CONCEPTUAL FRAMEWORK

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Authors	Pedro Ferreira, Anabela Simões
Email	pedro.ferreira@ulusofona.pt
Affiliation	COFAC
Contributors	UNIFI, CERTH, FHG, HUMANIST, SWMIZ

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EXECUTIVE SUMMARY

Following the state of the art presented in D2.1, this document presents the methodology to be used in RESOLUTE and its conceptual framework as the grounds directing the first application of Resilience Engineering to such a complex context as urban transport systems (UTS). Thus, D2.2 is the output of the work carried out in under task 2.5 (Synthesis and scoping towards the conceptual framework) being composed of the following sections:

The RESOLUTE OBJECTIVES AND METHOLODOGY highlighting the innovative approach to be followed in RESOLUTE, which goes beyond conventional risk management practices, namely the identification, assessment and safeguard against undesired levels of risk. The project main goals are expressed in the fundamental tools to be developed (ERMG and CRAMSS), involving two methodological stages (System Analysis and Data Gathering and Analysis). The chapter ends with the presentation of the RESOLUTE Conceptual Framework.

The RESOLUTE CORE highlights the wide diversity of knowledge and expertise domains, which requires the use of an equally diverse range of data gathering and analysis processes. Thus, data mining and processing to ensure a comprehensive basis of analysis with statistical meaningfulness, together with qualitative data collected from surveys, interviews and focus groups will provide the development of the intended models, as well as also subsequent validation. Four sub-sections (Sociotechnical assets, User needs and demands, Sustained adaptability and urban context and features) complete section 3.

The METHODS, presenting the different methods to be used: (1) The Functional Resonance Analysis Method (FRAM) supporting the system analysis process and aiming at identifying interdependencies and system emergent behaviours potentially relevant for resilience; (2) The Resilience Analysis Grid (RAG) supports the data analysis necessary to develop the structure and contents of the ERMG; and (3) The multi-layered network analysis that will support the evaluation of the cascade effects and produce resilience quantification. Two more sub-sections complete this section: Common language highlighting the importance of developing a project taxonomy; and the ERMG, as a guidance for resilience management in any kind of critical infrastructure system.

The OPERATIONALISATION OF RESOLUTE TOOLS, which require to be applied and tested in real scenarios putting together both sides of the urban transport system: (1) the physical side represented by the density of vehicles and/or people in a specific area, the location of fuel stations, the critical points of viability (presence of bridge, red lights, RTZ (restricted traffic zones), etc.; (2) the human side represented by behaviours based on individual limited knowledge of the status of the event, heuristic, physical skills, emotion, emulation, etc. Two sub-sections introducing the concepts of the RESOLUTE tools able to translate into practices the ERMG and to track the complex system resources allocation and exploitation complete this section: Big Data Management Platform and CRAMSS.

The SCENARIOS describing the composition of an urban transport system, which is essentially based on private and public transport. The features of both subsystems are described, particularly in what concerns the easiness of emergent and exceptional procedures to be activated in critical situations and the importance of public transport operators in such critical situations in order to mitigate damages and re-establish the normal operations as briefly as possible.

GOING FORWARD FOR RESOLUTE is a conclusive section highlighting the proposed innovative approach to resilience that abandons many of the conventional perspectives on risk management and

requiring deep research aiming at a flexible, adaptable and robust methodology towards resilient urban transport systems.

PROJECT CONTEXT

Workpackage	WP2: Evidence retrieval assessment and synthesis
Task	T2.5: Synthesis and scoping towards conceptual framework
Dependencies	This document will support the development of the ERMG and methodology for pilot testing

Contributors and Reviewers

Contributors		Reviewers
Evangelia Gaitanidou	Emanuele Bellini	Paolo Nesi
Alexandros Deloukas	Ioannis Symeonidis	Evangelia Gaitanidou
Gianluca Vannuccini	Maria Tsami	Maria Panou
Laura Coconea	Alexandros Zamichos	
Francesco Archetti	Anna Adamopoulou	
Anastasios Drosou		

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1 INTRODUCTION

This document constitutes the second deliverable (D2.2) from work package 2 (WP2) and presents the work carried out under task 2.5 (T2.5 - synthesis and scoping towards conceptual framework). It builds on the key outputs from previous tasks in WP2, integrating and interpreting the contents of D2.1 (RESOLUTE State of the Art - SotA) in view of project scope and objectives. This was designated as RESOLUTE conceptual framework. The referred tasks can be summarised as follows:

- T2.1 addressed the review of resilience related literature and other related domains such as risk management and assessment.
- T2.2 addressed the review of risk analysis and management guidelines, both at EU and member state level.
- T2.3 addressed the review of applied tools and methods on resilience and other related operational and managerial aspects.
- T2.4 addressed the review of training practices and programmes.

The conceptual framework aims at providing an overall methodological guidance for the development of RESOLUTE. This document presents the methods and tools to be applied and outlines the way in which these are to be brought together, so as to coherently deliver project objectives.

The conceptual framework extracts the relevant scientific arguments from the state of the art to support methodological options. Urban transport systems are briefly described as the context on which RESOLUTE methodology is to be applied. At this project stage, it is critical to clearly establish the research domain boundaries and ensure that the planned methods respond to all data gathering and analysis needs and requirements. To this end, project objectives are briefly introduced in order to demonstrate how the methods and tools respond to such needs and requirements, particularly in terms of scientific validity. The fundamental system components and variables are highlighted, followed by the description of methods to be used. This document also lays down the way for a taxonomy, which is to be enhanced throughout RESOLUTE development, in particular as a support for the structure of the guidelines and the collaborative assessment platform to be produced.

2 RESOLUTE OBJECTIVES AND METHODOLOGY

RESOLUTE aims at contributing to enhanced resilience in critical infrastructure systems, with emphasis on urban transport systems. Despite focusing on the specific needs of urban transport, the project aims to produce resilience management guidelines applicable across domains. Two fundamental tools will be developed:

- The European Resilience Management Guidelines (ERMG)
- The Collaborative Resilience Assessment and Management Support System (CRAMSS)

In line with RESOLUTE vision and based on the scientific evidence presented in the SotA (D2.1), resilience is about managing high variability and uncertainty in order to continuously pursue successful performance of a system (SotA D2.1). This requires an approach that goes beyond conventional risk management practices, namely the identification, assessment and safeguard against undesired levels of risk. In terms of resilience, the challenges faced by complex sociotechnical systems are two-fold:

- The wide diversity of potential foreseeable and unforeseeable threats, ranging from well-known/frequent events (normally within operational capacities and accounted within risk management practices), and low-frequency or virtually unknown events that tend to exhaust operational capacities and go beyond the scope of risk management practices.
- The large scale and fast-pace changing operations which, on the one hand, render systems inherently underspecified (to some extent operations are always unknown) and therefore, control-based management practices become unsuitable/insufficient, and on the other hand, the potential for rapid and unpredictable propagation, cascading and chain-reaction effects must inevitably be addressed. In view of this, many complex sociotechnical systems are often referred to as being “fault intolerant”.

The sources of operational variability and the mechanisms through which it may potentially propagate and impact on system performance must be investigated and the resources and system capacities needed to manage and cope with operational variability must be determined. This constitutes the core of suitable resilience management practices and tools, and the source of innovative research outputs. The key arguments that must be taken into account and based on which the proposed RESOLUTE methodology is built, are here recalled:

- Resilience is an emergent property of systems, and therefore can only be perceived through the performance of the system as a whole. An emergent system property cannot be monitored nor assessed through the characteristics or attributes of individual system elements, nor can it be deducted from the summation of such characteristics or attributes (the emergent behaviours of a system are much more than just the sum of behaviours observed in its individual parts). To this end, the focus must be set on system interdependencies (how system elements perform in relation to each other) and beyond linear cause-effect relations.
- Resilience is by definition, related to system purposes (the operational goals of the system; what the system is meant to deliver). In order for a system to fulfil its purposes, much more than risk management is needed, even if this remains a critical factor for any given system. Capacities for continuous adaptation to operating conditions must be developed and managed.
- Failure and success are context dependent attributes. An event can only be judged as either a failure or a success in view of a given time and location. What is today considered a

failure for a given organisation, may well be an opportunity for success for another organisation, and may even be considered a success for that same organisation at a different place and time. If for no other reason, the high competitiveness that characterises every industry sector (including transport) pressure organisations to pursue any potential competitive advantage. As resources are finite, so are markets (offer/demand capacities), and an increase of a company's market share normally indicates the loss of others. Regarding risk assessment, severity is often assessed based on the costs potentially incurred if ever a given event takes place. As costs may vary and sometimes quite significantly, so can risk levels be altered under different economic, social and market circumstances. Resilience must be managed in view of what may sustainably contribute to the fulfilment of system purposes, and cannot be (singly) built upon passed known failures.

Within this framework, the pursuit of RESOLUTE objectives faces the challenge of relating dynamic and emergent system features, to a wide diversity of human, technical and organisational elements that at each time and place, generate equally diversified operational needs. The issue at hand is to deliver management guidance on such human, technical and organisational elements, aiming to respond to different and possibly conflicting local operational needs, whilst achieving fundamental system level synchronisation and coordination that, as best possible, ensures successful operation. This requires two fundamental methodological stages:

- System analysis and understanding supports the identification of relevant aspects and critical issues.
- Data gathering and analysis supports the investigation of the relevant aspects previously identified, leading up to the development of the ERMG.

These two stages are outlined in the following sub-sections. Finally, the RESOLUTE conceptual framework is introduced, bringing together the fundamental aspects of RESOLUTE's concepts, methods, scope (context) and objectives to be delivered.

2.1 System analysis

Given that resilience implies the ability of a system to continuously adapt to respond to its operational goals, no actual work towards enhanced system resilience should be undertaken without a context dependent and detailed understanding of system's performance and all the relevant features that ensure the delivery of its operational goals. The systems understanding that is required goes much beyond the description of human, technological and organisational components. The focus is set on the analysis of system interdependencies, how such interdependencies support the provision of critical resources, and the types and degrees of variability to which these are submitted in the face of pressures emanating from a system's operational environment.

This analysis sets the boundaries for the data gathering and analysis process that is to follow and support the development of the ERMG and the CRAMSS. A systems analysis can be defined as an approach dedicated to the design, analysis and management of complex systems. This can be generically described as follows:

- The identification of system elements provides grounds for the selection of appropriate methods and disciplines for the study of each element.
- The subdivision of elements into smaller elements enables proper focus on relevant system parts.

- The **grouping of elements** provides means for better understanding the relations between elements with common goals and of overall system structure.
- The **identification of system boundaries** supports the definition of the system and its goals or purposes, as well as the identification of the elements that most contribute to these overall goals.
- The **identification of functions** for each system element further develops the understanding of system operations and dynamics, and how system functions are carried out.
- The **analysis of interactions** between system elements complements knowledge of system functions by looking into how elements perform together to achieve system goals.
- **Understanding the system environment** is crucial for the analysis of pressures on system operations and performance of system elements. Whenever relevant for system design or analysis, this may include looking at elements independently and their environment within the system, as each system element may have different environments and therefore, also be subjected to different performance constraints and pressures.
- The **identification of the emergent properties** of the system constitutes a crucial step for understanding system functions and goals, as well as boundaries.
- The **development of a synthesis of functions and structures** supports interpretation and understanding of system performance.
- Like in any robust scientific approach, **verification and validation** are fundamental steps to be considered.

Within this frame of mind, FRAM provides the means to investigate systems whilst making no assumptions on the human, technical and organisational elements that may shape them. The added value of this approach resides in the following arguments:

- A higher focus on understanding the fundamental aspects to achieve system purposes, namely the critical interdependencies and the resource flows that they support, thus offering valuable insight for enhanced system resilience.
- A suitable ground for application across different sectors, as while human, technical and organisational elements are subject to constant change and may significantly vary from one context to another, in principle, two systems with similar purposes would require very similar sets of functions to achieve such purposes, regardless of system environment.

Criteria and parameters for the definition of system boundaries are proposed beforehand in this section, followed by a brief description of the application of FRAM for the modelling of urban transport system scenarios.

2.2 Data driven analysis

The system analysis and understanding of emergent behaviours of system interdependencies must be traced back to local operational conditions and variability. Rather than establishing linear cause-effect relations, this amounts to understanding how the various critical local processes and decision making must be managed, so as to ensure a system level synchronisation that is within the capabilities of adaptation that system resources can sustain. To this end, various data gathering processes are foreseen, ranging from general surveys, individual expert and group interviews, to Big Data collection, processing and analysis, among others. In particular, heterogeneous data flows coming from the urban system (including CI operations and people behaviours) as city Wi-Fi accesses, traffic flows, environmental sensors, public transport service status, risk maps, among others, are fused through a semantic approach in order to enable integrated knowledge extraction and to connect real data to the theoretical models.

This stage closely relates to the guidelines development methodology, which is detailed in Deliverable 3.4 (Guidelines Methodology) and is briefly outlined in section 4.5. The data gathered and analysed will support the qualified or quantified determination of parameters deemed relevant for the guidelines contents and structure.

2.3 The conceptual framework

Figure 2.1 represents the proposed conceptual framework, on which these two methodological stages are grounded. The framework can be described as follows:

1. The expertise that supports system analysis and data analysis for the guidelines development, as foreseen under the Guidelines Methodology (D3.4).
2. The fundamental resilience related methods for the delivery of RESOLUTE objectives. While the Functional Resonance Analysis Method (FRAM) will support the systems analysis stage, the Resilience Analysis Grid (RAG) will relate system level understanding to meaningful and manageable human, technical and organisational assets, towards building the ERMG. These tools are further detailed in section 4 (Methods).
3. The four fundamental capacities for system adaptation and the fundamental aspects of sociotechnical systems will be used as grounds for the structure and contents of the guidelines.
4. The tools to be delivered by RESOLUTE along with the ERMG as a support for their effective implementation, namely the CRAMSS.
5. The context for testing and validation of both the ERMG and the CRAMSS.

Whenever possible, to facilitate interpretation, the outlining of these elements in

Figure 2.1 is provided along with the numbering of the document section (shown between brackets), within which further details are provided on each of the elements, mainly elaborating on the key methodological aspects and the principles under which these should be carried out.

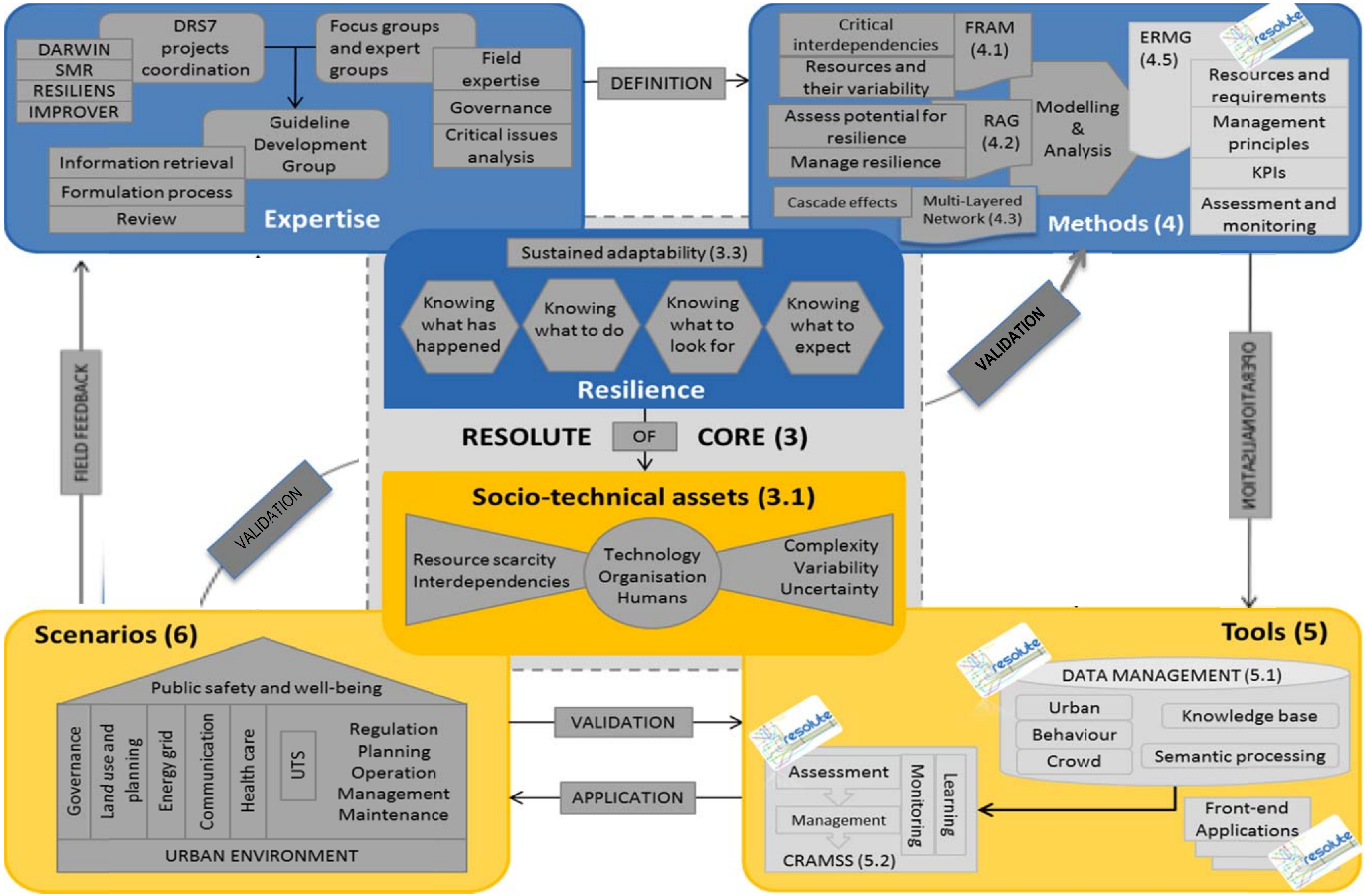

Figure 2.1: RESOLUTE Conceptual Framework

Within recent years, many critical infrastructure stakeholders have devoted significant efforts to the improvement of their risk management practices, taking into account various features relevant for the enhancement of resilience. This has been mainly motivated by the growing perception that strong system interdependency has rendered critical infrastructures increasingly exposed to large scale disasters, both of natural and man-made origin. The majority of such efforts have targeted sector specific and risk related concerns, namely resorting to improved risk prevention and protection measures, and to the heightened mitigation of damage when faced with undesired events. While risk oriented practices may (and should) contribute to resilience, they do not address the fundamental aspects of resilience that are previously highlighted and have been earlier detailed in the SotA (D2.1) as the foundations of RESOLUTE vision and objectives.

The endeavour of RESOLUTE is not to address risk management itself, but rather the system capacities and resources that are critical to ensure all operational and managerial needs (including risk management activities) under highly variable and unpredictable operational environments. To this end, RESOLUTE methodology must take into account the need to align the provision of resilience management guidance with practices and tools currently in place within the various relevant stakeholders, as well as the need to bring all such practices and tools under a common framework for urban transport systems. RESOLUTE guidelines must be designed in such a way that they may be tailored to support different operation and management practices and tools, within different system environments, and in view of different system requirements.

The validation scenarios to be carried out under RESOLUTE will provide unique opportunities to test the flexibility of the ERMG and explore their tailoring to different contexts and needs. For instance, on the Firenze scenario, various initiatives for cooperation amongst stakeholders are already in place, which suggests that many critical interdependencies might be identified and considerably understood in terms of performance. On the other hand, under the Athens scenario, Attiko Metro has addressed various resilience related aspects, even if grounded on conventional risk management practices. This indicates that the ERMG might be more useful by supporting the identification of system interdependencies and their performance trends and by steering the development of suitable resilience framework that (more than addressing known risk prevention, protection and mitigation needs) supports improved synchronisation and resource management within the larger system scope of Athens urban transport. Within this scope, the development of a resilience taxonomy may support the identification of complementarities, also between the ERMG and various context dependent aspects.

3 RESOLUTE CORE

RESOLUTE is grounded on a wide diversity of expertise and knowledge domains. To cover such wide diversity, the project methodology must contemplate the use of an equally diverse range of data gathering and analysis processes. Big system data mining and processing will ensure a comprehensive basis of analysis with statistical meaningfulness and will support the development of a historic perspective on each of the urban transport scenarios under investigation. Within the same scope of analysis, and in order to target specific issues that may not be addressed through big data, surveys and questionnaires may be carried out. This may be useful in particular to assess end-user experience when testing RESOLUTE key outputs. Interviews and focus groups will provide a qualitative or semi-quantitative means of interpreting specific performance aspects observed or identified throughout the various stages of RESOLUTE development. In particular, regarding the use of FRAM, interviews with experts at different operational levels may support, not only the development of the intended models, but also their subsequent validation. The following sub-sections outline issues potentially relevant for the delivery of RESOLUTE objectives, based on four categories of knowledge and expertise relating to both resilience and urban transport.

3.1 Sociotechnical assets

As described in RESOLUTE SotA (D2.1), from a resilience perspective, understanding system critical interdependencies and adaptive behaviours must take into account resource availability and allocation. Adaptive capacities require specific resource allocation and therefore, when deploying and testing ERMG, system resources and assets constitute a fundamental domain of analysis. Three fundamental sets of resources and assets must be considered:

- Human resources include technical skills, expertise and competencies, as well as cognitive resources, particularly those relating to decision making processes. These resources should be investigated within all relevant operational and managerial contexts. From an end-user perspective, both individual and collective behaviours (i.e. risk awareness and perceptions, risk aversion, among other aspects) are critical factors to be taken into account, as they may critically impact on the effectiveness and application of RESOLUTE key outputs. The levels of commitment of urban communities towards their own well-being and in particular the factors that may promote such commitment, must be considered a fundamental resource within the scope of RESOLUTE.
- Technological resources and assets (keeping in mind the focus on urban transport) comprises infrastructure related assets such as rail track, electrification and signalling systems or roads, and vehicle related assets such as rail rolling stock and engines, and road trucks, buses and cars, as well as traffic control and ticketing related assets. Special attention should be devoted to risk prevention and mitigation, and maintenance related resources and assets, as these tend to be both critical system operational enablers and constrainers.
- Organisational resources include hierarchical structures and formal procedures and regulations, as well as logistics elements. Information use and communication must also be taken into account, as they constitute the key resource for every decision-making process.

In line with the resilience engineering approach, system resources should be managed in such a way that they produce sustained adaptability capabilities. As described in RESOLUTE SotA (D2.1), this leads to consider the following fundamental issues:

- What capabilities are needed?
- How much of such capabilities?
- Where and when are such capabilities needed?
- Capabilities of sustained adaptability towards what?

3.2 User needs and demands

RESOLUTE state of the art (D2.1) highlighted the human purpose nature of every sociotechnical system. This means that responding to system purposes must foremost contemplate by whom and how systems are in fact used. Specific user demands and needs must be investigated, as these are always much more complex and dynamic than what is normally anticipated at systems design stages. In this context, the term "user" applies not just to "end-user" or customer. To a given extent and on many different aspects, people involved at various levels of system operation and management are themselves users of certain system resources and assets. Hence, user focus and human factors principles must be taken into account at every stage of analysis and development of RESOLUTE key outputs.

Furthermore, fitting user needs and demands/requests requires a desirable quality of service, which results from the balance between the identified user needs and requests and the operators' planned and delivered service. Thus, the quality of service is defined by users' satisfaction at the following levels: availability, accessibility, reliability, comfort and safety/security. A high level of service quality is also the guarantee of appropriate conditions for emergency communication and action, including rescue operations. As previously mentioned, the public perceptions on the quality and safety of urban infrastructures and services may greatly impact on the delivery of RESOLUTE objectives. RESOLUTE scope takes into account urban communities as stakeholders for urban transport resilience and therefore, public perceptions of well-being and reliance on urban infrastructures and services must be considered. The levels of individual commitment towards the well-being of the urban community as a whole, and the potential need to enhance such levels, must be taken into account throughout the planning and operation of urban transport systems.

3.3 Sustained adaptability

System operation aspects become relevant, as by definition, resilience may only be perceived through system performance. As defined in RESOLUTE SotA (D2.1), resilience is a system property that may or may not emerge from system operation. This implies the identification of system performance characteristics, aiming to produce a set of requirements for indicators and monitoring tools as a fundamental support for management and decision making. In line with the resilience engineering approach, the potential for resilience to emerge from system performance may be assessed based on the "four resilience cornerstones":

- Knowing what to do corresponds to the ability to address the "actual" and respond to regular or irregular disruptions by adjusting functioning to existing conditions.
- Knowing what to look for corresponds to the ability to address the "critical" by monitoring both the system and the environment for what could become a threat in the immediate time frame.
- Knowing what to expect corresponds to the ability to address the "potential" longer term threats, anticipate opportunities for changes in the system and identify sources of disruption and pressure and their consequences for system operation.
- Knowing what has happened corresponds to the ability to address the "factual" by learning from experiences of both successes and failures.

From this perspective, operational evidence (indicators and monitoring tools) should demonstrate that these four cornerstones are suitably embedded at all relevant system levels and context. Relating the issues previously mentioned regarding resources and adaptive capacities with the development of these four cornerstones, will then support the production of the Resilience Analysis Grid (RAG). Thus, resilience focuses on sustaining the capacity for a system to adapt in the presence of continuous change. Generating, maintaining, and deploying adaptability processes relies upon the allocation of a wide range of resources and at many different system levels and time scales. As such, adaptability capacities are intrinsically related to the level of resources that a system can allocate and its ability to manage these resources in view of specific adaptive cycles (SotA D2.1). An adaptive cycle is described based on the four stages of event management cycle that a system needs to maintain, in order to be resilient (SotA D2.1):

- Plan/Prepare: Lay the foundation to keep services available and assets functioning during a disruptive event (malfunction or attack)
- Absorb: Maintain most critical asset function and service availability while repelling or isolating the disruption.
- Recover: Restore all asset function and service availability to their pre-event functionality
- Adapt: Using knowledge from the event, alter protocol, configuration of the system, personnel training, or other aspects to become more resilient.

Adaptive cycles cannot be dissociated from system performance variability, as they are simultaneously the mechanisms that systems use to cope with variability and inevitably, an important source of variability themselves. In the same way that resources are inherently scarce, so are the capacities for adaptability. As such, the variability that a system can cope with is bounded by such limitations. The challenges to system resilience reside then in the ability to understand and monitor resources and the capacities that they provide towards coping with both expected and unexpected amplitudes of performance variability.

3.4 Urban context features

No system or sub-system is equal to another and complexity contributes to increased diversity of organisational, technical and human elements in sociotechnical systems. System context elements must be considered, not only because resilience must be placed within the scope of system purposes (all sociotechnical systems are systems of purpose), but also because they will generate specific interdependency characteristics, for which adaptive capacities must be tailored, so as to match adaptive behaviours to context demands and pressures.

Within urban contexts, transport systems are challenged to respond to a wide range of mobility needs, whilst coping with severe constraints of many different kinds, namely geographical, environmental, safety and security-related, among others. The urban context is an interconnected system (or system of systems) characterised by multi decision makers (civil protection, public administration, infrastructure managers, etc.), conflicting micro opportunistic behaviours (people, users), heterogeneous data sources, distributed (and sometimes not clearly defined) responsibilities and processes, etc. as emerged during the 1st RESOLUTE workshop in Florence (see Section 6). In such context the understanding of phenomena emerging from complex system interactions requires models and tools that go beyond current practices based on a linear cause-effect modelling of system operations. Thus, models and tools able to support the understanding of system performance variability and its sources are needed. In the following sections, a selection of models and tools that will be used for project execution is presented.

4 METHODS

The proposed RESOLUTE framework, as shown in

Figure 2.1, contemplates three different methods relating to resilience. The Functional Resonance Analysis Method (FRAM) supports the system analysis process, aiming to identify interdependencies and system emergent behaviours potentially relevant for resilience. The Resilience Analysis Grid (RAG) supports the data analysis necessary to develop the structure and contents of the ERMG. The multi-layered network analysis will support the evaluation of the cascade effects and produce resilience quantification. This section provides additional details on these key RESOLUTE methods.

4.1 Functional Resonance Analysis Method (FRAM)

The Functional Resonance Analysis Method (FRAM) is essentially a system modelling tool that focuses on system interdependencies, their dynamics and complexity. While it is not directly related to resilience and its assessment, it is grounded on resilience engineering principles and provides a fundamental support to such ends by supporting systems understanding.

The fact that FRAM modelling is based on system functions, not only supports the focus on operational goals, but also provides valuable insight on system dynamics. Beyond the analysis of human, technical and organisational system elements, FRAM provides the means to identify the mechanisms that allow a system to maintain its operation under a wide range of varying conditions.

The initial and crucial step of FRAM modelling is the clarification of modelling scope and objectives. In order to have a clear understanding of what system (or sub-system) is to be modelled, why the modelling exercise is being undertaken and what outcome is expected, it is essential to narrow down the relevant system areas. Particularly at the level and scale of RESOLUTE, a suitable FRAM modelling of the whole urban transport system and all the relevant functions of its operational environment is unrealistic. Therefore, it becomes essential to clearly establish modelling focus and objectives.

The identification of functions and the description of the six function aspects (input, time, controls, preconditions, resources and output) for each of the functions should follow. While there is no absolute criteria or rule for what should be the first function, the modelling exercise would normally be initiated, either at a function considered most critical or at one from which system key outputs are expected to be delivered. As example, Figure 4.1 illustrates a possible FRAM model for urban rail transport. The figure merely intends to show how a FRAM model may look like. Connections between functions are used as a means to identify function aspects. As such, they merely represent potential interdependencies or couplings between functions. Only through instantiations of the model do interdependencies become effective. The labels on the connections would correspond to the description of function aspects, meaning that if a connection exists in the model, then the designation of the aspects connected is the same. The model in Figure 4.1 should only be taken as a preliminary outline and is yet to be validated and verified. At this stage, the actual information and labels in the model shown are not relevant.

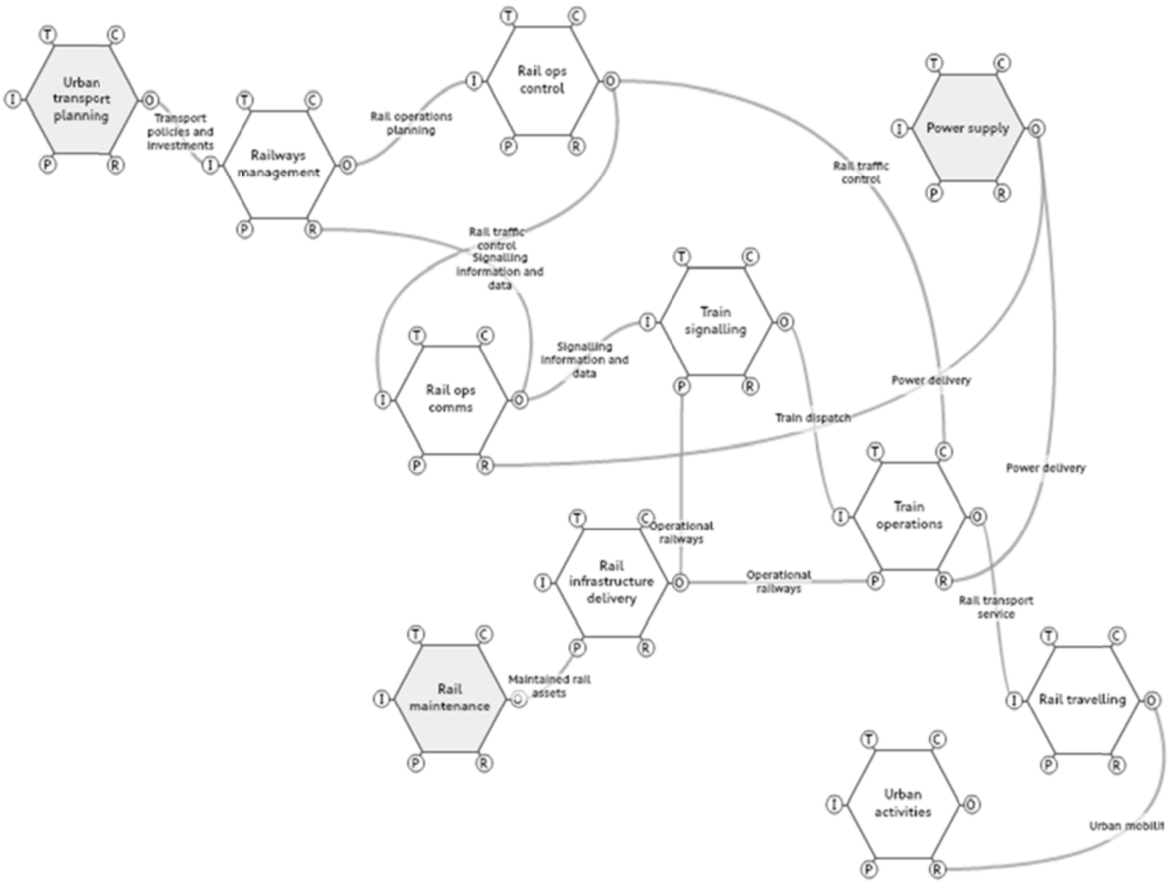

Figure 4.1: Example of a FRAM model

Overall, the features outlined in the previous subsections will provide guidance to FRAM modelling, mainly by responding to issues such as:

- What would be the functions that ensure the allocation and deployment of critical operational resources?
- What would be the functions that ensure the continuity of transport system operation under “normal” operating conditions? Under various degraded modes?
- What are the critical interfaces with other systems? With end-users?

A comprehensive reasoning over these issues facilitates the scoping of FRAM modelling. However, as highlighted in RESOLUTE SotA (D2.1.), system interdependencies remain relatively unexplored, particularly in terms of their managerial and operational impacts. To this end, the following interdependencies are put forward as relevant for RESOLUTE methodology:

- Interdependencies between road and rail infrastructures, transport operators and emergency services, public security and other municipal services.
- Interdependencies between road and rail infrastructures, and maintenance and other engineering work providers.
- Interdependencies between road and rail infrastructures and communication systems and networks.
- Interdependencies between transport infrastructure (in particular rail) and power grids.

4.2 The Resilience Analysis Grid

The Resilience Analysis Grid (RAG) is mainly intended as a resilience monitoring tool. It does not aim to assess risk levels in view of known threats and vulnerabilities, nor the effectiveness of risk management. Rather it focuses on determining the range and levels of adaptation of a system to its environment, and the adaptive capacities that it is capable of generating in view of both known and unknown operational pressures.

The RAG is foremost driven from the principle that no system is ever fully tuned or adapted to its environment. To say that a system is adapted to its environment leads to consider that it is able to deal with operational needs, "knows what to do" and "responds" appropriately to deliver its operational goals. It should be noted that this is in no way a static condition of the system, but rather an amplitude and range of variability (an envelope) within which the system is prepared to operate according to planned work (has the resources for). If we consider the individual, this would be the equivalent of having no cognitive dissonance. However, the reality is that, to a certain extent, any complex sociotechnical system is always out of tune with its environment and therefore, in addition to the need to be adapted to current operating conditions, the system must develop adaptive capacities. This amounts to being able to identify what, where from, and when pressures from the environment may emerge, pushing the system towards the need to review its configuration (the envelope) of being adapted. These adaptive capacities are essentially structured around the ability to "monitor" what is known to be a potential need for a change of the envelope, and to "anticipate" any possible unknown need for such a change. The recognition of the need for change requires the "ability to learn" from operational experience and feedback, and effectively place such learning into action at all system levels, thus supporting adaptive capacities.

Table 4.1 raises a set of issues based on which, each of these four capacities (four resilience cornerstones) can be assessed. This table also relates key human, technical and organisational aspects to each of the four capacities.

Table 4.1: Building the Resilience Analysis Grid

The four cornerstones	Human, Technical and Organisational aspects	Potential issues
Knowing what to expect ANTICIPATE - look ahead for the potential	• Types of threats • Constant sense of unease (no complacency) • Long-term and strategic planning	• What is the implicit/explicit "model" of the future? • How can the "world" be expected to change? • How long is the organisation willing to look ahead ("horizon")? • How many efforts are allocated to looking ahead? • What risks is the organisation willing to take? • Who believes what and why?
Knowing what to look for MONITOR - pay attention	• Performance indicators (leading and lagging) • Time to think and time to do • Information flows and decision making processes • Operational planning	• How have the indicators been defined? • How, when and why are they revised? • How many are leading indicators and how many are lagging? • How are the "measurements" made? (qualitative, quantitative) • When are the measurements made (continuously, regularly)? • What are the delays between measurement and interpretation? • Are effects transient or permanent?
Knowing what to do RESPOND - be effective	• Delivery of planned operations and procedures • Resource allocation and deployment • Adapting and synchronising various local needs	• For which events is there a response ready? • How was the list of events created? • When and why is the list revised? • What is the threshold of response? (Rate of change) • How soon can a response been given? • How long can it be sustained? (Size of buffers)

The four cornerstones	Human, Technical and Organisational aspects	Potential issues
	• Training of users at all system levels, seek improved awareness and preparedness	• How was the type of response determined? • How many resources are allocated to response readiness? • How is the readiness verified or maintained?
Knowing what has happened LEARN - build an organisational memory	• Reporting culture and processes • Accident models and investigation • Communication and feedback flows	• What is the learning based on (successes – failures)? • When does learning take place (continuously or event-driven)? • What is the nature of learning (qualitative, quantitative)? • What is the target of learning (individuals, organisation)? • How are the effects of learning verified and maintained?

These sets of questions can be answered with the support of other methods such as interviews or group discussions with subject matter experts, in order to produce a quantified or semi-quantified assessment of the issues raised. This requires context dependent approaches that can relate the consideration of these capabilities at a system high level with operational level and concrete aspects of system performance.

Within the scope of RESOLUTE, the use of this tool aims to produce an overview of a broad range of human, technical and organisational aspects regarding their contribution for system resilience. It should be noted that this does not aim to produce a measurement of resilience in itself, but rather depict the level at which a system may be prepared to adapt within various time scales (from current operation and short-term to long-term) to changes deemed possible in the operational environment, either as a threat or an opportunity for performance enhancement. This may be defined as assessing the potential for resilience. The RAG can be proposed as a monitoring tool to be integrated in the ERMG. Figure 4.2 shows an illustration for the potential system guidance that could be offered through the use of the RAG.

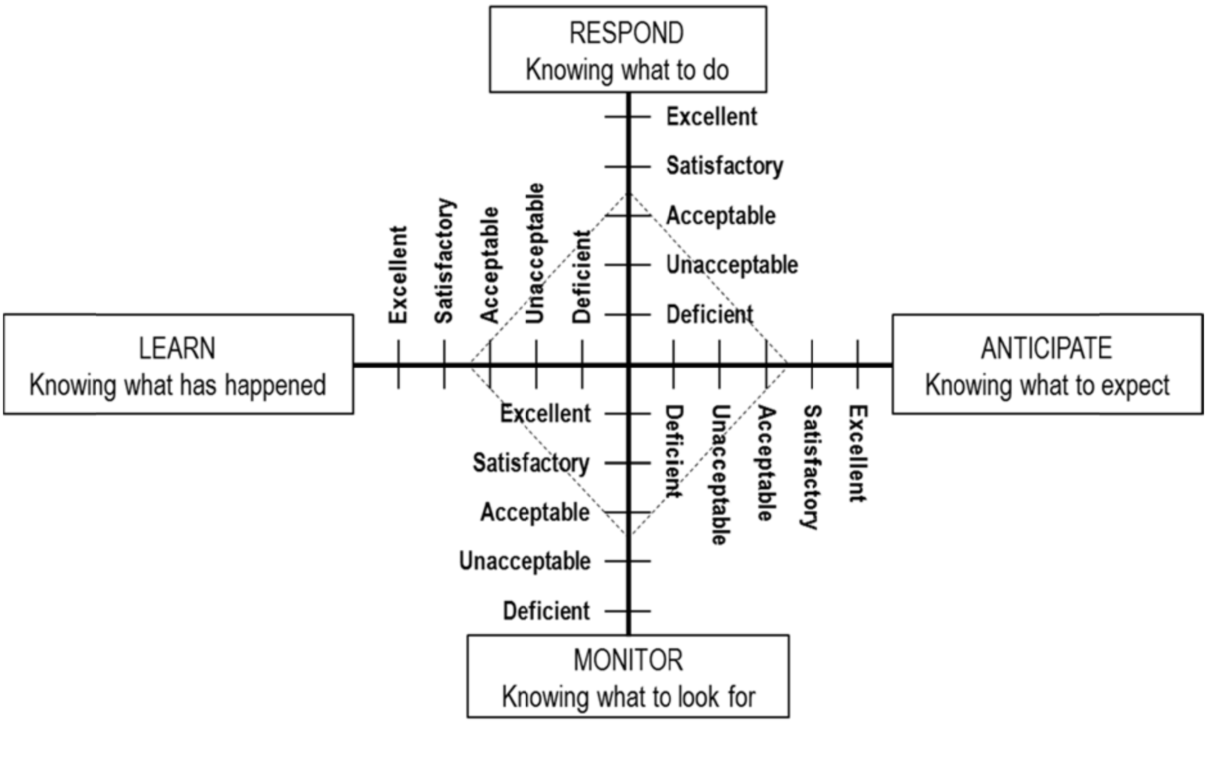

Figure 4.2: Illustration of the RAG

Regardless of this option, the fundamental contribution of this approach resides in the set of questions raised in Table 4.1, as they set the ground for the work undertaken within WP3, regarding resilience at generic critical infrastructure level (D3.5) and specifically for the Urban Transport System (D3.6). The data gathered at various project stages can be used to build qualitative or semi-quantified scales for the monitoring of the four resilience cornerstones.

4.3 Multi-layered network analysis

The above mentioned ideas specified by the RAG model will be analysed in close relation to the ideas of the multi-layered approach for resilience analyses, incorporating different aspects such as the physical, service and cognitive dimensions. Network science also supports the modelling of complex and interdependent systems, such as critical infrastructures, manufacturing processes and logistics chain.

It has been observed within many different system contexts and under different research scopes that interdependencies tend to be unevenly distributed across systems. While certain parts of a given system may develop numerous and diversified couplings and perhaps be prone to higher operational dynamics, other parts of the same system may be much less interdependent. The internet system is often given as example for such characteristics, as some areas generate considerably more connectivity than others. Such system areas assume critical operational roles and may potentially have more profound impacts in terms of generating cascading effects and chain reactions across system structures. Under network science views, destroying or disabling one or more network nodes or links does not always disrupt the whole network, usually through the propagation of disruption among components (i.e. cascading effect). Even if based on the knowledge of past events, network analysis offers the means to model system architectures towards identifying and assessing critical system areas in terms of their degree of interdependency.

By coupling the network analyses approach with an event driven architecture that supports the monitoring of functionality and appropriate proactive response based on predefined procedures (e.g. expert rules in complex event processing CEP systems) the RAG can be supported and modelled in an effective way. It is important to note that this approach inherently incorporates the time component, crucial when considering cascading effects in UTS networks.

While conventional approaches consider cascading effects from a static network point of view, that is showing consequences of removal of a group of nodes and edges, cascading failures in urban transport networks need to also integrate dynamics of traffic flow in complex networks including changes from edge overload to node failure, redistribution of flow, congestion propagation, among others. In line with the above analyses, RESOLUTE will conduct research and innovation activity, propose and implement a holistic approach to define resilience guidelines for UTS, in order to make the system able to “proactively” respond to unexpected events, changes and interruptions affecting the system’s performance with respect to the predefined operational standards.

The need to understand which damaged or failed component can cascade and trigger a system wide breakdown and to manage the recovery actions constitute fundamental aspects for the assessment of resilience, and clearly require a further level of integration, at least of some data source and modelling abstraction. Figure 4.3 provides an example of how smart city requirements may disrupt the traditional data “silos” at city level, based on Rinaldi et al., 2001[1].

[1] Rinaldi, M., Peerenboom, J.P. and Kelly, T.K. (2001) Critical Infrastructure Interdependencies, IEEE Control System Magazine, 12/2001

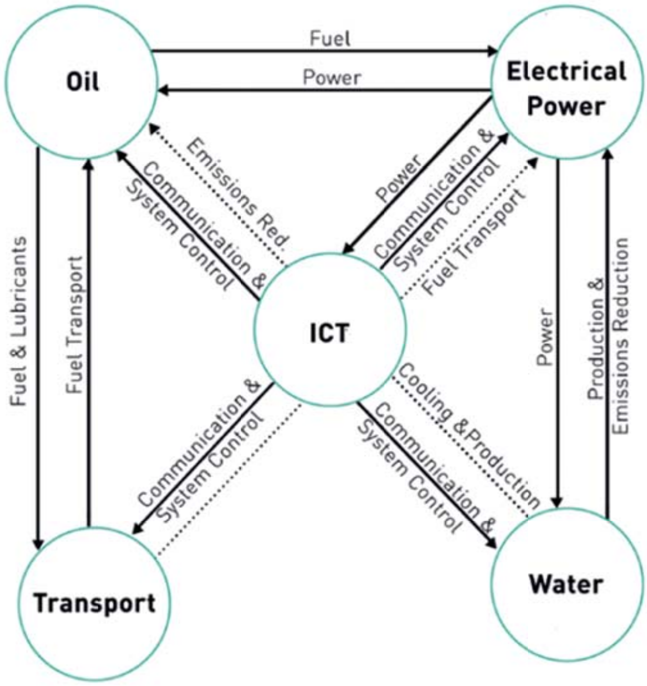

Figure 4.3: integration of data and information among different ICT-enabled urban systems

Network of networks or systems-of-systems (SoS) are prone to cascading behaviours in the sense that events in a given part or element of a system (or sub-system) may bring about unforeseeable (often catastrophic) cascading effects across other interdependent parts of the network. Since SoS is concerned with the integration and coordination of multiple systems to act in unison to achieve higher levels of performance, a unique perspective has to address different concerns at systems level in this field.

Understanding which conditions might lead to cascading effects and fragmentation of the network can be achieved mainly through graph theory and network science, which provides algorithms and tools to evaluate vulnerability with respect to different dimensions – and through different formal representations – such as at physical level, service level (including net flow and its related dynamics) and at system's dynamics level (dynamic networks/graphs analysis), thus contributing to the enhancement of resilience.

Resilience of a complex interdependent network has to take into account several aspects: identifying, representing, and measuring the ripple effects of system interdependencies is crucial. Anticipating these effects enables planners to minimise dependency risks that, if realised, can have cascading impacts on the ability of systems to deliver services. RESOLUTE will consider recent advances in modelling interdependent systems by integrating functional dependency network analysis (FDNA) and inoperability input-output model (IIM). Their integration enables hierarchical modelling of perturbations to systems at the physical or operational network levels. The most relevant insights, obtained by integrating FDNA and IIM is the possibility to simulate critical infrastructures/systems that feeds even large metropolitan areas.

4.4 Common language

As the basis for the project outputs, the RESOLUTE conceptual framework provides the roots for a project taxonomy that will bring together the identified operational interdependencies of the urban transport system and its critical resources to establish principles and defining categories, their properties and relationships, as well as specific attributes. The taxonomy will be the guidance for the development of the RESOLUTE European Resilience Management Guidelines (ERMG) and the Collaborative Resilience Assessment and Management Support System (CRAMSS) to support the application of the guidelines at various levels of urban transport system operations. It gathers some of the key terms used in RESOLUTE and provides their definitions. In fact terms like hazard, critical infrastructure, or resilience itself, have several definitions due to the different meanings assigned by the domains of use like environmental research economy, engineering, etc. Thus, a clear identification of the terms and concepts adopted, strengthen project coordination and communication.

4.5 European Resilience Management Guidelines (ERMG)

As clearly defined in the Description of Work, it is foreseen within RESOLUTE to provide a set of European Resilience Management Guidelines (ERMG) aiming to cater guidance for resilience management in any kind of critical infrastructure system. This is undertaken through an iterative and multi-actor process, involving both Consortium and external experts. Moreover, these guidelines will be further adapted, instantiated and validated for a specific system – the Urban Transport System – through the RESOLUTE pilots. The detailed methodology is described in Deliverable 3.4 “Guidelines Methodology”.

In line with the conceptual framework here proposed, more than updating existing guidelines (namely addressing risk management and assessment, and to transport operations), RESOLUTE aims to produce guidance on system aspects that remain considerably unexplored. As such, the following may indicatively be considered:

- Identify operational interdependencies and their level of criticality in terms of ensuring the allocation and deployment of resources.
- Specify the necessary resources for the continuous adaptation to both known (expected) and unknown (unexpected) operational changes and environments.

Managing system interdependencies has been identified as the fundamental aspect for systems resilience. Based on this notion, RESOLUTE guidelines should take into account the following steps:

- Describe critical interdependencies based on the types and levels of resources that they incorporate, and the operational requirements that such resources fulfil. As earlier stated and previously described in the SotA, FRAM modelling is based on the description of system functions and by definition, functions constitute a fundamental step towards fulfilling system purposes. Thus, FRAM models will support the identification of relevant functions, the purposes they serve, and on which interdependencies they rely to secure their operational resources (mainly from the description of the 6 function aspects).
- Identify what and how resources should be planned and allocated to develop system capacities to cope with ever changing operational conditions, and continuously adapt to both expected and unexpected pressures that these may bring about. The description of these capacities will be based on the four fundamental system capacities around which the RAG is built. Data from RESOLUTE 1st workshop (D7.3), together with additional means of survey, will be used to populate questions raised in Table 4.1 and support the provision of guidance on the capacities needed.

All the above, apart from being defined in the generic case of a critical infrastructure system, will be further specified for the case of Urban Transport System, as the focus of RESOLUTE pilots.

Figure 4.4 outlines how the methodology previously described aligns with the structure and contents of the RESOLUTE guidelines.

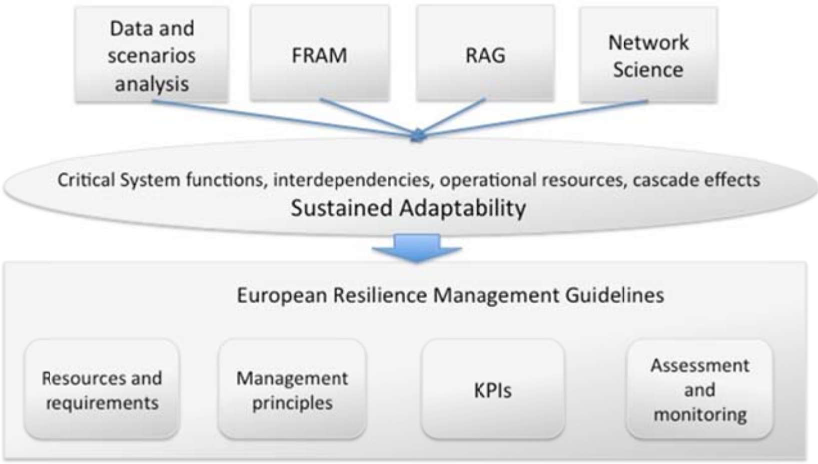

Figure 4.4: ERMG and RESOLUTE methodology

When addressing the four fundamental system capacities for adaptation, ERMG should refer to the operational pressures that may emerge from resource limitations and hinder the development and maintenance of such capacities. Within the scope of the principle of Efficiency-Thoroughness Trade-Off (ETTO), as systems strive to continuously enhance efficiency, the potential impacts on risk exposure and vulnerability must be also continuously monitored. This means that dedicating resources to efficiency requires undermining opportunities for enhanced safety, and conversely, investing in safety inevitably leads to sacrificing efficiency at some level.

Although these are clearly two opposing notions, they remain inherently dependent on local conditions. Favouring efficiency or safety only relates to a given time and location and does not constitute in any way an emergent system behaviour. What may favour safety in a given time and place does not necessarily do so under different operational conditions, or may even produce opportunities for enhanced efficiency in a different context. The nature of acute versus chronic and short-term versus long-term trade-offs should be addressed by the ERMG. This involves providing guideline users with an understanding of what resources should be allocated to develop the necessary system capacities for adaptation, and how allocating resources to generate a given capacity will potentially imply a trade-off with resources needed to generate other capacities.

The RESOLUTE approach allows going from general indications to specific applications and vice versa. Starting from identifying generic guidelines for resilience management applicable to any kind of critical infrastructure system, RESOLUTE methodology goes into applying them in Urban Transport Systems as what could be considered one of the most common critical infrastructures. This allows assessing the actual applicability of the proposed guidelines, while providing the opportunity to validate them in terms of acceptability, effectiveness and interoperability, among other relevant aspects. At the same time, gaps that are expected to be identified during the ERMG application in UTS may provide insight on modifications and/or additions that might need to be included in the generic guidelines, being also applicable to other systems. This structure may also serve as a starting point for other similar applications of the ERMG, following the same conceptual framework, in other critical systems. Such applications will not only further verify and enhance the generic ERMG, but will also enable the critical systems' operators to identify gaps and malfunctions in their existing (if any) resilience management procedures.

5 OPERATIONALISATION OF RESOLUTE TOOLS

The ERGM needs to be applied and tested in the real scenarios. To do that, the adaptive cycle/event management cycle principles are used as a framework to manage resilience at operational level. In particular, on the operational side the density of vehicles and/or people in a specific area, the location of fuel stations, the critical points of viability (presence of bridge, presence of red lights, presence of RTZ (restricted traffic zones, etc.), etc. can also represent further factors that can affect the level of resilience of the UTS. All these features are related to the physical side of the transport system. The human factor, characterised by behaviours based on limited (personal) knowledge of the status of the event, heuristic, physical skills, emotion, emulation, etc., will also be included. Human behaviour during a disaster represents a critical and often unpredictable variable that can affect the operational side of the transport system (traffic jam, accidents, etc.) as well as the physical infrastructure side (too many vehicles and people on a bridge, etc.). According to this and as illustrated in Figure 5.1, the following chapters introduce the concepts of the RESOLUTE tools able to translate into practices the ERMG and to track the complex system resources allocation and exploitation.

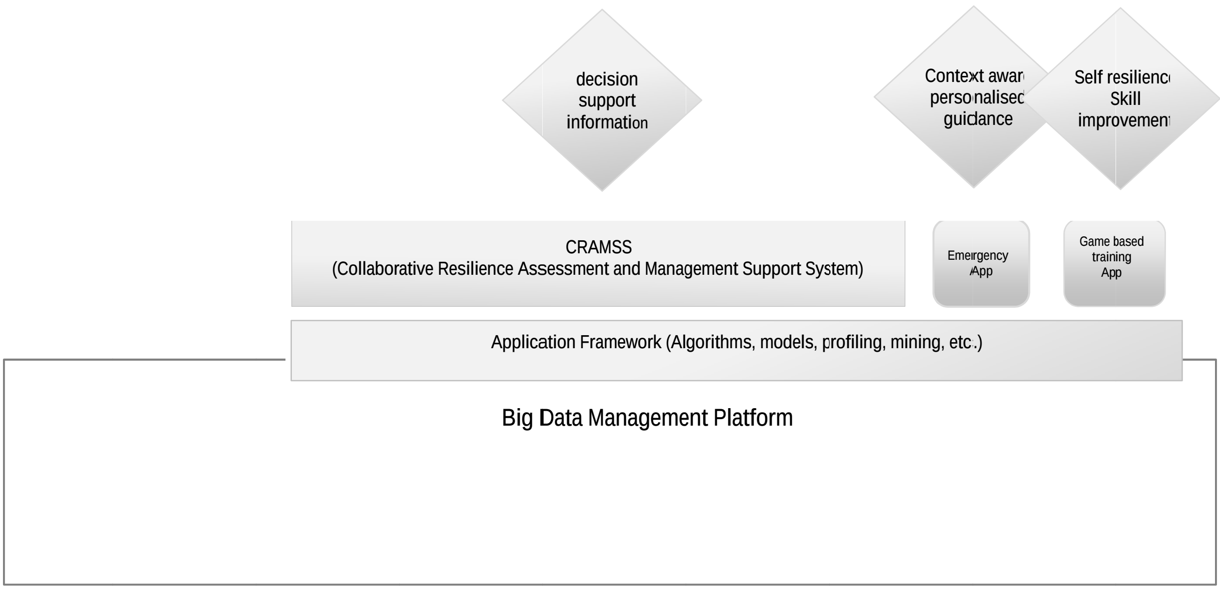

Figure 5.1: Operationalisation of RESOLUTE tools

5.1 Big Data Management Platform

There are three types of data being collected and managed by the Big Data Management Platform and used by the CRAMSS: urban data, human behaviour data and social network data. Urban data include municipality open data (e.g. seismic risk maps, hydrological risk maps, services, statistics, time series of major disasters, descriptors of structures such as schools, hospitals, streets, etc.), mobility operators (e.g. taxi, parking areas, Wi-Fi sensors for people flows, local sensors for car flows, public mobility operator timeline and real time status, etc.)

and user tracking flows extracted through Wi-Fi or Bluetooth. Privacy preserving rules are applied during the acquisition of all these data allowing the extraction of cross sectors correlations and the identification of risk mitigation strategies especially in critical situations.

Human behaviour data may be either individual or group-based and include activity related and behavioural profiles/models addressing psychological, habitual and cognitive aspects. These profiles/models are extracted based on advanced data mining techniques which are applied on various sensors, such as cameras, touch/proximity sensors, Wi-Fi, GPS, wearables, Bluetooth, HMI applications from WP5 etc. In addition, information through specialised surveys will be collected and evaluated in order to assess negative human feelings during a post-crisis period. All these multidisciplinary and multimodal raw data will be efficiently integrated in a common comprehensive format towards discovering meaning-bearing annotations.

Another important input of the Collaborative Resilience Assessment and Management Support System is data from social networks. A social network crawler will be designed in order to manage and analyse all real-time anonymised data streaming from the citizens and the city infrastructure. The crawler will be language independent utilizing multilingual thesaurus such as EuroVoc. Text processing and knowledge mining techniques will be used so as to discover hidden information.[2]

In addition to the dynamic data, an interoperable knowledge base contains cross sectors data that can be used to provide services to help the environment to become more efficient in disaster situations. Furthermore, the activities of data analytics and semantic reasoning are used to generate new knowledge that can be integrated into the interoperable knowledge base where cross sectors data are used to help improve resilience in situations of danger (e.g. data ingestion, mining and algorithms, computing models and recommendations).

5.2 Application framework

The Application Framework implements the models, algorithms and rules to mining and analysis available data mainly focusing on: managing user profiles and behavors, analysing cascading behaviour in UTS modelled network, predicting in time the evolution of the network itself and estimate the resilience metric with respect to the degradation of service (effect) and not only node failure (both cause and effect). This task will consider how to model the RAG analyses aspects as anticipating, learning, monitoring and responding in a resilient system through a network analyses approach. Furthermore additional relevant aspects of resilience of a system will be considered through a multi-layered approach (e.g. physical, service and cognitive layer) and integrated in the overall approach. This task will model and develop a software component accounting for the cascading effect between different components of the network. Specific focus will be put on analysing cascading behaviour in UTS modelled network and predicting in time the evolution of the network itself and its resilience metric with respect to the degradation of service (effect) and not only node failure (both cause and effect). The model will learn and "proactive" anticipate events that could lead to a failure of the UTS network and communicate to the monitoring and response components, hence assuring that the overall system can provide adequate response following predefined guidelines

[2] The exact specifications for the data acquisition platform will be described in deliverable D4.1

5.3 Collaborative Resilience Assessment and Management Support System (CRAMSS)

The Collaborative Resilience Assessment and Management Support System (CRAMSS) of RESOLUTE is a critical aspect of the project since it will implement the identified resilient assessment and management concepts and methods included in the European Resilience Management Guide (ERMG) for the Urban Transport domain. CRAMSS will adopt a highly joint approach taking into account intra and inter system interactions towards defining a resilience model for the next-generation of collaborative emergency services and decision making processes. The high-level conceptual architecture of CRAMSS is depicted in Figure 5.1. The CRAMSS is a Multiple Input – Multiple Output (MIMO) system having the capability of getting and analysing in real-time multivariate, asynchronous and/or pre-computed data. Moreover CRAMMS is capable of dynamically producing multivariate and context-aware holistic and/or personalised guidance (e.g. routing, first aid support, role assignment taking into account multi-dimensional criteria, such as spatiotemporal context, risk evaluation and detection based on environmental conditions, etc.) in an adaptive and indirectly interactive manner.

CRAMSS will mainly receive information from both the contextual and behavioural Data Gathering and Processing modules in WP4 (i.e. T4.2 & T4.4), interfacing to the Big Data Management Platform, through the integration framework (T4.5).

Based on all the received input, the CRAMSS will comprise an adaptive and constantly learning decision support system which will be able to extract a set of (Pareto) optimal possible resilience strategies in several layers of abstraction and subsequently it will select and implement the best ones according to the profile of the involved individual(s) or group of citizens. The output information of CRAMSS will be then communicated through situated displays (relevant stakeholders and the wider public), external stimuli (e.g. traffic lights) and/or users' devices providing visual/hearing and cognitive aids. The latter case also includes the emergency support smart mobile app that will be designed in the scope of task T5.3.

Two functional modes will be available: The first one will refer to the initial training of CRAMSS, which will be accomplished based on real annotated data as well as game-based or other artificially stimulated responses; The second one will regard the CRAMSS's application on the field, where all aforementioned analytical, predictive and decision taking steps will be realized. Both will be fully implemented in the context of task T5.2.

5.4 Game based training app

Game-based learning has become an optimal training tool for soft skills development since it fulfils the following five criteria:

- Compelling content
- Clear emphasis on practical application
- Interactivity and experimentation
- Genuine skills development through practice and feedback
- Motivation for people to learn and, above all, to complete the course they begin.

In fact, these are criteria any kind of training should fulfil regardless of format. Game-learning is able to offer these five characteristics. Game-based training has been reported to offer a safe, effective method of conditioning for people that results in comparable (and, in some cases, greater) improvements in physical and cognitive performance than traditional programs. While technical instruction training has been associated with a higher volume of skill executions (i.e., more 'touches'), game-based training has been associated with greater cognitive effort, as an important condition for skill learning. Indeed, studies investigating skill learning have reported comparable (and, in some cases, greater) improvements in skill execution, problem solving and decision-making following game-based training rather than training involving repetitious technical instruction. To this end, a RESOLUTE game based meta-application for training will be designed and developed, in order to train different user categories. For instance, people at large can be trained on risk or early warning interpretation, Critical Infrastructure managers on ERMG application, and so forth, according to the learning objectives. Games can produce complex scenarios by simultaneously randomising several conditions and hence help actors learn meta-competences more efficiently.

5.5 Mobile Emergency App

The success of mitigation practices requires the collaboration of specialized personnel and citizens. It is important that the whole community 'is aware of the risks and worry to take action to prevent them. Reactions with respect to incidents represent one of the greatest challenges in maintenance and emergency management. In most cases, the accessible information on the nature of the incidents is inaccurate as the needs to solve them; thus the personnel is inefficiently coordinated, informed neither on real conditions, nor on available resources. The logistics aspects related to the intervention and to the movement of personnel and patients are very relevant. Involved personnel need to have access at updated information and knowledge in the emergency and maintenance conditions. Therefore, mobile devices are mandatory tools for information access and to help sometimes in taking decisions. On such grounds, the Mobile Emergency App has to guarantee the access to any right and updated information in the needed time . The Mobile Emergency App aims at being a solution to guide personnel during maintenance and/or emergency conditions, that can help to reduce the time needed to react and to cope with organization and maintenance support, while facilitating communication, and indoor/outdoor navigation. The App is based on the formalization of protocol, the modelling of knowledge for navigation, the algorithms and a server device for integrated indoor/outdoor navigation. In this context, the application will be also connected to the CRAMSS framework and will support different end users roles (from emergency teams to individual travellers in accordance with the user profile used in each mobile device). The application will utilize optimally contextual information stemming from the smart device (e.g. location, environmental, etc), which coupled with its role and other individual characteristics, will provide micro-tasks and effective inter-communication and data sharing (e.g. among rescuers).

6 THE SCENARIOS

Despite the fact that RESOLUTE aims to provide guidelines applicable across all critical infrastructure domains, its focus is on urban transport systems, not just as a context on which to test and validate the guidelines to be developed, but also as grounds for delivering a more specific and detailed application of such guidelines. In line with this, this section highlights the relevant aspects of urban transport systems.

Mobility is a human right expressed in the Universal Declaration of Human Rights as the freedom of movement from a place to another with the aim of accomplishing any human activity (i.e. work, health, and leisure, social or shopping purposes, among others). In order to provide efficient, safe and sustainable mobility to citizens, transport authorities make decisions and, together with experts, create the required framework for the provision of public transport and suitable transport infrastructures in accordance to the existing and/or planned land use. Urban transport is coordinated by traffic control centre(s) with the aim of improving efficiency and overseeing compliance with safety requirements. Other urban transport related to societal activities (delivery, emergency vehicles, as well as garbage collection) comply with regulations concerning priority, operational schedules and parking issues. Each of these different types of transport, despite their different requirements and specific purposes, must be coordinated within a shared infrastructure and environment, and abide by the same set of regulations and principles that generically aim to ensure public well-being.

Urban transport systems are generically composed of different combinations of road and rail transport (in some urban areas waterborne transport plays an equally important role). Within urban road transport, a fundamental distinction must be made between private and public transport systems. Private transport remains a substantially open system deprived of any form of central control, even if various forms of improved coordination are rapidly being implemented across member states, both within and outside urban areas. Under critical situations, transport authorities, emergency response services, and traffic control centres, will manage urban traffic, mainly defining priorities, activating exceptional procedures to limit private traffic and providing conditions for facing the situation, aiming to mitigate damages and re-establish “normal” operations as briefly as possible. The importance of public transport operators in these critical situations is twofold:

- Contrary to private transport, public transport systems have developed much more closed natures (even if they remain inherently open to strong interdependencies within their environment), as they possess well established organisations, centralised control structures, skilled professionals, communication facilities and well defined safety and security procedures to be activated as necessary.
- Because of their higher social and economic exposure, public transport systems also tend to be much more vulnerable (and are frequently the target of attacks and other public disturbance acts), which normally reflects higher levels of risk awareness and preparedness and thus, a significantly enhanced potential for resilience. This becomes particularly relevant in terms of end-user perspective, as depending on social and cultural background, the use of public transport may be significantly affected by the perception of risk of the wider public (risk aversion), whereas for private transport, the accountability and responsibility falls entirely on the user himself, even if this may not always be apparent or explicit.

These factors are at the source of many initiatives taken worldwide towards improved disaster management. Within recent years, public transport stakeholders (including authorities and government) in most countries and cities have devoted considerable investments to governance, structural and organisational measures to improve preparedness, response and recovery in view specific scenarios and contexts. While perhaps in the majority of cases, this has produced positive impacts, it has left out critical resilience related aspects, such the coordination and synchronisation amongst many system layers and elements and the need to account for a wide range of unknown scenarios and context dependent factors, among others. As earlier mentioned in this document, RESOLUTE aims not to replace the work undertaken so far by many stakeholders, but rather to produce guidance on how to integrate that work into a common framework that is share and produces suitable synchronisation across all relevant system stakeholders, and actually pursues system operational purposes instead of singly (or independently) focusing on risk management needs (thus contributing to the enhancement of the potential for resilience).

With this in mind, public transport stakeholders must be taken into account as key players in any mechanism or resource to be implemented towards enhanced resilience, and as such, should be particularly addressed within the scope of RESOLUTE objectives. Nevertheless, the higher levels of uncertainty and variability that potentially impact private transport systems must be taken into account. The different natures in terms of vehicles and users (i.e. cars, motorcycles bicycles, pedestrians, among others), and the wide diversity of purposes encompassed within private urban transport, tend to generate very dynamic system interdependencies. In addition, because strong interdependencies also exist between public and private transport, the high variability and uncertainty that characterises private transport may also critically impact on public transport systems.

While interdependencies may be at the source of increased risk exposure, they also tend to assume critical roles in terms of operational efficiency and resource allocation. The identification and understanding of such interdependencies and their critical roles should be placed at basis of solutions towards enhanced resilience. Figure 6.1and Figure 6.2 illustrate an overview of key features to be considered for the definition of scenarios, aiming to highlight potentially critical factors, mainly around public transport as key urban critical infrastructures. Figure 6.1 addresses network and facilities, and Figure 6.2 focuses on operational factors.

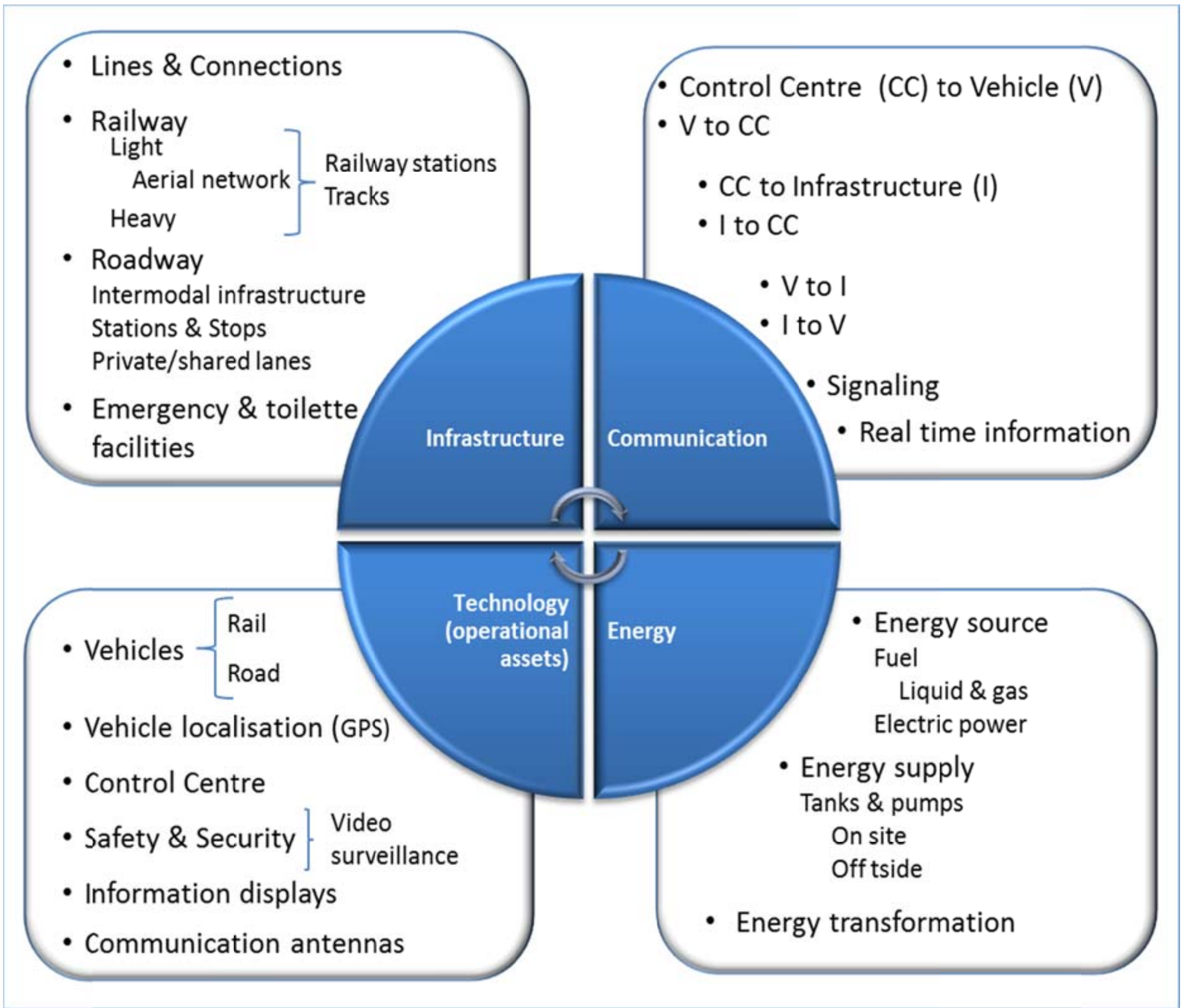

Figure 6.1: Urban transport networks

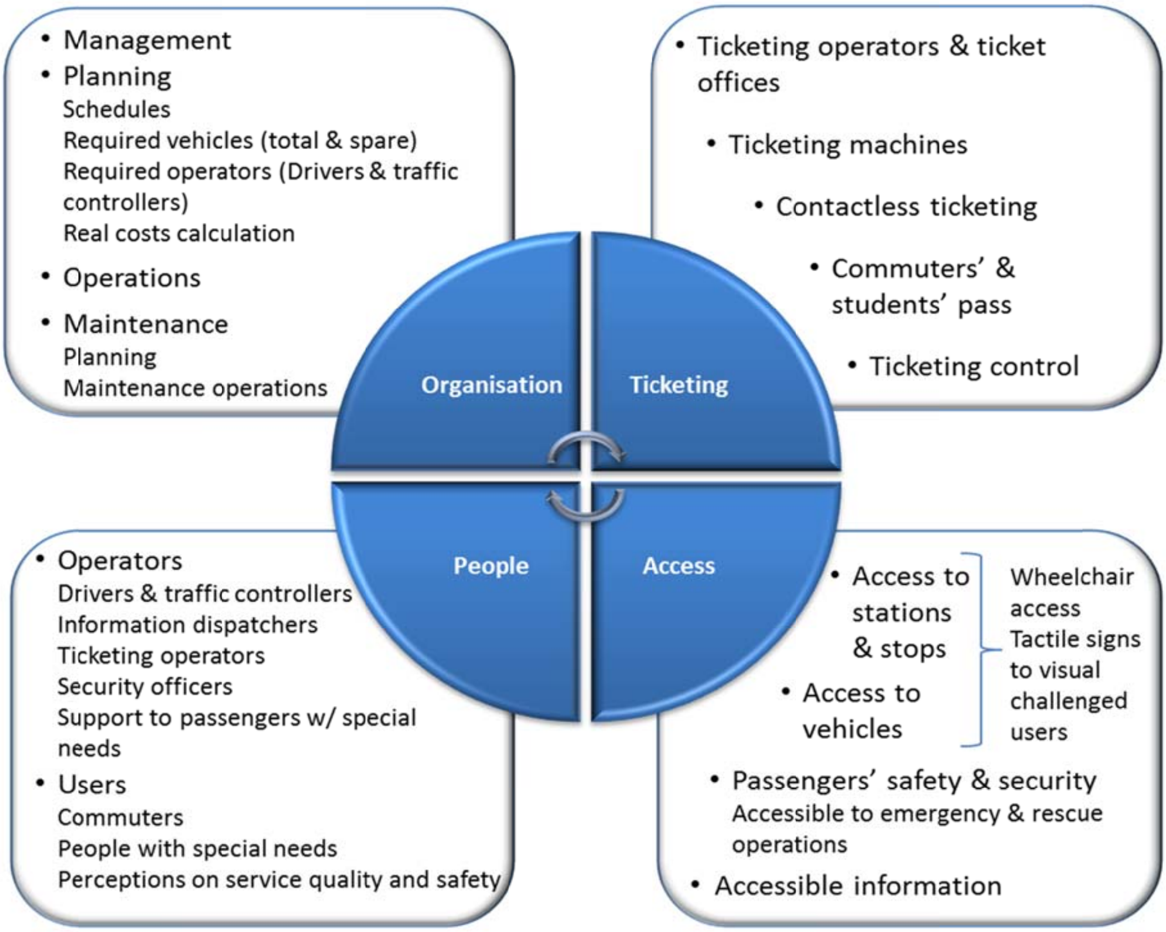

Figure 6.2: Urban transport operations (with main focus on public transport)

The data gathered during RESOLUTE 1st workshop (see D7.2 Proceedings of first workshop) constitutes an important first contact with transport operators and stakeholders, in particular those involved in the preparation of the testing and validation scenarios. This provides an initial basis to address the questions outlined in Table 4.1. Workshop data is structured around the adaptive cycle / event management cycle principles in order to collect needs and requirements for the operational point of view from the stakeholders. In particular 5 threat scenarios have been identified: water bomb, 30/200 years flooding, street accidents, bomb attack in the tube. These scenarios has been used to harvest processes, data and responsibilities for each step of the adaptive cycle (prepare, absorb, recover adapt) in order to drive the guidelines definition and the tools development. According to the workshop results the scenarios (Florence City and Athens metro) can be characterised by:

a) Multi-decision-makers (civil protection, public administration, infrastructure managers, etc.),

b) Actors with conflicting micro-opportunistic behaviours, different risk perceptions, beliefs, skills, etc.

c) Heterogeneous data sources (environmental sensors, traffic flows, social network, etc.) with different data delivery rate (raining from real-time to static), quality, reliability and semantics.

d) Fragmented and sometimes not clearly defined responsibilities and processes

e) Local and general vulnerabilities with complex interdependencies aiming the system (ICs, People, Organizations, Business, etc.) composing the urban sociotechnical system of systems.

f) Needs to optimally manage the scarcity of resources in term of first responders, goods, and tools available during an emergency

g) Needs of an authoritative multi-channel communication strategy and a situation-aware communication delivery tools (e.g. localised and personalized early warnings, installation of variable messaging panels, etc.)

h) Common attitude of the authorities to neglect the preparing and adapting phases in favour of the absorbing and reacting phases.

i) Weak population preparedness against unusual extreme events and wrong perception about their recurrence probability and potential effects

j) Needs to consider place/space with a recognised social value, as one of the critical functions to be recovered with a due priority in order to maintain social cohesion and the related community resilience.

The RESOLUTE project will take into account such scenario characterisers during the analysis and implementation stage.

7 GOING FORWARD FOR RESOLUTE

The importance of the critical infrastructure protection field has never been more pronounced as the XXI century continues to unfold, beset by unprecedented levels of complexity, emergence, interdependence, and uncertainty. The challenges of smart cities management bring about a disruption of the traditional way in which information systems are designed, implemented and deployed. The disruption will take place at company level and even more so at city level.

Urban societies, and in particular urban transport stakeholders, are faced with complex and multi-dimensional challenges. The scale of these challenges is such that despite substantial advances in tools and methods during recent years, many shortfalls remain. This was amply explored in the literature presented in the SotA (D2.1). The RESOLUTE framework and methodology here proposed target the need for innovative and multi-dimensional solutions, mainly by offering an approach to resilience that abandons many of the conventional perspectives on risk management. While this undoubtedly presents a considerable challenge, both in terms of data gathering and analysis process, the scientific evidence presented in the SotA (D2.1) demonstrates the feasibility of this endeavour and its potential to produce innovative added value for the outcome of RESOLUTE. The conceptual framework previously described underlines the importance of identifying system aspects, in particular interdependencies and their dynamic behaviours, as the fundamental approach to the definition of guidance that is simultaneously suitable for a wide range local operational needs, and for the enhancement of system resilience.