NEW ECONOMIC REGULATION FOR TRANSPORT IN CASE OF EMERGENCY EVENTS

Deliverable 5 - Handbook

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Handbook

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1. Foreword

This document proposes guidelines for analyses of infrastructure networks and models for the study of transport flows to obtain possible regulatory indications to be applied in cases of emergency.

The document is made up of two parts: the first, more substantial, concerns analyses - static and dynamic - of infrastructure networks and traffic flows, as well as highlighting the information required for these analyses to be effective. The second part focuses on the subsequent planning and regulatory phase, which outlines the general lines for the development of tools (models) and actions (collection and management of data and information, regulatory reviews). The indications presented in the second phase are outlined here as possible lines of intervention when dealing with an emergency which, even though foreseeable in general terms, will always have unforeseen forms, modalities and impacts.

The work - drafted by a working group belonging to the Italian Center of Excellence on Logistics, Transport and Infrastructure (CIELI) of the University of Genoa - is the last deliverable of a project submitted in the fall of 2018 by the City of Genoa to DG Reform for funding under the *Structural Reform Support Service*[1], which, taking as its starting point the collapse of the Morandi bridge in the summer of that year, aspired to study possible forms of regulation that would not affect a single mode of transport, but the whole transport system itself (different infrastructures and services, as well as multiple operators).

The project has highlighted the need to prepare the conditions for the realization of a continuous monitoring system of the transport network that allows for the analysis of phenomena and impacts - both at local and macro-regional scale - to identify the most critical elements of the network and to set up appropriate risk mitigation interventions and response in the event of a possible emergency.

[1] Deliverables of the project are freely available at CIELI website (www.cieli.unige.it).

2. Preliminary definitions

2.1. Characteristics of emergencies in transportation systems

In the field of transport and logistics, emergencies determine either the interruption or a drastic reduction of the flow of people and goods and can result from multiple causes.
The factors that characterize differing emergencies can be traced to:

- The natural or anthropogenic **cause** of the emergency event capable of reducing or even erasing the level of service of a transport infrastructure. In this sense, the emergency includes both the case of total unavailability of one or more nodes or arcs of the network - as in the case of the fall of the Morandi bridge (2018) and the railway accident in Ranstatt in 2017 - or important maintenance works able to significantly reduce the conditions of use of the infrastructural network.
- The **predictability** of the event, thus distinguishing between predictable and non-predictable events.
- The **impact** of the emergency, i.e. the size of the population and area affected by the emergency, including any spillover effects (or cascading effects) on other territories, populations, infrastructures.
- The **duration** of the effects of the emergency, i.e. the time necessary for the restoration of pre-emergency conditions.

Consistent with the objectives of the project, of which this Handbook represents the synthesis, emergencies are considered here as events that significantly reduce the level of service on a part of the infrastructure network, that generate a significant change in traffic flows (at different scales) and whose consequences cannot be resolved in a few hours or a few days.
The predictability or not of the event, and therefore of the consequent emergency, highlights the crucial importance of putting into place measures and actions to address the damage caused by the event more effectively.

2.1.1. Unpredictable emergency events

All emergencies that are caused by natural or "indirectly exogenous" events belong to this category of emergencies.

- Primary unpredictable emergencies. These are caused by natural events generally of an extraordinary or exceptional kind (earthquakes, floods, particularly violent meteorological phenomena, sea storms, etc.). These phenomena are generally unforeseeable except, in some cases, in the very short term, but not in time to take adequate contrasting measures.
- Secondary unpredictable emergencies. These are emergencies that firstly follow infrastructural shocks or malfunctions that may derive from the natural events described above, but not contemporaneous (posterior) either to their occurrence, or secondly caused by technical-behavioral issues. In the first case, they are due to land subsidence (landslides, landslips, etc.), whilst in the second case, the emergencies stem from sudden interruptions to or malfunctions of systems (collapses, shutdowns, failures of various kinds) in more or less direct relation to the state of maintenance and monitoring of the systems themselves. In these cases, we adopt the definition of "indirectly exogenous" for the causes, since they are not of natural origin, but are instead connected with the general state of the systems in ways that are sometimes complicated to define, and give rise to emergencies that occur in an unpredictable manner.

2.1.2. Predictable or planned emergencies

These are emergencies that occur as the result of planned interventions and therefore by definition predictable. The main causes of these emergencies are linked to maintenance interventions on transport infrastructure that cause a marked drop in performance and, in many cases, actual closures and service interruptions connected to extraordinary maintenance.
The latter can take on the character of an emergency when they simultaneously involve several infrastructure networks of the same territory, due to insufficient ways and means for coordinating interventions between the various infrastructure managers.

2.2. Criticality in transport

2.2.1. Critical infrastructure

The critical nature of the elements that shape the transport network can be of three types: taxonomic, functional and operational.

The first form of criticality, **taxonomic**, simply indicates that a series of infrastructures are classified as critical by an authority body on the basis of a particular criterion. Normally, this criticality concerns all infrastructures that have the same characteristics (e.g. seaports active in international traffic; highways; Alpine passes; etc.) and not single elements of each network.

Instead, **functional criticality** means a condition that depends on how the single element of the network is inserted in the remaining infrastructural network and territory. This criticality examines the potential of movement and development that one element and the network which it belongs to offers possible users. To evaluate this kind of criticality in transport systems a topological approach, using graph theory, can be used.

Operational criticality refers to the level of service in a transport system, or elements of it, in a given moment not only because of the infrastructure's static characteristics, but also because of the traffic that normally uses it.

We will focus on functional criticality (a static criticality), which examines infrastructure networks regardless of their traffic levels and which can be traced back to the concept of accessibility to suggest possible indicators. In the following sections of this document, we will discuss some elements of operational criticality.

2.2.2. Critical issues for individual modes of transport

To carry out a criticality analysis, land transport systems - road, rail, and local public transportation (LPT) - can be represented as spatial networks or graphs, where every single node represents a transport terminal and every arc corresponds to a linear transport infrastructure (or service, in the case of LPT) that enables movement between two nodes.

Transport networks can be described by carrying out both "micro" level analysis, i.e. at the level of a single arc or node of the network, and "macro" level analysis, aimed at providing a description of the properties of the entire network, including therefore the different transport networks serving the same territory. This approach captures users' possible intermodal path choices.

2.2.3. System criticality for the infrastructure network as a whole

The importance of modeling interconnected networks stems from the fact that relatively localized shocks occurring in a particular network can give rise to a cascading of shocks along the interconnected network, which in turn could lead to large aggregate effects. When two networks are involved in a shock, the ultimate effect is greater than the sum of the results that would occur in the case of destructive events involving only one of the two infrastructures. When a disruptive event occurs, there can also be indirect effects that affect the interconnected networks as a whole: in fact, direct physical effects can damage the interconnected infrastructures, also resulting in much broader social, demographic, economic, and political impacts.

In other words, two interdependent networks may be more fragile than each network considered alone. As the existence of isolated networks may be considered more of an exception than the norm, modeling "networks of networks" has received increasing scholarly attention in recent years.

In this context, it is important to emphasize how infrastructures are interdependent in many ways: for example, it is possible to consider physical interdependence, but also geographical, logical, functional and geospatial interdependence.

To model multilevel networks, the fundamental starting point is to define the way they are interconnected: depending on the way two infrastructures are connected, different aspects and characteristics of the infrastructure emerge.

In the case of transport infrastructures, the concepts of geographical interdependence and functional interdependence are particularly interesting.

In the first case, damage that initially affects only one infrastructure can also spread to another closely connected to it, for example, by mere geographical proximity. In fact, geographical interdependence occurs when the conditions of one infrastructure do not affect the conditions of another, but their elements are spatially close. This was the case with the collapse of the Morandi bridge, whose rubble interrupted rail traffic on the line below for several days.

Functional interdependence occurs when the needs of users utilizing one system can be met, at least partially, by another system that provides similar functionality. This definition can be applied where various modes of transport serve freight and passenger movement and is thus used to consider multimodal networks.

Once multimodal networks are constructed, it is possible to develop criticality analyses and compare the results obtained with those of the respective unimodal networks.

3. Emergency interventions

3.1. Emergency management organization

When an emergency occurs, measures are taken to deal with the inconvenience caused by the emergency. These measures can have different characteristics depending on the contexts and circumstances, but must always be characterized by maximum compatible timeliness and efficiency.
Timeliness is guaranteed by the pre-existence of agencies/institutions, dedicated or to be involved in emergencies. The organization and information should, as a rule, be contained, described and/or provided for in official documents of the agencies/institutions involved. The more accurate the contents and rules previously consolidated, the greater the timeliness guaranteed in the crucial phases of the emergency.
Efficiency will depend substantially on the overall content of the official documents mentioned above and the corresponding availability of information, decision-making support, organizational structures and resources, which can be enclosed within the concept of overall *organizational dimension*. In other words, efficiency depends on the overall organization of interventions. This functional dependence is valid as a basic reference point, but it must also be borne in mind that organization must always adapt to the actual situation. In emergencies in general, and in transport in particular, situations are almost never the same and therefore organizational recommendations need to be evaluated and adapted. In this sense, it is essential to record events, systematize the experiences made and the motivations adopted, and focus on the principles of *learning by experience* to increase the overall knowledge base.

3.1.1. Institutional levels and extent of the territory involved

The emergencies taken into consideration in this document are those deriving from serious events that have significant consequences on people, infrastructures, services and the territory. Therefore, the involvement of many institutional levels is almost a general rule thereby raising the problem of roles and competencies in the corresponding multilevel management system.

For the correct evaluation of the territory involved by any shock caused in the transport system, the availability of adequate cognitive and technological tools is necessary. In fact, it is evident that a serious disruption generated in a node or in an arc of the transport network entails consequences that are not only immediate and local, but also not limited to a single mode. Therefore, it is crucial to possess **ex ante information on the structure of the modal and local networks** (topology and state of service) and **on the use of these networks** (flows, saturation levels, structure of the supply of services, rough consistency of demand). While it is taken for granted that such information is available to the various transport operators or infrastructure managers (though this is not always the case), precisely because of the multi-level nature of emergency management, such information should be available at the central level (national or governmental authorities) in a systematic and up-to-date manner.

- **City Council Level**. The municipality is the smallest level of territorial aggregation. The size of municipalities is heterogeneous both in terms of population and size. Here, reference is primarily made to aspects of government and emergency management, and therefore both small and metropolitan municipalities are considered at this level. Where they exist, smaller aggregations cannot be neglected at this level, i.e. those portions of municipal territory that are homogeneous and have albeit limited operational and intervention bodies. Neighboring municipalities should be directly and immediately involved in helping people, and the necessary aids include those related to transport, emergency, replacement and restoration, and where possible, as managing institution, directly or indirectly, of urban transport services. Intervention in urban public transport remains, for the duration of the emergency, the primary task of municipalities in the case of emergencies affecting the transport system.
- **Regional level**. Regions are the territorial authorities that deal with transport planning on a regional scale and therefore also have the task of supervising the overall performance of the transport system as well as promoting the congruence of service provision. The regions are also the public procurers for regionally based rail transport and oversee quality levels for a considerable number of rail users. Understandably, in a serious emergency the regions can, and in many cases must, play a role of primary importance. In addition to these technical-transportation considerations, the Regions are the territorial reference point for the

national Civil Protection service, which legislation in force assigns, at least initially, a decisive role to. In fact, these bodies are in charge of measures following serious transport emergencies. The regional level is not limited to a single Region, either because the damage occurred on the borders between different Regions or because the damage is so significant that it has repercussions on the transport system also of surrounding Regions. In the latter cases, all affected Regions should be involved in the management of the transport system in the emergency phase. This involvement can be primary or, in case of higher order interventions, secondary, but always nevertheless participatory.

- **Central or Government level**. Serious transport emergencies involve central institutions, namely the Ministry responsible for transport and, where deemed necessary, the entire government. Usually, the Authority at this central level receives reports on all activities and interventions following the emergency event so as to implement high-level and regulatory measures. This liaison and information function is typically performed by the Prefect in charge of the territory, who acts as peripheral representative of the central government. All peripheral authorities refer to the Prefect, at least until the Government appoints extraordinary commissioners thus changing the delegation of powers.

3.1.2. Chain of command

By chain of command we mean here the composition of the set of agencies and institutions involved in making the decisions necessary to address the emergency and optimize the hierarchy within that set. Though laws exist in this area, some difficulties inevitably arise, also due to the immediacy with which decisions must be taken and consequent activities carried out.
The function of command during emergencies is and must be substantially public, distributed over the various levels described above, and is usually carried out through working groups or committees that are set up at the Prefect's initiative. The main problem that usually emerges is that the various transport systems are not, in general, managed by public bodies but by Concessionaires (railways, highways and state roads). The same municipalities usually manage public transport through directly owned companies. It follows that actions resulting from decisions must somehow be

agreed upon with managing bodies and concessionaires. Concession contracts almost never make clear what form of relationship can or should be established between concessionaires and grantors in case of emergency. A lack of decision-making power may occur on the part of those who hold the power of command and this power is therefore vested in a new role (Commissioner) who acts with certain powers and functions, above and beyond the normal rules and procedures, if necessary.

To exercise decision-making power in case of emergency crucially requires knowledge of the transport system, both general and particular, to enable measures that are adequate to the extent of the damage. This means referring to information and tools (models, schemes, surveys, statistics, ...) that allow for even in aggregate form approximate but credible assessments of the extent and magnitude of damage. Knowledge and information are obviously necessary also in defining the powers (territorial scope, matters on which to intervene, duration, resources) of a possible Commissioner.

3.1.3. Coordination

Coordination represents the most important component of the overall organization of interventions during an emergency and plays a fundamental and decisive role in obtaining acceptable results. Two elements promote effective coordination and positive relationships between those involved in managing the emergency:

- Information. This is by far the most important factor at play. All types of available information must circulate among the institutional actors involved, both those referring to the past (on the state of the systems) and those in progress, based on the evolution of events. This information is useful for knowledge and consequent steps to be taken and should not to be confused with the information released to the public, which is subject to different evaluations.
- Discussion and elaboration. This phase is also indispensable but, in a certain sense, taken for granted. It is the moment that precedes and shapes the decision-making process and must make the actions taken in series or in parallel compatible and coordinated.

Three types of coordination among the actors involved can be identified:

- Horizontal coordination is between organizations and institutions involved in the same working groups to ensure congruence and synergy between initiatives as well as between different working groups, where if they exist, there must be a coordinated exchange of information and actions.
- Vertical (or hierarchical) coordination. In the distribution of competencies, it is always possible to identify a higher level and a lower, more executive and operational level. In this case, coordination requires downward exchange and upward feedback to ensure clarity and effectiveness in decisions and actions.
- Cross-Functional Coordination. As mentioned above, during an emergency, there are two distinct functions: public bodies and institutions, and transport system operators. Usually, transport system operators have their own internal protocols to deal with emergency situations of differing levels of severity. And when an emergency occurs, these protocols are activated in ways that depend on the circumstances. The resulting initiatives generally do not consider, at least initially, the existence of other decision-making bodies (in fact, public ones) or other managers. Throughout the emergency, these two levels must, of course, guarantee an essential congruence and complementarity. This implies strong coordination, based above all on timely, complete and systematic information, but also on clear and explicit rules, both previous (for example, those written in the concession contracts) and defined at the moment (by force of government decrees).

3.2. The knowledge required for an effective management of the emergency

An effective management of emergency events requires from the various institutional figures thorough and continually updated knowledge of the fundamental components of the transport network, namely

- the infrastructural network;
- the transport services offered on the network;
- the flows of people and goods that materialize their mobility needs on the network, possibly as a representation of the multimodal passenger and freight transport demand on the network under consideration.

This knowledge must distinguish the two aspects related to:

- ***"static" characteristics* of the network under consideration**, i.e. typically topological, structural, service configuration and average load assessment characteristics that have medium or long-term variations. Government bodies at the local level as well as the entities/companies that manage the infrastructural networks of the various modes of transport must have access to this wide set of information, The importance of updating this information will be discussed below.
- ***current state* of the network, services and flows**, that is, information and knowledge updated to the present of the main performance indicators of the elements themselves (some not exhaustive examples are: the state of maintenance of the infrastructures, the transport performance of particular services, the average daily flows on the various sections, the residual operative capacity of sections or services, etc.), also including the planning of works on the network. Managing knowledge regarding the current state of the network is complex because of the need, firstly, to have instruments, technologies and measurement methods, and secondly to share information amongst Authorities and Companies with different functions, as underlined in the previous paragraph. In fact, information relating to the current performance of the transport system under consideration becomes crucial in the management of the emergency, since any decision and action is necessarily based on the operating characteristics of the system at the moment when the emergency occurred.

Furthermore, updating the two aspects outlined above involves very different timelines and procedures. Static knowledge elaborates topological, infrastructural and service information that is updated in the medium-long term, with the typical periodicity of the variations of the information involved. This periodicity is not less than annual, except in very particular cases. On the other hand, the knowledge of the state of the system requires a much denser update (with a timeframe to be defined according to the mode of transport and type of service) and an organization of the procedures of retrieval and management of information that is more complex and costly.

3.2.1. Area involved

An emergency event on a multimodal transport network worsens, as already noted, the performance of a portion of the network that can extend even considerably beyond the place where the event occurred. The impact of the emergency has a spatial effect that is not only local but also extensive, whose effects depend on the type of event and its severity.
The assessment of the extent of the area involved by the emergency event requires:

- An analysis of the network connection characteristics, which can be performed using a static indicator (as described in more detail later in this document[2]). Such methods provide *ex-ante* evaluations of several performance indicators that show how severe and extensive the effect of an emergency may be depending on where the event occurs. The analysis can also involve tools capable of solving assignment problems of traffic flows on the network. A solution to these problems enables, in fact, an analysis of the distribution of flows in the face of infrastructural variations and, therefore, a comparative analysis of the *before* and *after* emergency situation to understand which portion of the area is also indirectly affected by the emergency.
- A dynamic analysis, showing the temporal evolution of the network performance indicators to understand how the extent of the area involved changes over time. This second type of analysis can be carried out with models and simulation tools capable of determining a prediction of the behavior of the overall system in the short and medium term after an emergency event[3].

The identification of the area involved in the emergency is obviously an important knowledge factor, as it indicates where actions to mitigate the effects of the shock should be defined.

3.2.2. Infrastructures

As already mentioned, the static knowledge necessary to analyze a multimodal network concerns information available on the databases of the institutional

[2] For a more detailed analysis of this, please refer to project Deliverable 2.
[3] For a more detailed analysis of this, please refer to project Deliverable 3.

management bodies of the territory under examination, as well as of the concessionary companies of the infrastructures themselves. The updating of this information takes place on a long-term basis, or as a result of extensions or variations of the infrastructure network due to new designs, or to significant maintenance actions.

On the question of the condition of infrastructure, the need for regularly scheduled monitoring has drawn increasing attention of government bodies and concessionaires. The use of Structural Health Monitoring (SHM) systems, able to continuously monitor the health of the structure, also considering the dynamic evolution of the transportation load to which it is subjected, and to locate any critical issues, is recommended for the safe management of the main connection infrastructures.

The sensors used by SHM systems vary, using ground-based equipment and data detected by satellite systems, with the consequent need for integration, processing and storage of large amounts of data. Although SHM systems require significant investments for both design and implementation, they offer major advantages for monitoring the infrastructure (due to the automation of surveys that otherwise would be carried out manually), for the effective planning of maintenance and, above all, for significantly reducing risks - of failures or malfunctions - and improving safety. The use of SHM systems by infrastructure management bodies is therefore strongly recommended.

The issue of infrastructure monitoring is also the subject of very recent evaluation and assessment by national authorities (see, for example, the "Guidelines for risk classification and management, safety assessment and monitoring of existing bridges" defined by the Ministry of Transport in December 2020). However, the standardization of information and tools needed for retrieving, filing and managing such information on the entire multimodal transport network is not yet available.

3.2.3. Passengers and goods flows

A multimodal transport network is characterized not only by its structural/ infrastructural features, but also by the workload it is subjected to. Essential information, therefore, to assess the operating conditions of the network and to recover satisfactory working after a shock event concerns the flows of passengers and goods that travel on the network.

This information concerns passenger and goods flows for each single mode of transport over different time intervals as:

- hourly interval: the indication of flows on an hourly basis is aimed at understanding the distribution of loads throughout the day. This information can be stored with reference to typical days, not necessarily kept for extended time intervals.
- daily interval: information dedicated to highlighting changes over weeks or months.
- monthly interval: aimed at assessing any seasonal fluctuations in the presence of flows on the network.

Flow measurement is a non-trivial aspect and, above all, the integration of data managed by different institutional bodies/companies operating on the network for different purposes is crucially important.

As for passengers, information on flows may be available to the entity/company that is the concessionaire of a public transport service, of a private transport service or an infrastructure concessionaire (as in the case of the motorways). The data concerning passenger flows is not always measured and archived effectively both for the criticality in evaluating this data (as in the case of rail transport, for example) and for the criticality of integrating data from different sources.

Another complex issue in the availability of these data (which are essential for managing the reaction to emergency events) concerns their sensitivity. In fact, companies assign significant commercial value to these types of data and so tend to share them only on secure channels and with maximum confidentiality. Nonetheless, the availability of passenger flow measurements is critical in evaluating emergency management plans, when at least in the short term, those routes on the network able to host flows redirected from the disrupted portion of the network have to be identified.

As far as goods are concerned, determining flows carried on the network requires addressing different, but equally important, issues in comparison to those seen for passenger flows. A markedly high number of carriers means that freight transport services are generally even more fragmented than those found in passenger transport. The organized and effective collection of data on freight flows is therefore more critical, despite the fact that freight transport is more controllable, as it is always a-priori organized and is not affected by users' decisions that characterize passenger transport.

A possible alternative to knowledge of the flows using the network in its various modal components and according to the different services available is knowledge of the transport demand that generates these flows. Demand evaluation requires analysis with consolidated methods based on sample surveys, mathematical models with random utility, behavioral or descriptive models. Institutional bodies and companies managing the transportation services rarely perform such analysis as it is expensive to implement and to keep updated over time.

3.2.4. Knowledge sources

The availability of knowledge about the transportation network is fundamental for an effective emergency plan aimed at making the network able to resist and react to disruption events[4]. As indicated in the introductory part of this chapter, necessary information is classified as knowledge related to the static components of the network, and knowledge related to its current state and performance.
As regards the first information set, the main sources of knowledge can be indicated in:

- cartographic systems, executive projects of infrastructures, state and infrastructure maintenance programs, statistical surveys conducted by Istat or other national and international organizations gathering statistics (e.g. Aiscat)
- information related to the passenger transport services offered by public and private companies, information on freight transport services performed by public and private companies (in their various functions: forwarding agents, carriers, terminal operators, etc.). These reports should be available to the various regulatory and territorial management bodies according to the level and territory of competence. The Italian Ministry of Sustainable Infrastructure and Mobility already collects information on transportation services in specific databases (e.g. the National Observatory on local public transport policies)
- information regarding the load on the network in terms of average flows of vehicles, passengers and goods can again be found in the analysis carried

[4] For a more detailed analysis of this, please refer to project Deliverable 4.

out by concessionaires and entities managing the services or by the main entities of the national organizations gathering statistics dealing with mobility.

The information about the state of the network in its various components is available, when effectively measured and archived, to the management bodies of the territory and to the companies that provide the services. Overall, information, when it exists, is inhomogeneous and dispersed and the tools for collecting this information, storage formats, information processing and distribution methods are not standardized. Not to be overlooked is the information obtainable from archives of experiences referring to past emergencies, even though also this is generally not systematically documented and cataloged.

4. Short and medium run actions

In general, but particularly in transport systems, a serious emergency is followed by a typically long period of time when problems have to be addressed whose nature and extent usually depend on the temporal distance from the moment of the occurrence of the traumatic event that caused the emergency itself. In this chapter, we discuss the problems that arise in the time following the emergency.
In this context, it is not easy to distinguish between short and medium time frames, because this distinction depends heavily on the severity and extent of the damage.
Short time can be considered the period that includes activities to rescue people, those that eliminate or minimize residual hazards, and those that provide immediate solutions for (partial) restoration of interrupted services. The duration of this period usually does not exceed 7-10 days, unless the causes of damage are repeated or recurring (e.g., earthquakes), in which case, this duration becomes less predictable. These are therefore times within which significant intermodal interventions are not possible, except for those deemed strictly urgent, as discussed in paragraph 4.1.
The medium term, on the other hand, is characterized by a series of actions, often already experimented, that can be put in place on the basis of more extensive in-depth analysis. Although the results of medium-term actions are usually decisive, they should be considered temporary and subject to evaluations regarding performance and reliability so they can be modified if necessary depending on changing events. In the long term the solutions will be consolidated if they prove to be not only performing and reliable, but also economically acceptable. The duration of the medium term also depends on the extent of the damage caused and generally can also be set according to the time necessary to restore or reconstruct the destroyed artifacts. Therefore, we are talking about periods that can range from a few months to several years.

4.1. Intramodal and intermodal technical measures

In the short and medium term, the measures taken in the transport field can be of various types, depending on whether we are talking about transport services or infrastructure problems. If we restrict attention to new infrastructures or the restoration of damaged infrastructures, we refer to typically single-mode interventions. If, on the other hand, we look at interventions on transportation services that are provided, they can be single-mode or intermodal. While single-mode interventions imply that the decision-maker is delegated (concessionaire, subsidiary, owner) to manage the modal transport in question, intermodal interventions can only be carried out in the presence of agreements between the parties or, more generally, solicited or imposed by an overriding, pre-existing body that has the corresponding power or by an ad hoc body specifically created for the emergency (e.g. a Commissioner).

4.1.1. Independent activities of the interested parties

With reference to the definitions given above, a possible classification of interventions is as follows:

- interventions on infrastructures
    - restoration of pre-existing infrastructure, generally carried out by the transport operator or the concessionaire;
    - creation of new "temporary" infrastructures to replace others that have been destroyed, which may be the subject of autonomous decisions by the managers or concessionaires, or agreed upon with a superordinate body;
    - construction of works, possibly already in progress before the emergency, that are functional to the mitigation or removal of the emergency and that have characteristics of non-temporariness, which can be charged to managers, concessionaires or owners or agreed with a superordinate body;
- interventions on transport services
    - in the short term, single-mode interventions are generally carried out by the concessionaires or managers, while in the medium term interventions agreed upon with higher-level bodies may take place;
    - intermodal interventions are almost always the subject of initiatives agreed upon with higher authorities, even in the short and medium term, except in cases where users opt for alternative services or in cases where an operator decides, autonomously or upon request, to set up extra-modal substitute services (typical is the case of

replacement of rail routes with equivalent road routes, provided by buses).

4.1.2. Consistency between autonomous actions

The typology described above highlights that often actions, especially in the short term, are based on a logic of urgency and necessity that is difficult, and perhaps even wrong, to curb or prevent. Nevertheless, experience and evidence show that it is necessary to activate, as quickly as possible, forms of coordination and direction of actions, through formalized groups or committees of actors. This happens mostly in the short term, while in the medium term this organizational and decisional issue can be assigned to an institutional figure (Commissioner) provided with statutory extraordinary powers for a limited time. The tasks of such groups or persons include those of control that, on the basis of information, observations and data, may result in changes or revision of interventions that may have been taken in haste or due to a lack of information. In these cases, which are far from rare, continuous and exhaustive communication to users is recommended, in order not to increase potential misunderstandings and consequent confusion regarding the use of available transport services.

4.1.3. Compatibility of information available to various actors

This section will analyze primarily measures concerning transportation services.
All events in the short and medium term are based on recognizing the effects of the disaster and on the tools (information and models) available, in addition, of course, to the available resources (men and means).
In this sense, we can say that knowledge, both *a priori* and *in itinere*, is the premise and, in a sense, the necessary condition for effective intervention in emergencies in transportation systems.
As mentioned in Chapter 3, knowledge is here intended, for the sake of brevity, as the set of information and data as well as conceptual and formal models available to decision makers working to deal with the emergency.

- *A priori knowledge.* The concessionaires and managers of transport services hold different levels of detailed information regarding the configuration of their network, the type of traffic, flows, performance (service levels, degree of saturation), economic transactions. As far as railway traffic is concerned, information on the entire network is the responsibility of a single operator, while information on passenger and freight traffic is distributed among several operators. The situation differs with regard to road transport, as highway concessionaires manage only part of the network and therefore possess limited information. For the rest of the road network, the network of state roads has only one operator, but the remaining public network has local operators. In urban areas, the road network is managed by the municipalities, but the services are in almost all cases managed by subsidiary companies. In this fragmented situation, information and data, both general and specific, are difficult to manage, having mostly very different characteristics both quantitatively and formally (representations and formats), although clearly the entire structure of data and corresponding information should be available to anyone who is committed and authorized to act and make decisions in the event of emergency. As for models, i.e., decision aids (e.g., methods described in 4.2.1) that should be part of the knowledge base of the actors involved in the crucial phases of the emergency, they are rarely available for emergency management needs, as they are simply not provided for.
- *Knowledge in progress*. During emergency management, data and information are inevitably produced as actions take shape. Not all data and information are collected on behalf of the central instance coordinating body. But the effectiveness of interventions and awareness in decision-making imply that such information should be available and open. In conducting operations, conceptual or formal models can be brought into operation to facilitate the evaluation of options to be chosen (e.g., the models described in 4.2.2). These are usually simple models, heuristic or taken from existing routines. These, too, must be part of the knowledge base of the group in charge of making operational decisions.

The entire emergency management process should be treated as an "experience generator" and therefore needs careful collection of steps, decisions, assessments, information, and data that will constitute a history to facilitate preventive interventions and to guide actions in future, similar cases.

4.2. Technical tools for decision-making

As mentioned, in the crucial phases of emergency management, the cognitive and conceptual tools provide key support to the necessary decision-making processes. These processes that apply to transport domains involve both static-functional and dynamic-performance approaches.

4.2.1. Network status assessments

Analysis of an infrastructural system serving a territory provides information on the current state of the network both in order to intervene promptly and effectively in case of need and to start possible improvement planning.
Consequently, a static network analysis based on the complex network theory is useful to identify the critical elements of the network.
In this context, *centrality measures* are relevant. The concept of centrality of a node is related to the importance it has within the whole transport network. As "importance" has various meanings, this leads to the definition of various measures of centrality. If by importance, for example, is meant the number of connections, then we refer to *Degree Centrality*: the most basic structural property of a node, given by the number of arcs adjacent to it, i.e. its degree. When interpreted in terms of the proximity of a node to all other nodes in the network, we refer to *Closeness Centrality*. The term *Betweenness centrality* is used when a node is considered more central (or more important), i.e. the more it is on the minimum path between every other pair of nodes in the network. The importance of the node is therefore related to its ability to connect all other nodes. Finally, other measures of centrality consider not only the importance of the node, but also the quality of its connections. In this sense, not only is the connection to other nodes relevant, but also the importance these nodes have within the network (*Eigenvector Centrality*).
With respect to the macroscopic characteristics of the network, important considerations can be made through the study of the minimum path matrices. Moreover, it is interesting to study connectivity measures, such as the *Alpha Index* and the *Gamma Index*, which respectively evaluate the number of cycles in a network on the total number of possible cycles, and the number of arcs on the total number of possible arcs (to obtain measures about the network redundancy).

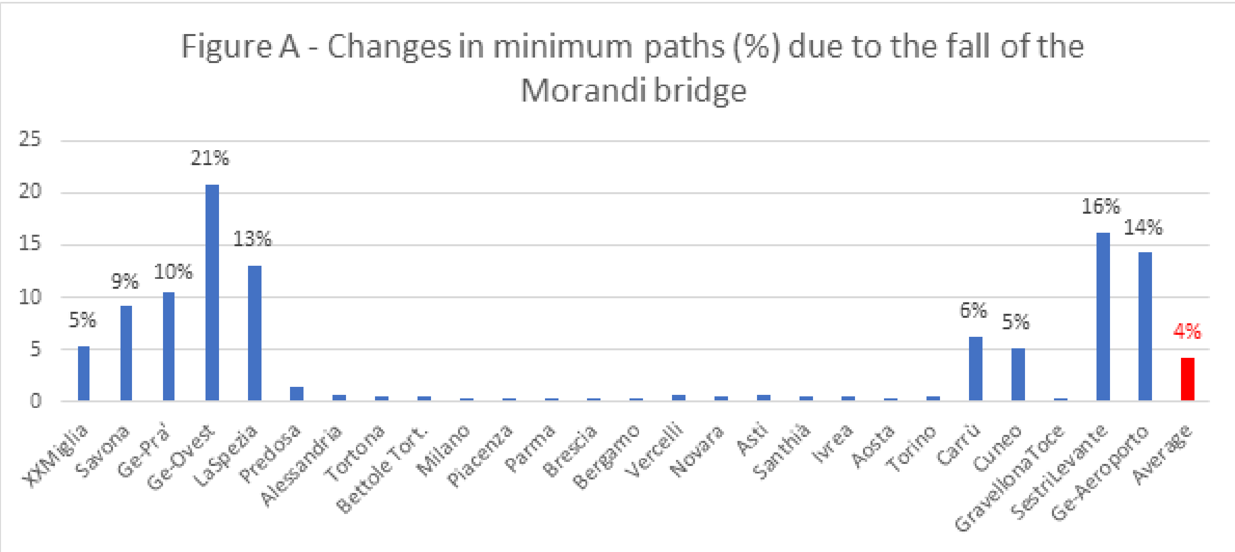
Network component centrality analysis is used to conduct vulnerability and resilience analyses.

Regarding the vulnerability of transport systems, this can be defined as the societal risk of interruptions and degradation of the transport system. Network disruptions can suffer varying degrees of impact severity depending on the causes of the disruption. Disrupted roads, broken trains, or flight cancellations cause longer travel times for people and goods and are associated with direct social and economic costs; terrorist attacks or major infrastructure collapses can generate direct and indirect damage and injury.

Thus, one can estimate the importance of each system component through a topological vulnerability analysis, which is directly related to the concept of efficiency. Specifically, the variation in efficiency levels after the removal of a network component, i.e., a node or an arc, is considered.

Box 1: The effect of bridge failure on the transport network

The application of network theory to primary transportation infrastructure enables us to pinpoint how minimum paths vary as one or more of the network's links fail. Figure A shows the increase in minimum paths connecting individual highway toll booths with all other toll booths in the Northwest network that occurred due to the fall of the Morandi Bridge.

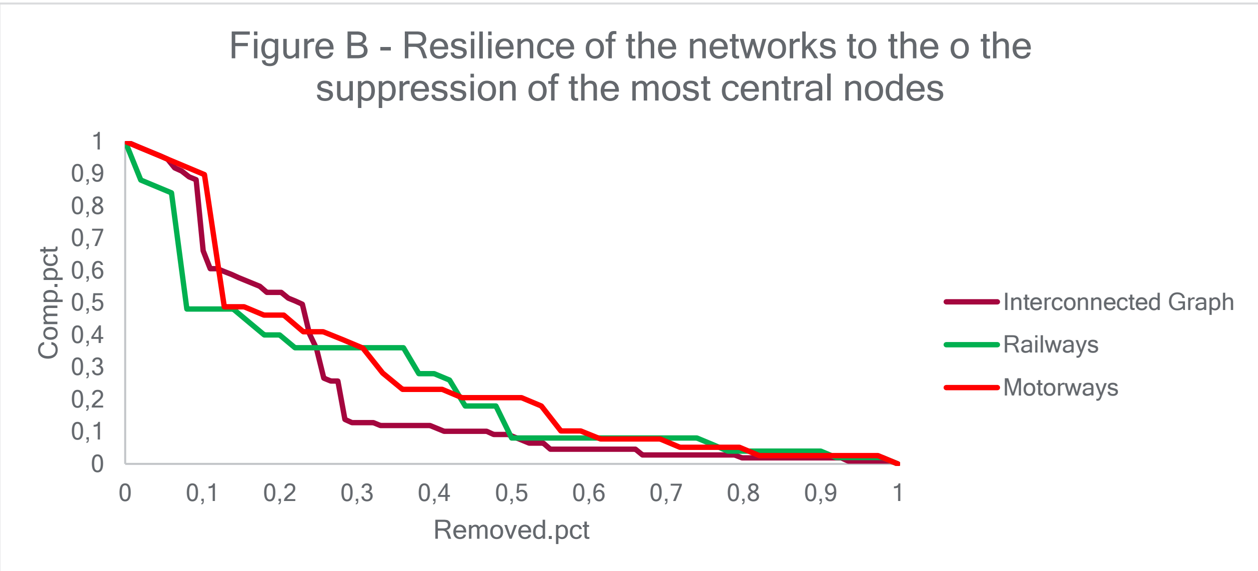


In addition, the criticality of each component of the system can be analyzed by considering the largest connected cluster. In this case, the number of nodes that remain connected in the main cluster after the removal of a node or a link is compared to the number of nodes contained in the entire network before the shock.

Besides the concept of vulnerability, it is necessary to consider the multi-faceted concept of resilience, of which several definitions have been provided. In general, the various definitions share the idea that resilience refers to the ability of a system to survive a shock. In the field of transportation, we typically refer to an engineering notion of resilience as the ability of the system to return to its previous state of equilibrium. In turn, this can be interpreted as a robustness measure, which is widely used in the literature. Robustness, in fact, describes the ability of the system to withstand a certain level of pressure without undergoing major degradation and the performance that can be preserved even in the event of attacks on it. Among the various measures used in the literature, resilience and robustness analyses observe the changes in size of the main cluster as individual network elements are progressively removed.

Box 2: Network resilience

A way of analyzing network resilience is to suppress an increasing number of the network's components (links or nodes), starting with those with the highest centrality index. Figure B shows how the percentage of nodes connected to the network varies for the railways, highways and interconnected (i.e. multimodal) networks of the North-West as nodes ordered by the betweenness centrality index (i.e. the index that measures how many times a node or an link is found in the minimum paths of the entire network; therefore, how important that node or link is to keep the network connected). As can be seen from the figure, the northwest rail network shows a significant reduction in the network when about 10% of the nodes are suppressed, while the interconnected network, initially appearing to show greater resilience as the number of suppressed nodes increases (between 25 and 30%) shows a marked decline in the core component.



4.2.2. Analysis tools and models for coordinated management

Coordinated management of emergencies includes the following aspects:

- sharing of information collected by the various transport managers/ operators. Previous knowledge (referring to both static and dynamic data) as well as information detected in the period following the occurrence of an emergency must be shared to define effectively the possible regulatory actions to reduce in the short-medium term the impacts of the emergency;
- coordinated definition of regulatory actions;
- assessment of the results of regulatory actions in terms of improvements in the network performance.

The choice of regulatory measures as well as the evaluation of the results obtained can be made with conceptual methods and tools mainly related to traffic assignment methods and simulation tools of transport networks, whose main features are:

- Traffic assignment models and tools: these determine the distribution of user flows on the network starting from the transportation demand defined on the existing origin-destination pairs. Traffic assignment uses, within stochastic models, a representation of users' choices both in terms of the mode of transport adopted for their movements and the paths chosen. The flows determined with assignment models represent the load configuration encountered on the network as a result of transportation demand dependent on the network and of existing transportation supply (considering both the infrastructures and services present in the area), in a regime configuration in which the flows reach an equilibrium condition. The assignment therefore evaluates the load configuration the system reaches after a transient period (which is not, however, evaluated by the assignment method). Based on the knowledge of the flows determined by the assignment procedure, different performance indicators of the system can be computed. In the event of an emergency, there is a reduction in the infrastructural part of the supply system and, also, the services can change due to the emergency and possibly due to any regulatory actions carried out on the network. Therefore, the assignment models can be used to evaluate the impacts on the network load at the occurrence of an emergency and, also, to compare the performance achievable with different regulatory measures;

- simulation models and tools: simulation is a method for evaluating and forecasting the dynamic behavior of a system based on a model (mathematical, but also logical and/or relational) which represents the evolution over time of the main quantities characterizing the system. The model at the basis of a simulation tool for transportation networks is determined by in-depth knowledge of the supply and demand systems and can certainly integrate regulatory actions.

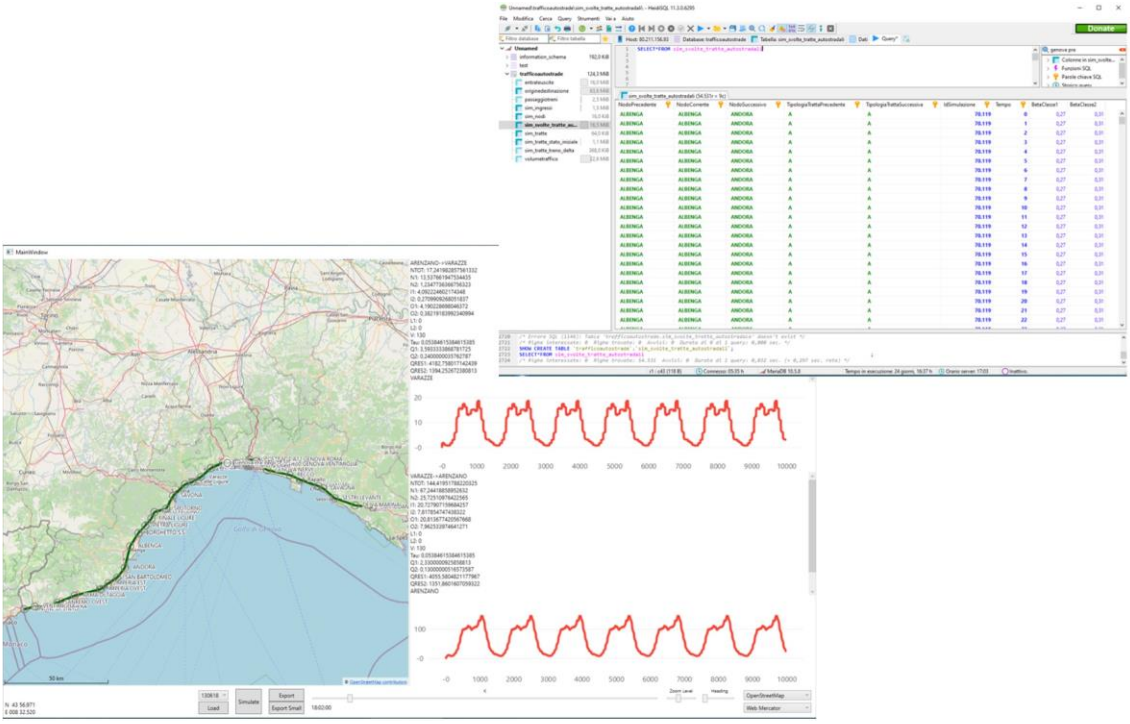
  A simulation model considers the network at different spatial and temporal scales, and it can deal with the system's dynamic characteristics at different levels of detail. A vast scientific literature exists on transportation systems simulation. Numerous simulation tools are also available with different levels of technological maturity (from prototype products to fully engineered and commercially distributed products).

  In the management of emergency events, the availability of a simulation tool constitutes an important value for the operators of the various sub-networks that need to define autonomous regulatory actions. Nonetheless, the availability of a tool capable of representing the network at different geographical levels (urban and extra-urban) with the different modes of transport, is essential for the shared management of the emergency by institutional figures coordinating the single operators.

  Simulation can, in fact, be used to evaluate the performance of the system in the short-medium term following a critical event, even in the transient period that precedes a steady-state equilibrium configuration. The simulation tool can certainly integrate different regulatory actions and, therefore, provide the evaluation of performance indicators, including highly customized ones, relating to both the regime and the transient periods.

Box 3: A simulation model applied to the Ligurian infrastructural network

The simulation model estimates the course of the flows choosing specific arcs of the network and specific temporal horizons of analysis. The graphical visualization of the network in the instrument of simulation reports a simple and immediate information of the state of the traffic.



Simulation can be conducted at both the regional and urban scale to understand mutual impacts and interactions between different spatial levels of the transport network.

The simulation tool designed and developed in the project (box 3) is important in analyzing effect the impact of emergency events, as well as in assessing possible regulatory actions. The tool integrates two spatial levels: a regional level in which the network available for mainly suburban journeys is simulated considering the coexistence of road and railway used for passenger and freight transport, and an urban level with the microscopic simulation of multimodal movements in the urban context affected by the emergency.

The use of a simulation tool with the designed characteristics makes it possible to evaluate the trend of passenger and freight flows on the pre- and post-emergency network, to forecast the impact of the emergency both in the regional and urban areas, as well as identifying possible alternative regulatory steps.

The tool was used to evaluate the emergency caused by the Morandi Bridge collapse in Genoa. In this specific case, the regional network considered is a portion of the Italian North-West network, while the urban area is the western area of the city of Genoa.

5. Long-term strategies for increasing resilience

Long term means a time span long enough to allow the replacement of all elements of the transport network with the aim of defining the best possible strategies for the economic and social development of territorial systems.
This definition, if applied to the built parts of the transport infrastructure - routes and terminals - is measured in several decades corresponding to the lifetime of the transport infrastructure, i.e. the time the infrastructure is able to serve the transport demand adequately. This means that the lifetime of an infrastructure is exhausted not only by technical obsolescence, but also when the level of service offered is so reduced as to exclude it from the basket of potential user choices or when there is no longer any demand for it.
A relatively shorter time span is envisaged when the long term is limited to technologies applied to infrastructures, such as, for example, blocking systems or railway traffic signaling, which are characterized by a significantly shorter useful life.
At the same time, infrastructure technologies can extend the lifetime of the infrastructure by facilitating better management and maintenance, thus moving forward the moment when the infrastructure needs to be restored or replaced. Hence the relation between the lifespan of infrastructures and the actions that can be put in place to increase their safety and resilience to the occurrence of adverse events; in fact, these actions are intended to maintain high standards of service and therefore to maximize the economic returns of infrastructures over time. These actions require an effective monitoring system, both static and dynamic, of the infrastructures, as an essential condition for the adoption of effective strategies for the resilience of the infrastructural network.

5.1. Transport infrastructure

The resilience of transport routes considered as the built part of the infrastructure passes through a review and updating of the maintenance practices of the buildings to identify in time the necessary ordinary and extraordinary maintenance. These are under the responsibility of the managers of the individual infrastructures, but the supervision of the safety conditions of the national railway system and road and highway infrastructures since the end of 2020 has been entrusted to a specially created agency (pursuant to art. 12 of Decree-Law no. 109/2018, converted with amendments by Law no. 130 of 16 November 2018 and subsequent amendments): the National Agency for the Safety of Railways and Road and Highway Infrastructures (ANSFISA).

On this front, the use of sensors for the static analysis of civil works and traffic detection is intensifying and the use of drones for the visual analysis of the state of the works is spreading, as well as artificial intelligence to reproduce infrastructure works in a virtual environment. The set of technologies that constitutes 5G will be able to facilitate the development and subsequent adoption of such applications.

Resilience, understood as the ability of the infrastructural network to withstand an attack or an emergency, may also depend on the degree of interdependence between different transport networks (or layers of the infrastructural network). In this way, the resilience of the overall transport network can be enhanced by increasing the number of nodes that allow interconnection between networks (or layers). This means not only that a spatial proximity between the nodes of the networks that are to be interconnected is necessary, but that all measures must be taken so that the shift from one network to another is not only technically possible but also simple, both in a technical and economic sense, in terms of both time and cost. The development of MaaS (Mobility as a Service) systems can certainly contribute to this aim, as well as the creation of routes that connect nodes belonging to different layers of the network or areas dedicated to transhipment (such as, for example, parking lots near rail stations), as well as the reprogramming of transport services to facilitate intermodality (for goods and passengers), thus reducing the waiting times due to transhipment.

5.2. Forecast and control measures for passenger and freight flows

Analyzing movements on multimodal transport networks plays an important part in the various decision-making processes, including long-term planning. The evaluation, as a forecast, of the number of trips that will take place on the transportation network is fundamental in understanding the state of the network in its various supply components, as well as the distribution on the network of the different categories of users.

This information is already relevant for the ordinary planning of the transport network, and it becomes fundamental for the management of emergency events. In this situation, the distribution of movements on the network at the time of the emergency and their redistribution in the post-emergency period will significantly influence regulatory policies aimed at reducing the impact of the criticality.

The measures that can be implemented in the long term concern the following aspects:

- design and implementation of methods and tools for monitoring and forecasting the movements on the network: as already mentioned, monitoring the loading state of the network as well as forecasting (short-medium term) the dynamics of movements are important actions for effectively managing the network itself. The choice of techniques and tools to be used, both for monitoring and forecasting, takes place over the long term when designing the information structure (for measuring and processing information) to be used for the transport system. This is usually devoted to a single mode of transport, whilst the sharing of information concerns the entire network and the sharing protocols are again to be outlined in the long term.
- use of decision-making models (simulation, assignment or optimization) for the evaluation of choices related to transport supply on the network; some of these choices are long-term actions. For example, the design of modal exchange zones for both passengers and freight takes place over the long term when infrastructure and services are designed. Long-term choices are made with decision-making tools typically based on optimization models, but often also adopting the solution of assignment problems as well as the results obtained with simulation tools.
- design of actions to regulate flows on the network at the occurrence of criticalities or emergency events: as already mentioned, various regulatory actions can be implemented in the event of disruptions. Possible regulations are defined in the long term by evaluating the actions that can be implemented on the network, on the basis of the available infrastructure, of the planned services, of information on the number of trips on the network, and of legal and regulatory aspects that must be considered, analyzed and, in some cases, resolved over the long term.

- design of decision-making methods and tools for the assessment and the choice of interventions to be implemented at the occurrence of criticalities or emergency events: in the event of critical or emergency events, models and tools must be available to choose the most effective measures to reach the best performance obtainable by the network in its degraded configuration. The choice can be made again with simulation tools or with the solution of assignment problems.

5.3. Economic impacts

Major emergencies often give rise to significant economic consequences. First, damage to private and public infrastructures; second, some of this damage might create cascading effects, with possible significant reductions in the GDP of the local areas that have been directly or indirectly affected by the emergency event. For example, a disruption in a transportation node may directly affect not only those sectors that were intensive users of that node, but also sectors upstream and downstream. Moreover, the associated reduction in the number of jobs can produce considerable contractions in aggregate consumption as well as business expenditure, which in turn might lead to a further contraction in economic activity. These various indirect effects may actually generate economic losses that are greater than those produced directly. Quantifying the costs associated solely with the destruction of the infrastructure stock is a relatively easy task compared to calculating the impact on GDP in the local areas that have been hit by the emergency event. To quantify this restricted definition of the economic effects of an emergency event, it is of paramount importance that the various tiers of government (the National government well as the regional or urban levels) have the modeling capabilities to produce, in a very short time framework, preliminary estimates of the short run economic effects, both direct and indirect, associated to the emergency event. In this way, a systematic set of policy interventions can be defined that policymakers can use to help those worst hit sectors and local areas. In the economics literature different families of models can be used to quantify the economic damage caused by emergency events that involve the transportation network (or other critical infrastructures). The more popular are variants of the Input-Output (IO) model and of the Computable General Equilibrium (CGE) model. Briefly, IO models allow users to model the economic interdependencies across sectors that are originated in changes in the demand or supply in one of more sectors of the economy due to an exogenous event (e.g. an earthquake). IO models can also be extended to identify the spatial distribution of the economic effects associated with the emergency. IO models have also some drawbacks, such as the difficulty to incorporate behavioral changes (of economic agents) caused by the event. CGE models, which are based on some debated theoretical assumptions, are perhaps more flexible, as they assume that firms and consumers alike optimize their decisions by responding to price changes. When these models are applied to a multi-regional scale, they are able to quantify the spatial distribution of economic damage. Additionally, the most recent CGE models include both the structure of the transportation network and information on the use of that network by economic agents. This ability is clearly important because the damages associated with an emergency event could be lower if economic agents have the chance to use alternative routes. It is therefore important that local tiers of governments, or at least the National Government, have the capability and knowledge to effectively use these models, so as to produce, in a short time, more informed decisions about both the spatial and sectoral distribution of the economic damages but also a more selective definition of aids and subsidies as well as a quantification of the social and economic effects of resulting policy interventions. Notably, the effective use of these models depends on data availability and, more generally, information about some critical parameters for the local economies hit by the emergency event (for example, some price elasticities). This in turn generates a flow of information that is required to undertake the network and flow analysis previously mentioned in this Handbook. For example, following an emergency event that has affected the transportation network, demand for transportation services critically depends not only on the network characteristics, but also on transport prices. Therefore, if policy makers need to forecast how transportation demand (which will feed IO and CGE models) will evolve over time, they have to have sufficient information about how that demand will evolve following a change in the network, for a given set of transport prices, but also about how transportation demand will change when transport prices change (they are likely to change if policymakers decide, for instance, to reduce ticket prices for the local public transportation services). In other words, the various tiers of government that need to use IO and CGE models must have not only the technical knowledge to use them, but also the data and, more generally, the key information necessary to use the model effectively. However, the availability of such information is not clear, in the light of the multiplicity of stakeholders, both private and public, that manage the relevant data, and the difficulty to collect information at a very granular spatial level.

5.4. Regulatory issues

To date, transport regulation covers an individual transport mode and generally defines the fair and non-discriminatory methods of accessing it under normal conditions, i.e. conditions of full operability of the regulated infrastructure as well as a comparative analysis of other transport infrastructures serving the same territorial context or the same demand. Interdependencies between competing modes of transport are therefore considered in a static form to examine how the differing conditions of these interdependencies impact users' choices.

Emergencies in the infrastructural field, whether because of the non-operation of a part of the network or of a severe drop in service levels, entail reallocating traffic flows onto an available infrastructure, thus determining a cascading effect of the emergency throughout the entire infrastructural network and on the various transport service managers. Emergency regulatory interventions are therefore needed in addition to those already routinely envisaged by the managers of the individual modes of transport. Possible intermodal interventions are:

- monetary, adopted, for example, following the collapse of the Morandi bridge, with compensation or free local public transport to influence individual choices regarding modes of transport and routes followed;
- prescriptive, in order to impose certain choices on users, such as mandatory routes for certain types of vehicles, or on infrastructure managers or producers of transport services, for example by imposing the implementation of certain services;
- planning, to promote coordination between the various parties involved (infrastructure managers and transport operators), as well as possible forms of compensation for the various operators involved.

These emergency regulatory interventions must have a limited duration, corresponding to the time necessary to re-establish the *ex-ante* situation or, in

any case, a situation of normality (not by restoring the previous network but by modifying the network topology).
The possibility of an external regulatory intervention to be implemented in emergency cases should be drafted into the agreements that regulate relationships between the granting bodies and the concessionaires and identify appropriate restrictions of application.
Clearly, regulatory actions must be supported by advanced knowledge of the state of the transport networks and the flows taking place on them, so as to calculate used and residual capacity if they are to contribute effectively to the resilience of the infrastructure system.

5.5. Long-term data measures

An extensive literature exists on long-term emergency-induced activities in transportation systems as well as that aimed at decreasing the probability of future possible emergencies and minimizing their impacts. Consequently, research covers a broad range of disciplinary, methodological, technological, political and organizational aspects. These facets, implicitly, are also present in this paper, which is essentially oriented towards the problems of safeguarding and restoring the mobility of people and goods and, therefore, the use of information and models to make decisions across various time horizons and, in this section, in the long term.
Long-term activities relate to planning, monitoring, or knowledge of the state of systems, and regulatory interventions; those related to problems induced by emergencies are among them. Subsequently, many of the proposed activities have multiple valencies and utilities.

5.5.1. Planning

The set of activities to keep under control the general conditions of operation of transport systems, in given conditions of demand and supply, to minimize the probability of emergencies and to cope with them, if they were to occur, do not differ from those typically used in the planning of transport systems. They can be:

- Maintenance

- Identification of criticalities
- Verification of performance, given supply and demand
- Interventions for removing the main risk factors and for increasing intermodal changes
- Definition of modal and intermodal technical protocols

Maintenance. The maintenance of the artifacts and infrastructures that make up transport systems is fundamental and decisive in minimizing the risks of emergencies. However, in management practice maintenance is often overlooked, if not actually neglected, with a lack of controls and an underestimation of the effects of the lack of planned interventions.
In the transport sector, both ordinary and extraordinary maintenance should be included in the sphere of "planned" actions, as they normally directly affect the services provided. In some cases, there may even be cases of planned emergencies, due precisely to extraordinary maintenance interventions, which should, however, be studied and managed with adequate formal and quantitative models.

Identification of criticalities. Transport systems and networks have different degrees of risk, which can be due to different causes. The risk linked to the degradation of vehicles, buildings and infrastructures can be decreased by maintenance interventions (mentioned above).
There are also risks and hazards that may depend on the location of the infrastructure, such as overlapping or interference between subsystems of different modes or areas (nodes, network parts, ...) particularly stressed by services.
Other causes can be considered "exogenous". Among these, for example, users' behavior (typical of road transport), induced by rules or signals that are not entirely appropriate, or the geo-morphological structure where the networks are located (landslides, flood zones, ...).
All the above-mentioned criticalities should be identified with adequate technological tools and kept under observation, especially those arising from interference between infrastructures, also of different modes, because they imply potentially greater damage.

Verification of performance, given supply and demand. This type of control is normally carried out when planning interventions are required to adapt supply to demand. Such verifications regard above all times of distance, flows and origins/destinations. The same models can easily be used to direct demand or reduce/expand supply in areas of the network. “What if” models, able to suggest alternative ways, should be developed and used to analyze effects provoked by interruptions, to hypothesize the shift from one mode to another, to study the stress of performance on part of the network, to understand the effects on price/rate variations, etc..
In brief, tools should be developed to form a library of conceptual interventions in urgent cases.

Interventions for removing the main risk factors and for increasing intermodal changes. In the context of long-term planning, "physical" interventions play an important role, at least from an economic point of view, i.e. those that intervene on buildings to replace them or add new ones, or those of an environmental nature that insist on infrastructures. Within the proposed interventions, it is a question of identifying and choosing, according to some priority criteria, those able to increase the overall resilience of the transport system.
Among the possible interventions, those concerning modal exchange nodes play an important role. They are those which, in case of need, can allow intermodal regulation actions. While these interventions are quite simple for passengers, the problems to be solved for goods are much more complex and consist in additional equipment of relatively close nodes, in order to allow and guarantee the temporary transhipment of goods.

Definition of modal and intermodal technical protocols. The result of the aforementioned should give rise to the development of intervention protocols using models (simulation, assignment, economic, ...), to be used in cases of necessity, especially in the proximity of the criticalities detected. These protocols should complement existing rules, mostly oriented towards short- and medium-term interventions. The purpose of these protocols is to facilitate the decision-making processes necessary to cope with emergencies, which need clear rules, coordinated behaviours and quantitative analysis tools.

5.5.2. Monitoring

With this term we refer to the set of activities enabling knowledge of the state of transport systems and their evolution over time. Understandably, such knowledge is critical in addressing possible emergencies and minimizing the probability of their occurrence.
This document reiterates what is already known: at present, information and data concerning the transport system are lacking both quantitatively and qualitatively.
Moreover, information, when it exists, is:

- scattered and fragmented,
- nearly always not accessible except through unregulated and non-transparent procedures.

Data and information, in general, are stored without taking into account the necessary interoperability, as required in modern data management systems.
The result is considerable difficulty in dealing with emergencies when they arise because interventions and decisions that are not supported by comprehensive and previous data tend to prevail. Problems also exist in the temporal phases that should be dedicated to the study and preparation of rules and activities aimed at mitigating the risks of such emergencies, often referred to in the literature as improving resilience.
This situation is mainly due to the fact that the information is held almost entirely by the concessionaires or operators of the transport subsystems, and that the related data are considered by them as "private" and/or commercially relevant.
Frequently, data are not provided or are made only partially available for concerns of privacy. These reasons are often ignored as most information on infrastructure and flows is non-personal.
There is a perceived need to undertake a strategy of complete revision of the rules and behaviors regarding data and information in the transport sector, a necessary condition to adequately address problems due to emergencies.
This need is reinforced at the European level by Commission initiatives (see "A European Data Strategy Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions" - COM 66, 2020).
Data availability and processing, aimed at emergency management in transport systems, is entirely in accordance with the "strategy for policy

measures and investments to support the data economy" outlined in (COM 66, 2020).

In particular, a national strategy needs to be adopted that includes a number of benchmark methodological and organizational steps, briefly summarized here.

- Identification of a national reference institution (MIMS, Transport Regulatory Authority, ...) for the collection, maintenance and use of data and information regarding the transport system. Such a move recognizes the enormous difficulty in adequately managing emergencies, especially serious ones, without the almost immediate availability of comprehensive and up-to-date knowledge of the state of the transport system. This Institution should be equipped with adequate organization, technologies, models and personnel.
- Following the lines contained in (COM 66,2020), data governance should
    - be based on all existing data, especially those held by private parties (business-to-government [B2G]), all the more plausible if they are private concessionaires or managers on behalf of public entities;
    - be realized according to FAIR principles (*Findability*, *Accessibility*, *Interoperability*, *Reusability*), in order to build an exhaustive and coherent archive of all existing and useful data;
    - be guaranteed by both static and dynamic transport data flows, able to represent the evolution of the system accurately and online, if necessary requiring new information acquisitions (e.g. the measurement of highway flows through spirals);
    - maintain and catalogue for possible use all available reports on past transport emergencies, if necessary promoting their production and publication.
- Data publicity should be guaranteed, as is already the case in other European countries (e.g. the Netherlands), except for personal information subject to privacy constraints. In particular, all data and information generated as a result of interventions carried out during the management of an emergency should automatically be considered public, as they are generally publicly funded.
- The entity or institution responsible for the governance of transport and mobility data should also oversee the production and collection of new data and information that, because of technological evolution (e.g., the

Internet of Things), should become available. It is foreseeable, in fact, that new and more detailed data and information regarding the transport system may be collected by other economic operators, who should adopt the same measures in safeguarding public interests during an emergency.

During public meetings held to present the results of the project, representatives of infrastructure concessionaires expressed their awareness of the usefulness of formal tools and models (including multimodal simulation, static network analysis, economic models). Substantial agreement also emerged regarding the activation of centralized initiatives for the collection of data and information, useful, among other things, for feeding these models and tools, which should receive the information relating to concessionaires.

5.5.3. Regulatory actions

To implement these measures, regulatory intervention is needed in the form of new laws or revision of contracts and conventions that determine the relationship between public and private in the field of transport and mobility. It is necessary to identify the body to be entrusted with the creation and management of a national mobility model fed by the information released and acquired by the various players (both infrastructure managers and transport operators) and stored in shared and public databases (or at least available to the planning body). Among the objectives of these models should be the definition of the limits and modes of intervention, i.e. when an emergency arises that requires an intermodal form of regulation.

In particular, the regulation of data and information considered useful for the purposes of regulating the sector should respond to an overall and coherent vision, capable, among other things, of facilitating and speeding up action in cases of emergency.

Italian adhesion to the birth of common European data spaces, including that of mobility, would also move in this direction.

This would give substance to what has already been provided for by art. 33, paragraph 1, letter b) of Legislative Decree no. 76/2020, which amends art. 50 of the Digital Administration Code, establishing the obligation of the concessionaire to make available, in open format, to the granting administration all the data acquired and generated in the provision of the service to users.