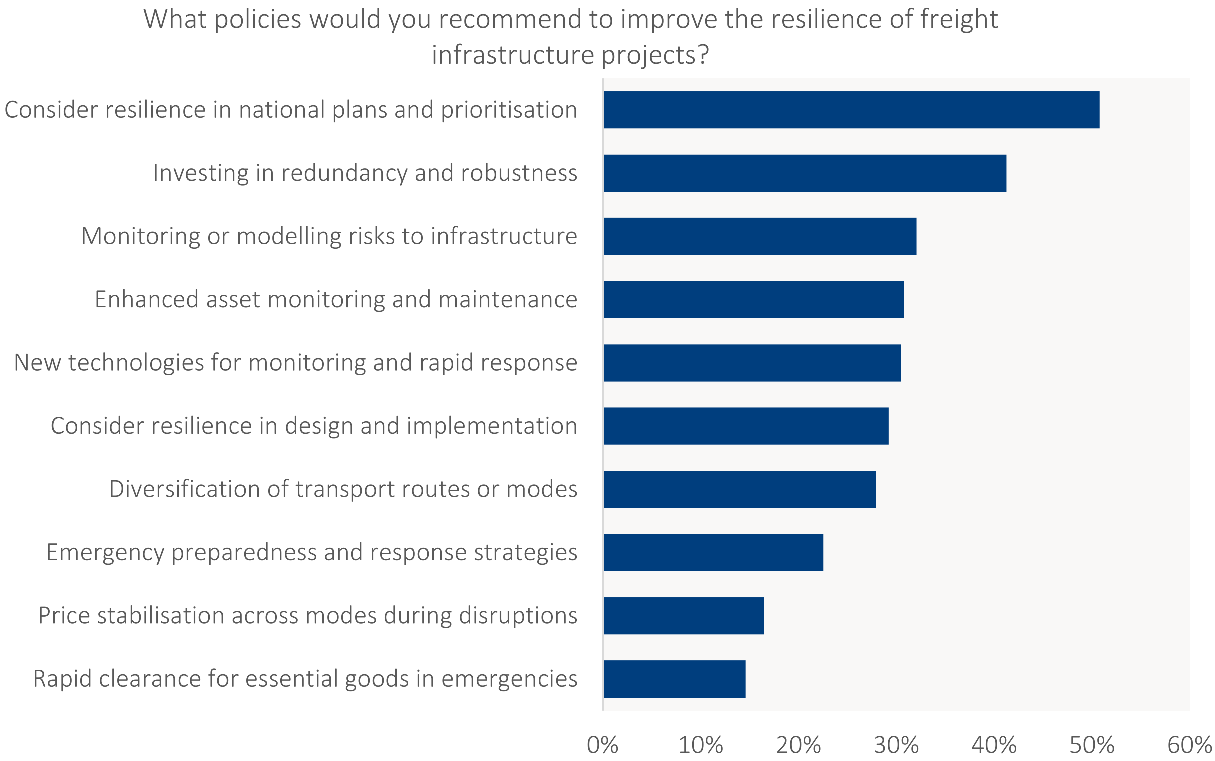
In terms of future recommended resilience improvements, (i) further incorporating resilience into national freight plans, (ii) investing in infrastructure redundancy and robustness, (iii) monitoring or modelling risks to infrastructure, and (iv) adopting advanced technologies for real-time monitoring and rapid response were identified as key resilience options, as presented in Figure 12. Based on the existing literature (see Box 1) and the survey results, three recommendations for enhancing the resilience of freight transport in Central Asia can be made:

1. <u>Embedding resilience in policy</u>. According to survey respondents, the resilience of the regional freight transport network is receiving top-down attention, but resilience has not been adequately embedded in project planning or prioritisation. A stronger top-down policy push is therefore required to mainstream resilience in national freight plans and project planning and prioritisation. For Central Asia, it is increasingly important that resilience planning occurs on a bi- or multi-lateral level, given that the major freight corridors span across borders.

2. <u>Improving network redundancies</u>. Existing network redundancies are still insufficient from a resilience perspective, making the system particularly prone to risks that can affect the system as a whole (e.g. conflicts and pandemics). Network redundancy should be planned alongside infrastructure expansion projects, including better capacity for modal substitution.

3. <u>Technology for emergency preparedness and response</u>. There are currently limited emergency preparedness and response mechanisms to manage shocks to the regional freight network. The use of advanced technologies to monitor freight flows can benefit this objective, as well as an emphasis on improving the capability to respond rapidly to shocks. Scenario and storyline exercises with regional stakeholders can help to identify shortcomings within existing emergency response plans and the interventions that could help to improve them.

Figure 12. Survey results on future resilience improvements for Central Asia



Box 1. Embedding climate change into transport design in Central Asia

A recent Asian Development Bank (2023) report sets out different types of strategies to make land transport in Central Asia more resilient to shocks from climate-related extremes. It provides practical recommendations within the Central Asia context to adapt engineering guidelines and standards for transport infrastructure. These solutions can be summarised in four categories:

- Stabilising soils under roads to protect from flooding, as well as ensuring that drainage systems can cope with future climate conditions.
- Reinforcing slopes against soil erosion using grey engineered or bioengineering solutions.
- Introducing modified bitumen to protect roads from extreme heat, both extreme high temperatures and extreme low temperatures.
- Installing barriers to protect against avalanches and rockfalls driven by snow accumulation or excessive melting periods.

The report also provides a comparison between adaptation options in terms of embedded CO2 emissions. These examples highlight trade-offs between solutions that are more durable but may requires more financial resources and have greater embedded carbon emissions.

Strategies to improve regional freight resilience in Southeast Asia

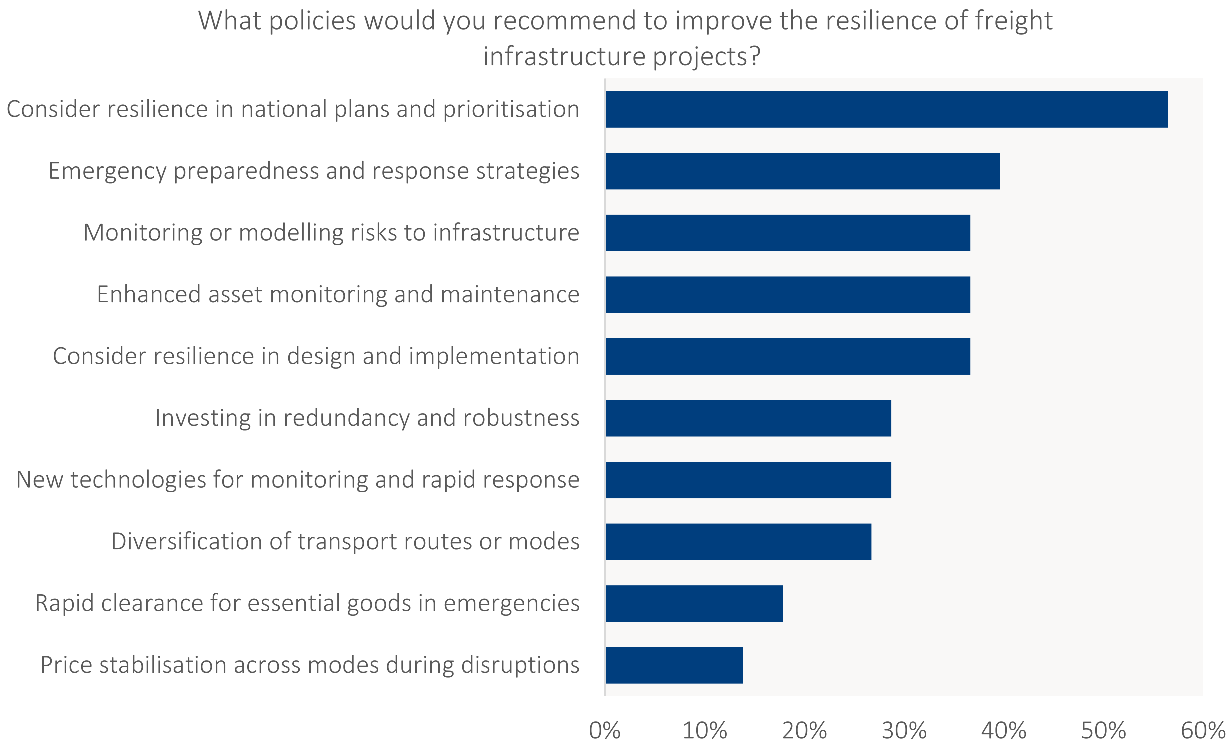
In total, 124 survey respondents in Southeast Asia reflected on current resilience practices and policies in the region (see Annex A, Figure A1). Most respondents identified the following resilience policies as most indicative of current practises: (i) emergency preparedness and response strategies for infrastructure disruptions, (ii) incorporating resilience into national freight plans and project prioritisation, (ii) adopting advanced technologies for real-time monitoring and rapid response capabilities, and (iv) improving routing asset monitoring and maintenance.

Compared to Central Asia, there is a larger focus in Southeast Asia on emergency preparedness and response using advanced technologies, yet less focus on policies for network-based resilience (redundancies and diversification). In other words, the existing resilience practises are a combination of organisation resilience approaches (top-down policies, real-time monitoring, emergency preparedness) and asset-level resilience (routine maintenance).

The recommended resilience improvements in the region, as shown in Figure 13, include (i) incorporating resilience into national freight plans and project prioritisation, (ii) emergency preparedness and response strategies, (iii) risk monitoring and modelling, (iv) embedding resilience in project design, prioritisation, and asset-level maintenance. Based on the survey results and previous literature (see Box 2), three recommendations for enhancing freight transport resilience in Southeast Asia can be made:

1. <u>Embedding resilience in policy</u>: While existing national plans and project prioritisation do not yet provide enough guidance on how to improve resilience and make sure resilience is prioritised in project selection and appraisal. However, various initiatives are ongoing, in particular on a multilateral level, to embed resilience in various high-level policy initiatives, including maritime transport and hinterland-dry port networks (see Box 2).
2. <u>Improving resilience through multi-modal freight transport</u>: Approaches to diversify flows and embed redundancies in the regional freight networks are underdeveloped and should be prioritised in the future. In particular, local redundancies are important to enable flows to be rerouted during localised shocks such as climate extremes or disasters. On the other hand, the regional freight network of Southeast Asia includes a variety of modes (air, land, and maritime), with the potential for modal substitution currently underdeveloped. Policies aiming at improving resilience from a multi-modal perspective should receive more attention, particularly when alternative modes are being further developed (road and inland water transport).
3. <u>Mainstreaming resilience into new infrastructure expansions or upgrades</u>: The Southeast Asia freight network is already well developed. However, given the expected demand surge in the region, supply chain diversification away from China, and the modernisation of freight transport networks (to improve the reliability of freight flows), new infrastructure will need to be constructed, and infrastructure upgrades are required. Given that Southeast Asia is one of the most climate-vulnerable regions, it is essential to mainstream climate resilience into these infrastructure developments, as well as within asset management cycles. To do this, it is important to (i) have a clear understanding of how climate change may change important input parameters for infrastructure design and (ii) understand which transport segments require the most urgent adaptation efforts through criticality analysis.

Figure 13. Survey results on future resilience improvements for Southeast Asia



Box 2. Improving the resilience of regional freight transport networks

Resilience of freight transport systems is increasingly recognised as being an important pillar of the Asia transport network. For instance, the Regional Action Programme for Sustainable Transport Development in Asia and the Pacific (2022-2026) has resilient transport and logistics networks a main priority (UNESCAP, 2022).

Resilience is currently being mainstreamed in Asia through various high-level international initiatives, for instance the International Agreements on the Asian Highway Network, the Trans-Asian Railway Network, and Dry Ports. These initiatives aim to improve the efficiency and sustainability of freight transport, as well as the resilience by offering a more diversified and interconnected regional transport network. However, the primary focus remains the improvement of transport connectivity, without an explicit focus on resilience. Resilience is recognised within the scope that improved connectivity can (i) diversify freight flows from road to a mix of road and rail, and (ii) better cope with large-scale disruptions such as the COVID-19 pandemic. Moreover, it recognises the need for improved cross-border crisis-response mechanisms during large-scale disruptive events.

Conclusions

This paper aims to provide a methodology for evaluating the resilience of freight transport systems, contextualised in the regional freight transport systems of Central Asia and Southeast Asia. The paper proposes an overarching framework that captures the risk and resilience considerations of freight transport networks. It approaches freight resilience on separate yet interconnected levels, including the asset level, the network level, the user or operator level, and the organisation level.

Several quantitative and qualitative approaches to evaluate freight resilience are considered, classified by the information required and the intended application. Quantitative approaches include criticality-based approaches that are intended to compare the criticality of different infrastructure assets within a freight transport network. These approaches can range from relatively simple network or graph-based analysis up to complex dynamic freight transport models, with or without detailed asset-level risk information. Qualitative approaches to evaluate resilience are complementary to quantitative approaches and are intended to evaluate softer or intangible aspects of freight resilience, such as policies, emergency preparedness and response, institutional capacity, and resource mobility, among other factors. Through surveys, these softer aspects can be highlighted, and gaps can be identified. Storyline or scenario approaches help decision makers determine the appropriate response during extreme scenarios (low probability with high impact) and highlight shortfalls in existing approaches.

The resilience framework is contextualised within the regional setting of Central Asia and Southeast Asia through the use of literature reviews and a regional survey. The two regions face different risks and, thereby, have unique resilience challenges. Central Asia has been significantly affected by the COVID-19 pandemic and, more recently, the Russian invasion of Ukraine, both of which have put enormous pressure on the regional freight system. While the region managed to adapt to these pressures by diverting flows from the Northern to the Central and Southern Corridors, the challenges of this adaptation highlighted a need for improved resilience to cope with sudden shocks, mainly because of limited route and mode diversification. At the same time, climate extremes, such as extreme heat, flooding and landslides, threatened regional infrastructure. Southeast Asia managed to cope better with the pandemic, and freight demand is expected to grow in the years to come, mainly because of production diversification away from China. While freight infrastructure is more developed compared to Central Asia, there is still an untapped potential for better cross-border freight integration and modal substitution. However, Southeast Asia is one of the most climate-vulnerable regions, with climate extremes happening frequently and disrupting regional freight flows.

In line with the literature, the survey among freight actors in Central Asia highlighted geopolitical conflict, climate extremes and political instability as key risks for the region's freight transport sector, followed by sudden demand shifts and pandemics. In Southeast Asia, the respondents identified climate extremes as the key risk for regional freight transport, followed by geopolitical conflict, sudden demand changes and political instability. These results illustrate that the two regions have different priorities in terms of the risks that policy makers should prepare for, with climate extremes and sudden demand changes being more prevalent in Southeast Asia and geopolitical conflict, pandemics and political instability being a greater risk in Central Asia.

Freight actors in both regions also identified the focus of existing freight resilience policies and practises and their priorities for further improvements. Based on these survey results and the literature review on the regional setting, several priorities for freight transport resilience could be determined.

For Central Asia, the three resilience priorities identified are:

1. Embedding resilience in national and cross-border policy.
2. Improving network redundancies.
3. Technology for emergency preparedness and response.

For Southeast Asia, the three resilience priorities identified are:

1. Embedding resilience in policy.
2. Improving resilience through multi-modal freight transport.
3. Mainstreaming resilience into new infrastructure expansions or upgrades.

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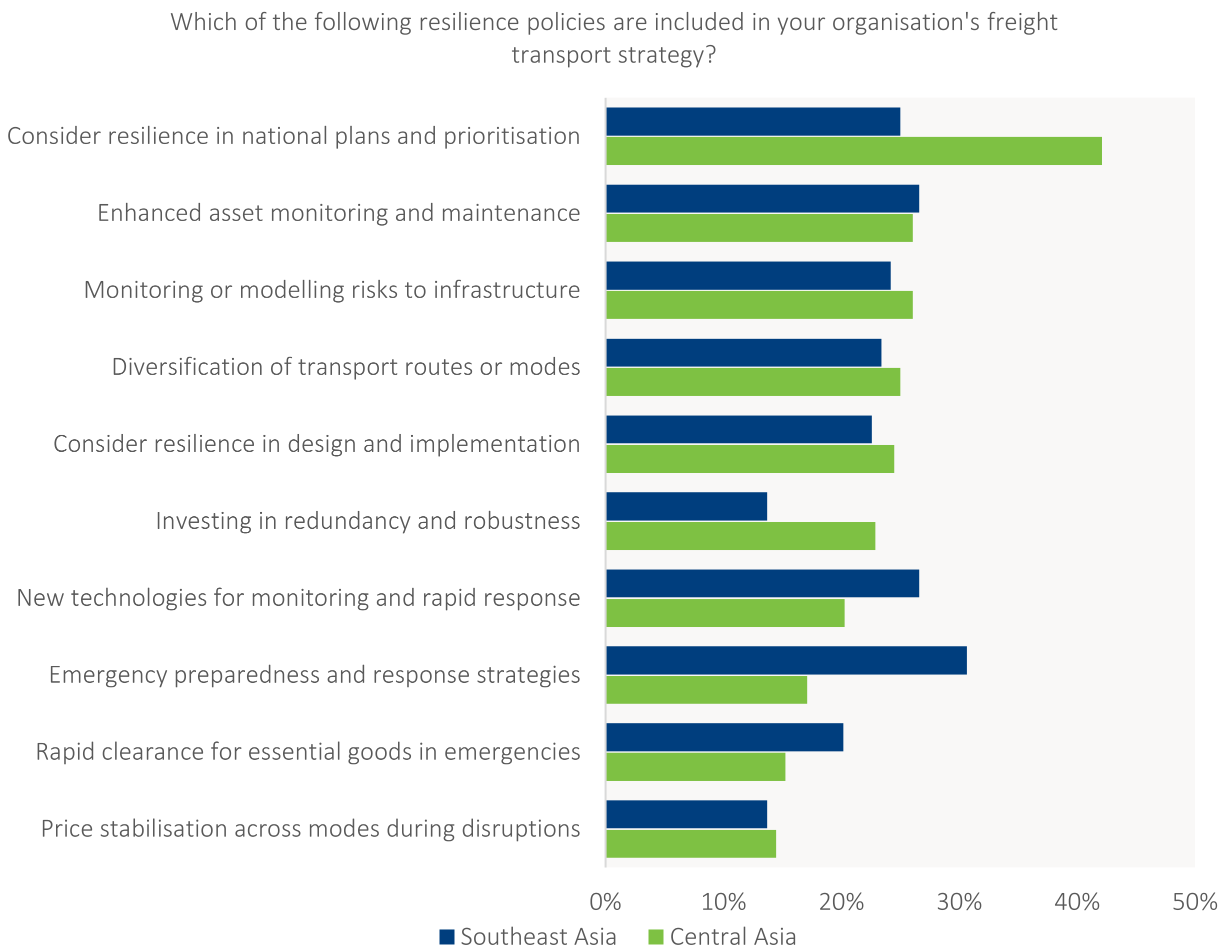
Annex A. Survey results

Figure A1. Results of the survey question on existing resilience policies for Central and Southeast Asia



Enhancing freight transport resilience through analytical frameworks

Applications to Central and Southeast Asia

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The ITF leads the transport component of the SIPA programme (SIPA-T). The SIPA-T project helps decision makers in Central and Southeast Asia by identifying policy pathways for enhancing the efficiency and sustainability of regional transport networks. Project outputs include two regional studies that explore opportunities to improve the connectivity, sustainability, and resilience of freight transport systems in Central and Southeast Asia.

This paper is the third in a series of four ITF expert working papers that collectively provide the methodological foundation for the two SIPA-T regional freight transport studies.

Related publications

The full series of SIPA-T expert working papers on regional freight transport includes the following:

1. Enhancing freight transport connectivity through analytical frameworks
2. Enhancing freight transport decarbonisation through analytical frameworks
3. Enhancing freight transport resilience through analytical frameworks
4. Evaluating the relationships between connectivity, decarbonisation and resilience in freight transport

Access these papers, more information, and other SIPA-T project deliverables by scanning the QR code or visiting the link below:

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