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Urban Mobility Resilience Roadmap

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1. Introduction

Following the "Integrated Urban Mobility Roadmap" published by ERTRAC in 2017, which identified the required research and innovation to meet mobility needs stemming from societal challenges and economic trends emerging in cities, this roadmap specifically addresses the resilience of the urban mobility ecosystem in times of crisis. It defines the research necessary to improve the capacity of the transport system to fulfil its role when disruptions through crisis occur.

The current pandemic has uncovered weaknesses in the urban mobility system, which should be considered as lessons for its reinforcement. It has for example caused a fall in public transport demand, with heavy consequences on public transport operators. Social distancing almost halved the transport capacity[1]. Private car use in comparison to public transport ridership has risen in post-confinement periods, leading to an excess in traffic[2]. The difficulties experienced by mobility operators and users have been observed, measured, and analysed, as the multiplication of reports and studies at EU and local level show. Thus, they build a good basis for reflection on the overall system ability to absorb crises.

The objective of this document is to support the preparedness of the urban mobility ecosystem to future shocks, by identifying the gaps in research currently conducted on periods of crisis and the mitigation of impacts of these crises. Unlike other papers related to the consequences of the pandemic on mobility, it does not focus on this specific crisis, but intends to address any type of catastrophe disrupting the mobility system. It also covers a wide range of aspects, from planning to monitoring, including the implementation through different services and governance models. Research recommendations provided do not concern the component level (e.g., robustness of vehicle parts under changing conditions), but the system level. Therefore, steps to set up or improve the local mobility system are covered, and research requirements are investigated for all modes and services, physical and digital.

Although the pandemic has triggered this research roadmap, the crisis addressed by it are broader than COVID-19. This brings the definition of the crises considered, as well as a definition of the term "resilience", to the forefront. These are provided in the first part of the document. Then the research and innovation needs identified are structured in the following steps:

- *Planning* a resilient mobility system, which includes research on the types of crises and their impacts on mobility, the adoption of a scenario-based approach in planification, and the constant monitoring of the urban mobility ecosystem conditions;
- *Enabling* a resilient mobility system, through an appropriate governance model for the system and infrastructures, and based on the necessary data to be collected and exploited;
- *Providing* a resilient mobility system, by ensuring the needed infrastructure, services and network management are in place.

After detailing these research topics, required to achieve resilience in the urban mobility system, methodologies for this research are covered. Aspects for which capacity-building, exchange opportunities or simulations would be relevant are identified.

This roadmap intends to provide guidance on research and innovation priorities to address the issues identified on resilience of the urban mobility ecosystem. It is a support and does not pretend to be exhaustive. This ERTRAC roadmap has been developed in close consultation with the joint ERTRAC-ERRAC-ALICE Urban Mobility Working Group. It results from the investigation of past and current research conducted at EU level, as well as from discussions with experts involved in it.

[1] Arthur D. Little and UITP, "The Future of Mobility post-COVID", July 2020.
[2] ITF, "COVID-19 Transport Brief: Respacing our cities for resilience", May 3rd, 2020.

2. Defining Resilience

Resilience is a term which is applicable to various contexts and must therefore be described and defined for the topic it is used for. Following a general description of the term, based on previous research, and in particular the Topic Guide "Planning for more resilient and robust urban mobility"[3] developed in the framework of the CIVITAS SATELLITE H2020 project funded by the EU – with contributions of a broad range of H2020 IAs and RIAs, principles to apply it to urban mobility are proposed.

2.1. General definition

Resilience describes the capacity of a system to resist, adapt itself and transform itself to recover from a shock, absorb its consequences and maintain levels of functionality[4]. It emphasises the importance of anticipating and reducing one's vulnerability in combination with the monitoring efforts, the ability to respond to and the capacity to learn from crises[5].

Resilient development can be defined[6] as a development that can "anticipate, prevent, absorb and recover from shocks and stresses, in particular those brought about by rapid environmental, technological, social and demographic change, and to improve essential basic response structures and functions".

This implies that, beyond recognizing, identifying, and monitoring weaknesses, external factors must be followed as well, to anticipate changes and prevent crises or recover from them. Hence, these factors to observe and monitor must be defined. And to be aware of the factors leading to or revealing upcoming crises, the crises themselves must be analysed.

This is a priority research action to be conducted: shocks and stresses which can disrupt the urban mobility system must be defined as well as the contexts in which they occur and the impacts they have on the system.

2.1.1. Principles for urban mobility system resilience

Urban mobility system resilience implies resilience of the city, and resilience of the mobility system.

City resilience is related to the wide range and unpredictability of events which can occur and disrupt cities' organisation, rather than purely natural disaster traditionally considered[7]. Urban resilience aspires to secure the performance of urban systems in the face of multiple hazards and crises. A resilient city has the following characteristics[8]:

[3] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[4] Azolin, L. G., Rodrigues da Silva, A. N., & Pinto, N. (2020). Incorporating public transport in a methodology for assessing resilience in urban mobility. Transportation Research Part D: Transport and Environment, 85, 102386. https://doi.org/10.1016/j.trd.2020.102386
[5] Mattsson, L. G., & Jenelius, E. (2015). Vulnerability and resilience of transport systems - A discussion of recent research. Transportation Research Part A: Policy and Practice, 81, 16–34.
[6] ICLEI - Local Governments for Sustainability. (2018). The ICLEI Montréal Commitment and Strategic Vision 2018-2024. Bonn, Germany.
[7] ARUP,The Rockefeller Foundation. (2016). City Resilience Index: Understanding and Measuring City Resilience. ARUP International Development, 47. https://assets.rockefellerfoundation.org/app/ uploads/201712061102 44/170223_CRI-Brochure.pdf.
[8] CWA 17300 (2018) City Resilience Development – Operational Guidance. https://www.din.de/resource/blob/297796/8e4862e244910feb6d12d620a 2b87211/cwa-17300-standards-series-flyer-data.pdf

- *Reduce* vulnerability and exposure to disasters,
- *Enable* the identification, resistance, absorption, adaptation and recovering from shocks while maintaining essential functions,
- *Involve* all stakeholders in risk reductions through co-creation,
- *Increase* capacity to respond to shocks through emergency preparedness.

Resilience in the context of urban mobility is the capacity of a social-ecological system (i.e., a transport infrastructure network, its maintenance crew, financing arrangements, contracts etc.) to prevent heavy impacts in the first place, and to cope with disturbance when it occurs. This means to maintain essential functions, identity, and structure, while adapting to changes and transforming[9]. A resilient transportation system is one that promotes safe, equitable and inclusive accessibility by providing sustainable, integrated, flexible, and robust mobility options – during normal times and times of crisis[10]. Urban mobility resilience entails the identification of key resources for mobility, and the consequence of a potential reduction of these resources, for whatever reason or crisis.

Considering these two aspects of urban mobility system resilience, the City Resilience index developed by the Rockefeller Foundation in 2016 can be applied to urban mobility. Based on the Topic Guide developed by the CIVITAS Satellite project and published in 2021, the key principles characterising resilient urban mobility systems are presented in Table 1 below: reflectiveness, robustness, redundancy, flexibility, resourcefulness, inclusiveness, integration. The Topic Guide provides an extended explanation for each of these principles, detailing how they concretely translate into urban daily actions, and illustrating with precise examples.

Principles	Resilience principle in the context of urban mobility	Explanation (not exhaustive)
Reflectiveness	Planners and policymakers should reflect on the inherent and ever-increasing uncertainty and changes that affect mobility systems. Mechanisms should be set up to systematically review and adapt them with learnings from past experiences.	Monitoring the quality of mobility services and infrastructures based on key indicators allows mobility planners to reflect on the continuous evolution of mobility systems.
Robustness	Robust mobility systems are well conceived and constructed to withstand the impacts of disruptions and hazard events without significant damage or loss of function. They allow anticipating potential failures. Robust urban mobility is also a robust spatial layout and structure of the city, independent from vulnerable transport systems and vehicles.	Set up solid business models and manage spatial urban organisation to reduce dependence on motorised transport. Identify the age of transportation system infrastructure, expectable remaining lifetime, and maintaining it to make it resistant to potential hazards.

[9] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[10] 100 Resilient Cities. (2015). Resilience point of view series Transport.

Redundancy	The presence of multiple ways to achieve a given need or fulfil a particular function illustrates redundancy. It should be intentional, cost-effective and prioritised at a city-wide scale, not an externality of inefficient design.	Street and footpath networks allowing for multiple choices, reserves of resources and vehicles to provide alternatives in case one element of the system fails, cooperation plans for reallocation of resources from private transport operators for emergency purposes
Flexibility	Flexible mobility systems can change, evolve, and adapt in response to changing circumstances, with decentralised and modular approaches to transport infrastructure and ecosystem management.	Designing flexible public paces can allow for variable use and accessibility regarding changing circumstances, from stay function to traffic places for example.
Resourcefulness	Resourcefulness implies that mobility practitioners can rapidly find different ways to achieve their goals or meet their needs under stress or in time of shocks.	Have a plan available to justify the prioritisation of the use of specific resources in case of extreme events, Promote cooperation among institutional groups and stakeholders
Inclusiveness	Addressing the shocks or stresses faced by one sector, location, or community isolated from others requires broad consultation and engagement of communities, especially the most vulnerable groups, and contributes to a sense of shared ownership and adhesion to measures.	Identify the vulnerability of certain groups in relation to certain needs, considering differences among social groups in terms of connectivity, daily travel distances, the time required for regular trips and to get out of the city, etc.
Integrated	Integrate urban mobility systems with other city systems for decision-making consistency and mutually supportive investments towards a common outcome, integrate each part of the overall transport network, systematically include resilience within and between city systems.	Create joint ownership of several city government policies among different agencies helps to exchange information and data exchanges and thus to align responses across departments.

Table 1 - The 7 principles for building resilience applied to urban mobility

Research on the definition of resilient urban mobility systems and theory on how it could be implemented is available, as our references show. **This puts the focus on further dissemination and exploitation of these results, as well as the transfer to real life environments, in order to achieve the defined concepts and principles**.

3. Research and Innovation needs

After giving an overview of the currently available state of play with regards to resilience definitions and aspects, we now look into global needs for research to enable the translation of these theoretical principles into practices, tools, and resources, which contribute to improve urban mobility systems' resilience. The notion of resilience is added as an additional layer to ongoing transitions in view of transport decarbonisation and digitalisation.

As announced in introduction, the research and innovation needs are categorized in three parts: *planning* - by means of understanding the risk and potential of crises, the use of crisis- and risk-oriented methods, and the constant monitoring of the system conditions; *enabling* – through the improvement of governance and processes on the one hand, and through the processing of necessary data and the set-up of supporting technical tools on the other hand; *providing* the required infrastructure, services and networks.

3.1. Planning a resilient mobility system

As defined in the introduction, the resilience of urban mobility systems is broader than just the robustness of their components under changing conditions. It firstly concerns the preparedness of the system management and the capability to get organised for unpredictable events.

This next part provides recommendations on research and innovative topics with regards to planning a more resilient urban mobility system.

3.1.1. Establish a crises an risks typology

A striking observation when investigating works on resilience in the context of urban mobility is the number and diversity of potential events which can shock and stress the usual functioning of infrastructures and services: from pandemic crises to natural disasters, including climate change, extreme weather, political, economic, and demographic crises, migration, supply chain disruptions, terrorism and cyber-attacks[11]. Urban mobility crises can also arise from the system itself, through its contribution to climate change for example.

Recent research on city resilience recommends deepening the understanding of the risks that threaten city stability[12]. To achieve this, a complete overview of potential crises is needed. In developing goals distributed in categories, the City Resilience Framework[13] considers the different types of risk to be mitigated in a resilient city. There is however no explicit map of all the different trends bearing risks of acute shocks and chronic stresses. **A study specifically focused on this part of resilience planning and monitoring, which comes before designing resilient systems, parts, and services, would support risk integration in urban mobility planning.**

Based on use cases and literature review, a typology could be established, identifying categories of crises with common characteristics, such as timeframe of impact[14]:

- *Short-term* crises have an immediately most intensive impact on urban mobility (pandemic, terrorist attack, natural disaster, man-made catastrophe)

[11] Resilient cities network, "What is urban resilience?", web article, last consulted on April 13, 2021.
[12] Resilient cities network, "What is urban resilience?", web article, last consulted on April 13, 2021.
[13] Jo Da Silva (ARUP), Braulio Eduardo Morera (ARUP), City Resilience Framework, The Rockefeller Foundation, April 2014 (updated December 2015), available online, last consulted on April 13, 2021.
[14] CIVITAS SATELLITE CSA, COVID-19 practitioner briefing, July 2020.

- *Medium-term* crises have a longer lasting effect (pandemic second wave, migration crisis, economic crash, disruptive service implementation)

- *Long-term* crises have an impact beyond the time period that is predictable (demographic change over several generations, climate change).

The crises and risks' territorial impact can range from global to (hyper)local, bringing the additional challenge of understanding the interaction between the different geographies of crises and their effects. Also, crises which are expected but in an unknown timing can be considered apart from crises which are not expected at all when they arise.

This typology would need to include an in-depth analysis of the potential impacts of each type of crises on the urban mobility system. Adopting a similar approach to the one proposed by ARUP and the Rockefeller foundation in creating a City Resilience Index[15], indicators and intensity levels can be defined, but unlike the Resilience Index, they would focus on external conditions bearing a risk for the system, rather than on the condition of the system and its processes themselves. These indicators and levels definition would be based on case studies from previous shocks, such as the ones conducted on the current pandemic[16] or on past catastrophes[17], and on currently conducted observations, as recommended following analysis of the current pandemic crisis[18].

Beyond the analysis and monitoring of the phenomenon themselves, more psychological investigations must be conducted on the consequences of the considered shocks and stresses on urban mobility users. Indeed, as shown by the changes in travel behaviour in the current pandemic crisis, societal shocks in cities can lead to confidence crises in public transport or other parts of the urban mobility system, thus bringing about a second wave of consequences to the first shock.

Finally, work should also be done on improving robustness and resilience regardless of the type of threat. Better spatial planning, for example, makes cities more resilient by relying on the resilient character of active modes in general: hardly anything or literally nothing can break down when vital needs are in reach of walking efforts.

3.1.2. Adopt crisis- and risk-oriented planning methodologies

Beyond the study of crises and external factors with a potential impact on the system, the inclusion of the resilience aspect in all decisions and undertakings on transport planning is necessary to improve urban mobility resilience. To this end, a crisis- and risk-oriented approach is necessary. Resilience implies the planning and prevention of potential risks, beyond ensuring adequate responses to them.

On one side, following the example of a recent EU-funded research methodology[19], **the adoption of a scenario-based approach to decision-making in urban mobility enables the development of more services and structures which are planned to overcome uncertain future challenges**. The scenario-based method helps to re-think possible futures of cities and take steps towards desirable options. In view of resilience, desirable options would be the ones viable in most if not all scenarios, instead of only in the most probable one, but at high risk in others. This approach implies acceptance that future is not predictable and urban systems should be fit for any potentially occurring situation.

[15] ARUP, City Resilience Index at a glance, developed with the Rockefeller Foundation support, available online, last consulted on April 13, 2021.
[16] Arthur D. Little and UITP, "The Future of Mobility post-COVID", July 2020.
[17] Feike de Jong, "Parks and Bicycles Were Lifelines After Mexico City's Earthquake", Bloomberg CityLab, September 2017, available online, last consulted on April 13, 2021.
[18] Tom Texeira, Stefano Milanese, Marcus Beard, Emanuele Salvador, Rick Eagar, "Risk: Strengthening business resilience after COVID-19", Arthur D Little, Prism, February 2020, available online, last consulted on April 13, 2021.
[19] Several recent and current EU-funded projects, including MORE, LEVITATE, and MOBILITY4EU, have adopted a scenario-based approach, which supports transport planning in the face of an ever-changing mobility ecosystem. They provide methodological guidance on how cities can embrace uncertainty and make more robust strategies so that they perform well in a range of situations.

In parallel, **resilience must be integrated in Sustainable Urban Mobility Planning**. The aim is to prepare cities and regions better for disruptive realities while at the same time maintaining the pursuit of important policy goals such as decarbonisation[20]. To this end, research on methodologies has already been conducted, but can be updated and enriched with use cases. Implementation by cities and exchange and communication at EU level are now needed.

Thirdly, to improve the resilience of the urban mobility system, an analysis of the decision-making process in times of crisis is required. This includes research on the impact of policy measures adopted in times of crisis on travel behaviour, on short- and long-term. It should also entail an analysis of the consequences of citizen participation to decision-making on travel behaviour in times of crisis. **From these studies, protocols and recommendations could be established on most efficient crisis decision-making processes in view of resilience**.

Besides, in terms of land use and city planning, the trend towards the "15-minute city", strongly shaping the form of the city and mobility services, will surely be strongly related to new forms of risk management and resilience of urban mobility and logistics. **This topic deserves research efforts, to make sure new city planning concepts, which are currently developed and implemented, fully integrate resilience in their thinking process**.

Finally, **planning resilience of the mobility system in changing contexts should be part of the planification of an overall resilience plan**. As urban systems are interdependent, ensuring the performance of mobility implies the maintenance of construction systems, logistics, water, etc. Planification methodologies should combine all sectors. For example, the growth of e-commerce during the COVID-19 pandemic increases the number of vehicles transporting goods in the city, and this trend must be considered when planning urban mobility resilience.

3.1.3. Monitor the mobility ecosystem condition to predict crises

A resilient urban mobility system is a living system, constantly integrating externalities and adapting to a changing context. To enable this constant adaptation, both external parameters and aspects of the system itself must be watched and closely monitored. External parameters are part of crises and risks definition, which we previously investigated. On the other side, aspects of the system to monitor must be defined here. As recommended in studies drawing lessons from the current pandemic crisis for the future[21], **indicators and critical levels must be defined to assess the status of the system and provide up-to-date crisis predictions. Allocating resources and assets to this constant monitoring would enable early action to prevent critical situations before risks escalate**. These indicators can exploit the already defined principles of resilience, presented in the definition part of this roadmap. They can also build on the City Resilience Index established in 2015, with a focus on the urban mobility system and updates related to more recent contexts. Additional indicators emerging from experts' interviews and discussions include for example the return to normal delay, the definition of critical infrastructures and services, etc. Resilience and accessibility indicators could also be defined per transport mode, **to optimize the response to crises by quickly enabling the use of resilient modes**.

Parts of the system which must be observed and attentively analysed include infrastructures, services management and organisation, but also users and their behaviours, which can both cause crises and be impacted by them. Indeed, if recent studies mostly focus on the consequences of the pandemic crisis on citizens' travel behaviour, which can in turn cause secondary crises[22], older but still relevant research shows how sociological phenomena such as urban migration, society individualisation and middle-class citizens' increased wealth can lead to shocks and stresses of the urban mobility system[23].

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[20] POLIS and Rupprecht Consult, Topic Guide: Planning for more resilient and robust urban mobility, February 2021.
[21] Tom Texeira, Stefano Milanese, Marcus Beard, Emanuele Salvador, Rick Eagar, "Risk: Strengthening business resilience after COVID-19", Arthur D Little, Prism, February 2020, available online, last consulted on April 13, 2021.
[22] Przybylowski, A.; Stelmak, S.; Suchanek, M. Mobility Behaviour in View of the Impact of the COVID-19 Pandemic—Public Transport Users in Gdansk Case Study. Sustainability 2021, 13, 364. https://doi.org/10.3390/su13010364 ; Arthur D. Little and UITP, "The Future of Mobility post-COVID", July 2020.
[23] Shin-Pey Tsay and Victoria Herrmann, "Rethinking urban mobility: sustainable policies for the century of the city", Carnegie Endowment for international peace, Brief and Report, July 2013, available online, last consulted on April 14, 2021.

Building on the findings of current and previous research, new social behaviour indicators must be defined to be able to predict crises originated or amplified by changing user practices. Following aspects must be included in the design of these indicators:

- *Preferred* modes of transport
- *Times,* places, and reasons of travel
- *Confidence* in transport providers and authorities
- *Urban* demographic evolutions
- *Sociological* evolutions and stratification in cities
- *Average* wealth of citizens
- *Housing* trends
- ...

Beyond enabling the anticipation of future crises, these indicators can also help recognize opportunities for behavioural change in times of crisis[24]. Observing tendencies in social reactions to crises can support the design of specific measures to either avoid these specific changes or encourage evolution towards more resilient changes: for example, distrust in public transport should be directed towards more active travel, which supports the avoidance of future health crises. To enhance the seizing of these opportunities, there is a **need for study on the impact of policy measures adopted in times of crisis on social behaviour, on short-term and long-term**.

Monitoring the system condition includes assessment, in addition to observation. First assessment to conduct is the assessment of indicators defined, to make sure they remain relevant and useful. Secondly, services, infrastructures, processes and uses of mobility must be tested and compared with foreign systems. To this end, standard indicators should be evaluated, in order to obtain comparable and usable data. **There is a need for standardisation of the defined indicators, and of the data collected. This must be supported by an analysis of data collection processes in cities and the efficiency the data exploitation**. The link between this indicator set and the SUMI[25] approach should be studied.

Finally, **an EU wide benchmark test for resilience should be developed**. The benchmark could consist of several tests simulating certain reduced resources (energy, infrastructure, communication, financial support), and testing the reaction of the mobility system. The benchmark should be standardized or at least harmonized in the EU. It should be updated regularly, and could be integrated in Sustainable Urban Mobility Plans.

To conclude on EU research and innovation needs for the planning of a resilient urban mobility ecosystem, main points to retain are:

- *Encourage* research on the type of crises which can endanger urban mobility, including an in-depth analysis of the potential impacts and a definition of indicators and intensity levels to monitor;
- *Support* the adoption of crisis- and risk-oriented planning methodologies by cities, through the dissemination of project results and the promotion of their transferability at city/international level, through research on urban mobility decision-making processes in times of crisis, and through communication and support for the set up and improvement of an urban overall resilience plan;

[24] Arthur D. Little and UITP, "The Future of Mobility post-COVID", July 2020.
[25] The EU-funded SUMI project defined Sustainable urban mobility indicators for cities and urban areas to identify the strengths and weaknesses of their mobility system and to focus on areas for improvement.

- *Facilitate* the definition of new indicators and critical levels for up-to-date crisis predictions and encourage resource allocation and community building on constant monitoring to enable risk anticipation and early action, also with an analysis and standardisation on data collection and exploitation.

EU Research & Innovations needs with regards to planning a resilient mobility system		
Establish a crises and risks typology	1.	Map all the different trends bearing risks of acute shocks and chronic stresses
Adopt crisis- and risk-oriented planning methodologies	2.	Adopt a scenario-based approach to decision-making in urban mobility
	3.	Update and enrich research on the integration of resilience in SUMPs with use cases
	4.	Define protocols and recommendations on most efficient crisis decision-making processes in view of resilience, based on studies of previous situations
	5.	Include Resilience in definition and implementation of the 15-minutes-city concept
	6.	Integrate resilience of the mobility system in an overall resilience plan
Monitor the mobility ecosystem condition to predict crises	7.	Define indicators and critical levels to assess the status of the system and provide up-to-date crisis predictions, and provide recommendations on allocation of resources to this constant monitoring
	8.	Define new social behaviour indicators to predict crises originated or amplified by changing user practices
	9.	Study the impact of policy measures adopted in times of crisis on social behaviour, on short-term and long-term
	10.	Provide a standardisation of the defined indicators, and of the data collected, based on analysis of data collection processes in cities and the efficiency the data exploitation
	11.	Develop a standardised EU wide benchmark test for resilience

Table 2 - Research recommendations with regards to planning a resilient mobility system

3.2. Enabling a resilient mobility system

The second part on research and innovation recommendations for the improvement of the urban mobility ecosystem's resilience focuses on enablers. After defining how to plan resilience in urban mobility, critical conditions to set up for the implementation of a resilient system are now investigated and the corresponding needs for European research are analysed. Two main enablers were identified: set up a suitable governance model for the reinforcement of urban mobility resilience and ensure the required data to improve resilience is produced, collected, exploitable and exploited.

3.2.1. Governance models

To govern is to foresee. In the context of resilience, which is all about adaptation to unforeseeable sudden challenges, governance is both a challenge and a solution. Recommendations provided here aim at defining governance models bringing a solution to the urban mobility resilience challenge. Aspects of governance investigated to this end are the set-up of solid partnerships for empowerment and shared ownership, leading to the improvement of decision support tools for a more resilient governance, and thus to the definition of protocols for adaptation processes.

3.2.1.1. Partnership models

Resilience is depending on the availability of alternatives, also in terms of governance. Situations emerged in previous crises have shown the potential of empowering diverse actors to support the urban mobility system in times of crisis[26]. Involvement of these actors implies trust and empowerment. **There is a need for pilot projects and exchange of best practices on partnership models fostering trust and enabling empowerment of these actors**. And beyond empowerment, a multi-governance body must be shaped, including government and authorities across multiple mobility domains, public and private mobility players, and user representatives. This enables joint ownership of policies, and helps data exchange, thus aligning responses for a harmonised overall resilience to shocks.

3.2.1.2. Decision support tools

Following the scenario-based approach recommended as a crisis- and risk-oriented urban mobility planning approach and enabled through tools developed in EU-funded research projects, **a model must be defined to value resilience in decision-making processes**. Choices in terms of subsidy awards, tenders, and other procedures for governance must include the resilience aspect to develop the right components of a resilient urban mobility ecosystem.

Regulations governing the urban mobility ecosystem must ensure its resilience and enable its ability to adapt to short- and long-term crises. In this regard, **a systematic scrutiny of laws monitoring their update and suitability to currently identified risks and challenges should be conducted and promoted at EU level**.

3.2.1.3. Protocols

Processes must be defined to ensure the readiness of mobility services and networks to overcome unpredictable events. Protocols for emergency situation, as in any mode of transportation, must be planned in advance and repeated to be easily applied whenever crises occur. These protocols, as defined for the whole system, require design, management, updates and above all activation when necessary. **Communication and community building on processes related to resilience protocols are needed at EU level, to launch a multistakeholder discussion and optimize these processes**.

[26] For example, ride hailing services can provide food delivery in a situation of pandemic crisis where citizens are kept at home, as in some cases with Uber in Italy. They can also support urban mobility recovery after terrorist attacks, when public transport is not immediately ready to operate, like the support of Uber ride-hailing services has shown in Nice after the terrorist attacks in 2016.

3.2.2. Data as a resource

3.2.2.1. Key data enabling monitoring and preparedness

Data is a key resource to enable anticipation, adaptation and drawing lessons from crises. There are three types of situation and datasets contributing to the set up and continuous update of urban mobility resilience:

- *Data resulting from case studies*, research and analysis from past crises and situations, which supports the long-term learning process on resilience. The type of data to collect and exploit to this end includes theoretical literature review, sociological research, experts' consultation, legal and political reviews.

- *Data coming from the monitoring of indicators*, both on external conditions to better predict upcoming crises and on conditions of the urban mobility ecosystem to anticipate risks of rupture or weakness. The type of data to collect is dynamic and must inform policy making on a regular basis.

- *Data on the use and real-time status of the system*, for users to make informed choices and either avoid creating stress and situations difficult to handle or adapt in case of shocks or in crisis period. The type of data to collect is also dynamic but focuses on transport use and is centred on travellers' interest.

Table 3 below states the data content needed for each type of purpose, the sources to collect this data and the research need at EU level to ease access to it.

Timeframe of Preparedness	Data content	Collection purpose	Sources	EU R&I needs
Long-term	Type of existing and potential shocks and intensity of risk for mobility	Define more accurate indicators for risk-preparedness	Analyses of previous crises, case studies, scientific research	Provide a framework for this type of research and support through dedicated call topics
Long-term	Consequences of shocks and stresses on urban mobility users	Anticipate potential confidence crises and better manage the recovery	Sociological studies on previous crises	Foster communication on these studies, create a community for exchange

Long-term	Global societal trends, challenges and solution representing key factors influencing mobility	Define possible future development paths to propose scenarios for a most accurate crisis- and risk-oriented approach	Surveys, literature reviews, exchanges and brainstorming, experts' intuitive estimates	Provide a clear overview and assessment of methodologies to draft representative and efficient scenarios
Long-term	Consequence of policy measures on travel behaviour	Define most efficient policy measures and decision-making processes	Sociological studies	Support harmonization of indicators to assess processes and measures efficiency
Medium-term	Condition of the health system, Seismic movements, demographic indicators, ...	Monitor the overall condition of external factors with a risk of causing a mobility crisis	Domain experts	Define relevant indicators for each type of crisis identified
Medium-term	Robustness of services, acceptance of measures, redundancy of networks and services, ...	Monitor the overall condition of the urban mobility ecosystem	Transport authorities, transport operators, infrastructure providers, surveys	Define relevant indicators of the overall condition of the urban mobility ecosystem
Short-term	Times and frequency of vehicles and stations sanitisation, vehicles occupancy, road traffic intensity, works, ...	Provide relevant information to users, for them to choose the most adequate mode for their mobility needs	Transport operators, Traffic management authorities	Provide a legal framework and support technology development for real-time data-sharing

Table 3 - Data resource needed

3.2.2.2. Data sharing governance

As indicators must be monitored to provide real-time updated crises predictions, data must be shared. This raises the question of the collection of this data, its storage, ownership, transferability conditions and governance. Based on recent works conducted by the Sustainable Mobility for All initiative[27], supported by the World Bank Group and the United Nations, following recommendations for research needs at EU level can be formulated:

- *Explore* new control models through methods such as developing and funding pilot projects for innovative control models (e.g., data trusts and data collectives) or establishing or identifying preferred institutions to govern new data control structures.

- *Examine* IP laws to avoid unreasonable barriers to data sharing, initiate discussion on ownership rights, conditions for transfer of ownership, liabilities for misconduct, and limits of liabilities, in particular for co-created data, provide guidance on the responsibilities of data providers and data controllers toward the quality and traceability of their data.

- *Create* frameworks for public–private partnerships that allow mobility organizations and stakeholders to collaborate in governing local data sharing initiatives.

- *Define* optimal organisation of governing bodies to enable data sharing best practices convergence, build greater consistency and efforts harmonisation, and ensure data interoperability across geographies.

3.2.2.3. AI and Data Science

In addition to the defined data content and uses necessary for preparedness, and to the governance frameworks conditioning data sharing, **artificial intelligence (AI) and data science are technologies enabling the improvement of the mobility system resilience, which must be tested and further developed.** The potential multiple configurations and services enabled through AI need to be structured and implemented in trials to optimise the opportunities they offer, and ensure they are aligned with and contribute to public policy objectives. Data science use should be fostered and encouraged to support its use towards the reinforcement of urban mobility resilience.

[27] Sustainable Mobility for All. 2021. Sustainable Mobility: Policy Making for Data Sharing. Washington DC, License: Creative Commons Attribution CC BY 3.0, available online, last consulted on April 15, 2021.

As a conclusion, research needed at EU level to reinforce required concepts enabling urban mobility resilience is about communication and community-building around resilience protocols, data governance models and data collection to monitor the disruption readiness of different aspects of the urban mobility ecosystem. Legal scrutiny for better frameworks is also required, as well as the definition of cooperation and management models which value resilience. Finally, relevant data collection for mobility resilience requires the establishment of frameworks at EU level, and support in terms of methodologies, capacity and harmonisation.

EU Research & Innovations needs with regards to enabling a resilient mobility system		
Governance models	1.	Conduct pilot projects and exchange of best practices on partnership models fostering trust and enabling empowerment of these actors
	2.	Define a model to value resilience in decision-making processes
	3.	Provide recommendations for and promote systematic scrutiny of laws, monitoring their update and suitability to currently identified risks and challenges
	4.	Enable communication and community building on processes related to resilience protocols, to optimise them
Data as a resource	5.	Support access to necessary data, based on recommendations provided in Table 2
	6.	Explore new models for data control to facilitate data sharing
	7.	Examine IP laws to avoid unreasonable barriers to data sharing and provide guidance on the responsibilities of data providers and data controllers toward the quality and traceability of their data
	8.	Create frameworks for public–private partnerships in the governance of data sharing initiatives
	9.	Define optimal organisation of governing bodies to enable data sharing
	10.	Test and further develop artificial intelligence (AI) and data science as technologies enabling the improvement of the mobility system resilience

Table 4 - Research recommendations with regards to enabling a resilient mobility system

3.3. Providing a resilient mobility system

After investigating the support needed at EU research and innovation level for the planification and set up of enablers of urban mobility resilience, the implementation of the concept is analysed for the concrete infrastructures, services, and network management which constitute the resilient urban mobility system.

3.3.1. Infrastructures

A key aspect of resilience, in the framework of the urban mobility ecosystem, is a quality infrastructure – that is, a robust one, which is also flexible and reflective[28]. The urban mobility system relies on three types of infrastructure: the digital one, the physical one, and the energy infrastructure (i.e., charging stations, electricity grid, etc.).

3.3.1.1. Digital Infrastructure

Data is an enabler of the resilience of the system, by allowing planning, monitoring and informed choices, both of decision-makers and users. Digital infrastructure provides resilience of the system by offering services such as multimodal journeys, last-mile solutions, contactless delivery, payment solutions, automated mobility, and other transport telematics, for example through the implementation of MaaS[29]. Digital services are personalised and reduce the overall budget allocated to mobility. Depending on the level of public governance incorporated into the development of the MaaS concept, they may have a significant impact on sustainability and inclusiveness of the urban mobility ecosystem. They provide an additional channel of communication and engagement.

There is a need to create a robust, secure, and transparent data infrastructure that can handle in real-time all mobility-related data, whether generated by moving or fixed parts of the mobility system, whether privately or publicly owned/operated, and whether shared or unshared. The model needs to have in place standards and protocols to enable data exchange, a middle layer to ensure real-time provision of services and management with empowerment of all actors, and the MaaS/TaaS front ends to orchestrate different mobility services to deliver a seamless experience to users.

A robust digital infrastructure requires consideration of risks related to cybersecurity and to ethical use of individual data sets, data security, and fairness in utilization of data, such that data access remains open to all, and contributors benefit in return for the value they have provided. To this end, **redundant and flexible technical solutions must be developed, and the applicability and use of current standards and protocols in crisis situations must be tested and ensured.**

3.3.1.2. Physical Infrastructure

With the current pandemic crisis, physical infrastructure has proven to be flexible and inclusive, with the quick development and implementation of lanes for active modes, sidewalks enlargements, urban logistics warehouse and delivery zones, micro-mobility parking places, e-mobility charging points, etc[30]. Works are needed towards the integration of infrastructure dedicated to different parts of the urban mobility ecosystem: resilience should be integrated in the design of currently tested and developed hubs for new and multimodal services[31]. **European research should focus on how to integrate systematic planification and indicators of resilience when building infrastructure or connecting existing assets with new modes, vehicles, or uses**.

Accessibility of physical transport infrastructure in times of crisis might be challenged, due to destruction, necessary distancing, or economic barriers for example. An emergency transport hierarchy

[28] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[29] Arthur D. Little and UITP, "The Future of Mobility post-COVID", July 2020.
[30] Arthur D. Little and UITP, "The Future of Mobility post-COVID", July 2020.
[31] The EU-funded eHubs project investigates the set-up of hubs for electric micro-mobility and logistics vehicles, from e-scooters to e-cargo bikes and e-cars.

is needed, identifying the most resilient modes ensuring critical functions of the system in challenging times. Analyse key destinations to be reachable, such as green spaces, will help reconcile different ways of seeing and using a neighbourhood in times of crisis[32]. **R&I could focus on good practices exchange on what is effective in terms of prioritisation and what does not help. Feedback collection and living knowledge creation around this topic is necessary**. Besides, the 15-minutes-city concept will reshape the reflection on critical infrastructure accessibility, and should integrate risks and unexpected events in the planning processes. **Research and tests on this concept should be connected more in depth with research on infrastructure resilience**.

Finally, physical infrastructure's resilience, which could be considered in a traditional way as hardened infrastructures, security barriers, emergency operations, house raids, and lockdowns[33], produces "atmospheres" changing the experience of the city for residents. For example, an army of anti-terrorist bollards may contribute to an area's safety, but also alerts on the existence of a threat, which might have contradictory effects: changing people's behaviour, focusing on a threat at the expense of another one, making other targets more vulnerable. **More research and investigation is needed on the consequences of securing infrastructure in view of a specific threat, like terrorism**.

3.3.1.3. Energy infrastructures for mobility

Infrastructure to ensure energy provision is key for the performance of the urban mobility ecosystem, especially when considering sustainable modes. To increase resourcefulness in electromobility, cities need to invest in the capacity of the network to anticipate future conditions of grid vulnerability. Indeed, decentralised renewable energy production and usage is essential for a fast uptake of zero-emission transport and related applications without being bound by public grid limitations[34].

Energy infrastructure is often considered as a system in itself, composed of charging points, energy production assets, energy transportation grids, and now also vehicles which are consuming but also able to produce and provide energy[35]. Planification of energy management covers long periods, due to the necessary heavy investments. These characteristics of the energy infrastructure make it difficult to integrate it in mobility planning, and in an overall urban resilience plan, as needed.

European research should focus on tools to enable this integration, guaranteeing critical energy infrastructure is in place and capable to provide sufficient energy supply in unforeseen crisis situations. The other way around, methods for a systematic integration of energy considerations in the set-up of new services in the urban mobility ecosystem should be investigated.

3.3.2. Services

Provide a resilient urban mobility ecosystem means to ensure the functioning of services, which fulfil the objectives of sustainability, safety, equity, integration, and inclusiveness, during normal times and in times of crisis[36]. Following the principles of urban mobility resilience, services provided must be redundant, so the same itineraries must be possible to travel with different modes and options. They must also be reflective, regularly identifying critical points and investment needs, resistant to potential hazards, flexible and resourceful in transforming under new conditions, and inclusive and integrated by striving for accessibility and consideration of all citizens' needs, and by ensuring continuity with the entire mobility ecosystem. Research needed to foster these characteristics is recommended below for the different types of services.

[32] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[33] Atmospheres of (counter)terrorism in European cities, UK Research & Innovation project, lead by the University of Birmingham, School of Geography, Earth & Environmental Sciences, 2021-2023.
[34] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[35] The way to carbon-neutral road transport - a long-term race over three decades!, ERTRAC Plenary, December 2020.
[36] 100 Resilient Cities. (2015). Resilience point of view series Transport.

3.3.2.1. Public transport

Public transport is the backbone of urban mobility. The COVID-19 crisis has highlighted how essential public transport is to guarantee access to and continuity of basic services in times of crisis[37]. But it is vulnerable to demand, as dramatic decrease in ticket revenues during the crisis has shown. It also presents risks related to crowding: maintaining sanitary distances in case of a pandemic requires additional capacity, frequent disinfection and cleaning demands resources and is challenging in crowded vehicles, and proximity is favourable to thefts and criminality, and increases risks for terrorist attacks, which reinforces travellers' feeling of unsafety. **Further risks must be identified with a thorough research on the topic, in order to enable anticipation and mitigation**. **Furthermore, data to inform on the intensity of these risks and the probability that they could occur must be defined, to enable the monitoring of services and reinforcement or adaptation when and where it is needed**.

For instance, needs for services redundancy must be defined in relation to demand peaks. Studies must then be conducted on the best complementary services which can be developed and the required investments. Public transport economic viability is another need which must be determined in function of the reliability level of the underlying business model.

Considering this business model, as public transport is supported by public funding, the right level of emergency budget must be defined, as well as the governance and decision-making process to enable a quick and relevant attribution of funding. **Living labs and pilot projects supported by the EU could support good case practices exchange and methods for the definition of the required funding levels and governance frameworks**.

Connectivity of the public transport system reinforces its contribution to urban mobility resilience. Connectivity serves adaptability by enabling appropriate choice among alternatives[38]. It is essential to ensure real-time information to users, and to palliate to transport modes' stigmatisation and avoidance through communication on measures adopted and data on their impact. **European research could study the information required by users on services in case of disruption (e.g., cleaning frequency for a pandemic, occupancy of vehicles, etc.). Support to the development of a bidirectional data infrastructure for data collection by citizens and specific data provision by authorities is also needed, as already detailed in the enablers' part.**

3.3.2.2. Active travel

Active travel modes are inclusive, flexible, resourceful, redundant, integrated, reflective, and robust. They are by definition resilient, as they rely on physical activity and require little investment, labour force and infrastructure. Moreover, they improve citizens' health condition as they represent the easiest and most equitable type of physical activity for people to engage in[39], and thus participate in the sustainability of the urban mobility ecosystem, which includes users. Therefore, a resilient mobility system is a system where active travel has a preponderant position[40].

But giving such a place to active travel in urban mobility is a challenge for cities because their contribution to resilience, sustainability, accessibility, and other desired outcomes has been historically undervalued due to car-centric urban planning, which has resulted in a lack of appropriate urban infrastructure for safe walking and cycling. **It requires awareness raising, reallocation of space and infrastructure building, modelling and assessment of use**.

[37] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[38] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[39] Travel in London, Report 13, TfL's annual report, 2020.
[40] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.

EU support is needed in each of these measures, in undertaking research as proposed in the table 3 below.

Objective	Recommendation for EU R&I
Awareness Raising	Communicate on pilot projects and benefits
	Provide tools and support capacity building at city level for the enforcement of measures on active travel and the education of citizens on how to best use them
Reallocation of space and infrastructure building	Train transport practitioners in short-term design solutions
	Communicate and enable community building and exchange on available technical guidance for good quality quickly deployed infrastructure, providing solid foundation for planning safe, temporary infrastructure that can be implemented almost immediately in towns and cities.
	Support the transition to permanence for these measures, by sharing good practices, conducting pilot projects and promoting their results
	More guidance on street design during pandemics needs to be published
	Conduct pilot projects to propose and test models of partnership between different actors (including politicians of different departments and levels, health NGOs and research institutes, citizens, active travel industry, etc.) to increase ownership of adopted measures
	Support the development of the 15-minutes city with tests and pilot projects
Modelling and assessment of use	Identify relevant data to collect and methods for data collection and assessment for the monitoring of active travel practices
	Provide capacity building for on-site tracking and survey of users' perception over the course of the crisis

Table 5 - EU support for active travel integration in urban mobility planning

Besides, the sedentary lifestyle adopted by the very wide majority of people in our contemporary societies is at the origin of many trends leading to crises (health, ageing, energy use, climate change, economics), and also an obstacle to resilient mobility. **Studies on the consequences of this sedentary lifestyle and opportunities for change must be conducted**. **And parallel research is required on the obstacles to the transformation of this lifestyle into a dynamic one based on active travel**, such as questioning the extent to which public investments in automated cars, air taxis, etc., represent a risk for active travel.

3.3.2.3. New mobility services

New mobility services can help cities achieve inclusiveness across geographical areas[41]. They can also augment existing mobility options and facilitate car-free lifestyle if made part of a wider city strategy. Cooperation, partnerships, and dialogue are crucial to create a redefined public transport system that integrates these new complementary services with public transport in an efficient and sustainable way. **European research and innovation can support in defining partnership and cooperation models and test them through pilot projects**.

Besides, solid public funding must be in place and digital platforms used to adapt transport services quickly in line with shifting demand patterns, increasing the flexibility of the system. **Capacity building for the attribution of public funding and the development and maintenance of digital platforms can be supported at EU level**.

Planning for enhanced connectivity and the digitalisation of all mobility options lays the foundations for the long-term development of resilient transport systems. **Research at EU level should further develop standards for connectivity and digitalisation and can provide a framework for planning**.

3.3.2.4. Urban Freight logistics

Urban freight provides the services that are mostly needed to citizens in times of crisis – food delivery, transport of health workers, etc. Therefore, it represents a key aspect of urban mobility resilience.

European research priorities to improve urban freight's contribution to urban mobility resilience should include a scenario-based participative research to define critical needs for citizens in times of crisis and the services that should be prioritized.

On another aspect, to improve the resilience of urban freight logistics, several actions can be taken:

- A potential successful long-term measure is **the inclusion of new technologies and services in city logistics**, among which
  - Cargo bikes have helped cycle logistics operators complete first- and last-mile deliveries while improve urban freight's sustainability.
  - The use of AVs helps to keep-up with consumers' expected levels of efficiency and effectiveness in logistics operations, and automation reduces personal interaction in the supply chain.
  - Delivery drones offer a better and wider access to remote areas than road transport modes.
- **To capture the impacts of crises** and strengthen the economy, actions are needed towards
  - The integration of land use and transport planning.
  - Building data-driven capacity to identify, track and deploy innovative urban mobility solutions.

[41] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.

3.3.3. Traffic and Network Management

Besides providing resilient infrastructure and services, overseeing the traffic to avoid congestion, limit negative externalities and prioritise most resilient modes also participates to improve urban mobility resilience. Below three traffic management tools are quoted, which require further support at EU level.

3.3.3.1. Traffic Management as a Service

Traffic management is a digital service which supports the urban mobility ecosystem resilience, by preventing critical traffic congestion and ensuring transport networks' fluidity. EU-funded research, led by city authorities, proposes pilot projects to implement a less cumbersome solution for Traffic Management as a Service (TMaaS) in small and medium sized cities[42]. To improve the solution developed, **further pilots and capacity building actions should be conducted for the integration of NMS, and the prioritisation of most sustainable and accessible modes in TMaaS**.

3.3.3.2. Access Regulatory measures

3.3.3.2.1. Parking

Since every car trip starts or ends with a parking spot, parking space management is a key enabler to shift individual motorised trips towards more walking, cycling, an increased use of public transport and more engagement in new mobility schemes (like car sharing or bike sharing systems)[43]. Crises can cause a fall in revenue streams from paid parking zones, thus reducing funding for sustainable alternatives. A solution to this would be a strategic parking revenue approach. It can consist in the relaxation of parking policies, and the reallocation of space to commercial ventures or lanes for active transport modes. European research is already investigating cases of reallocation and has shown the necessity to include smart parking management in sustainable urban mobility plans (SUMPs)[44]. **Further needs concern the pilot implementations of parking strategies in the SUMP of European cities**.

3.3.3.2.2. UVAR measures

The pandemic has shown that Urban Vehicle Access Regulation (UVAR) measures and strategies are not just a trend, but a necessary step towards developing sustainable and resilient cities[45]. They are key to create space for active transport and high quality of life, improve air quality and road safety, and reduce congestion and noise. They are a good jumping-off point, on which to add or adapt emergency measures. To be well prepared, cities need to know what access regulation options available, and how current schemes can be adapted in a crisis. Recent EU research identifies and structures UVAR measures, which supports their adaptation in times of crisis[46]. **Engagement and awareness raising on the results of this research is necessary**.

[42] The TMaaS project conducted by the city of Ghent proposes a platform tailored to the city it is deployed in, providing an overall picture of mobility in the city, including real-time traffic events thanks to third parties' data, position of public transport vehicles based on In-vehicle GPS trackers, etc.
[43] European Parking Association, 'EPA Position Paper', 2019, https://www.europeanparking.eu/media/1583/epa_position-paper.pdf.
[44] The EU-funded PARK4SUMP project aims to help cities integrate innovative parking management solutions into Sustainable Urban Mobility Plans (SUMPs) for a better mobility and quality of life.
[45] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[46] The ReVeAL project has identified and structured 68 UVAR measures into four categories. Each measure is a building block (e.g., a parklet) that moves in the direction of a larger vision (e.g., superblock). These could include, for example, parklets, urban freight regulation, or measures that help implement an aspect of a controversial LEZ (e.g., a logistics hub). Understanding the UVAR building blocks available to a city will help them decide which ones may be appropriate for them, not only in crisis situations.

To improve the resilience of UVAR measures, findings also show that cities must be able to re-design or update UVAR measures regularly to ensure they are adapted to present conditions and support urban mobility resilience[47]. EU-funded research has developed tools to this end, and **further research should focus on the communication about these tools and the testing and validation of their functioning through pilot projects.**

Besides, future technologies such as geofencing can enable a flexible designation of given areas of a city with lower emissions, noise, or speed[48]. Urban design and digital aspects of UVARs will need to be coordinated, but this redundancy will mean that one system can also take over if the other fails. Digital aspects will also enable the communication of available and planned UVAR measures, enhancing familiarity and experience of positive benefits of these measures. This will make it easier to adapt and implement them as needed and obtain public acceptance. EU-funded pilot projects to develop the digital aspects of UVARs and support their communications are already being conducted[49]. **Further support is needed to increase stakeholders' involvement in these projects, for a wider use of their outcomes**.

EU Research & Innovations needs with regards to providing a resilient mobility system		
Digital Infrastructure	1.	Create a robust, secure, and transparent data infrastructure with back-end processes and standards, middle layer real-time information sharing, and front-end MaaS/TaaS seamless service for the user
	2.	Provide recommendations for redundant and flexible technical solutions, and testing of the applicability and use of current standards and protocols in crisis situations
Physical infrastructure	3.	Define models to integrate systematic planification and indicators of resilience when building infrastructure or connecting existing assets with new modes, vehicles, or uses
	4.	Support good practices exchange and living knowledge creation on what is effective in terms of prioritisation of destinations and infrastructure, and what does not help
	5.	Connect research on infrastructure resilience with research on the 15-minutes-city concept
	6.	Investigate the consequences of securing infrastructure in view of a specific threat, like terrorism

[47] Moa Berglund and Julie Schack (WSP Sweden), "Initial Assessment of Resiliency of Pilot Cities' Regulatory and Policy Measures", ReVeAL Milestone 11, Report, 30 May 2020.
[48] POLIS, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2021. Topic Guide: Planning for more resilient and robust urban mobility.
[49] UVAR Box is a preparatory action developing a standard machine-readable language for the digitisation of UVARs, and UVAR Box II, building up in the first project, will support the implementation of UVAR measures' digitisation and integration in navigation applications and other service providers.

Energy infrastructure	7.	Explore and test tools to integrate energy infrastructure in urban mobility planning to guarantee critical energy supply in unforeseen crisis situations, and to systematically integrate energy considerations in the set-up of new mobility services
Public transport	8.	Identify key data to inform on the intensity of risks on public transport and the probability that they could occur, to facilitate monitoring and prevention
	9.	Support the definition of the required funding levels and governance frameworks for public transport adaptation to shocks through living labs and pilot projects
	10.	Investigate on the information required by users on services in case of disruption, and support the development of a bidirectional data infrastructure for data collection by citizens and specific data provision by authorities
Active travel	11.	Support awareness raising, reallocation of space and infrastructure building, modelling and assessment of use of urban space, to promote active travel, as recommended in Table 3
	12.	Encourage and support studies on the consequences of the sedentary lifestyle and opportunities for change, in parallel to research on the obstacles to the transformation of this lifestyle into a dynamic one based on active travel
New Mobility Services	12.	Define and test partnership and cooperation models between NMS and public transport authorities
	13.	Build capacity for the attribution of public funding and the development and maintenance of digital platforms
	14.	Develop standards for connectivity and digitalisation, and provide a framework for planning connectivity
Urban Freight Logistics	15.	Develop a scenario-based participative research to define critical needs for citizens in times of crisis and the services that should be prioritized
	16.	Improve the resilience of urban freight logistics by including new technologies and services in city logistics
	17.	Capture the impacts of crises on city logistics by integrating land use and transport planning, and by building data-driven capacity to identify, track and deploy innovative urban mobility solutions

Traffic Management as a Service	18.	Conduct pilots and capacity building actions to integrate NMS in TMaaS, and prioritise most sustainable and accessible modes
Access Regulatory measures	19.	Facilitate the pilot implementations of parking strategies in the SUMP of European cities
	20.	Raise awareness and facilitate the use of UVARs and related tools

Table 6 - Research recommendations with regards to providing a resilient mobility system

To summarise, research and innovation at European level can support the set-up of more resilient infrastructures, services, and networks to increase mobility resilience in European cities. Improving the resilience of these system components implies desk research, literature review, data collection, surveys, and case studies on each topic and for each envisaged option, but also on-ground testing through pilot projects and living labs, and good practices exchange, communication, dissemination, stakeholders' engagement, and promotion. Tools, methodologies, and procedures require European guidance, validation, and expanded communication to have the expected impact they are designed for. Frameworks, harmonisation, and standardisation are also needed at EU level, as well as capacity-building.

4. Research Methodology, capacity building and exchange

Given the specific nature of the topic, and the fact that severe crises cannot be 'tested' in real life, the resilience 'condition' requires a specific approach to research and innovation activities. For many of the R&I needs mentioned, qualitative research methods will apply: access to reliable data and information to allow for structured mapping, inventories and analysis of response to previous crises, exchange on experiences, ...

In this sense, the principles highlighted in the Integrated Urban Mobility Roadmap[50] with regards to methodologies for the mainstreaming, transferability and upscaling of UM innovation are valid for resilience in urban mobility as well. Due to different contexts and specificities of cities and countries, each with their own social and mobility challenges, policy objectives and user needs, such methodologies are crucial to allow for the successful transfer of good practice from one city to another, across mobility service providers and infrastructure stakeholders, taking full account of key-barriers, enablers and success factors.

Capacity building, knowledge transfer and site visits (i.e. to have first-hand experiences) are key measures that have been successfully applied to upscale and transfer the best and most innovative urban mobility solutions. This experience can be exploited for the purpose of mainstreaming resilience into UM practices. Making policy makers aware of best practices and solutions and handing them the tools to assess whether these solutions suit their own local context, is often the key to effective roll-out and implementation of promising innovations. However, such hands-on exchange and peer-to-peer transfer activities require accompanying support and capacity building for local practitioners and policy makers. Focus of these actions should be on the creation of an innovation culture and establishing the right context conditions for innovation in the field of resilience.

[50] See UM Roadmap, section 2.2.4. Transferability, Capacity building and Upscaling.

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