Operationalize Data-driven Resilience in Urban Transport Systems[i]

Emanuele Bellini[1],Paolo Nesi[1] and Pedro Ferreira[2,3]

[1]DISIT Lab, Information Engineering Dept. University of Florence
[2]Centre for Marine Technology and Ocean Engineering – University of Lisbon
[3]Department of aeronautics and transport - Lusófona University

Contact: emanuele.bellini@unifi.it

Keywords: Sustained adaptability, Decision Support System, Big Data, Urban Transport System, Sociotechnical system

Resilience and sustained adaptability in urban transport systems (UTS)

Today, enhancing resilience in Urban Transport Systems is considered imperative for two main reasons: a) such systems provide critical support **to every socio-economic activity** and are currently themselves one of the most important economic sectors in Europe; b) the **paths that convey people, goods and information, are the same through which risks are propagated**.

Transport systems have thus developed a prominent safety and business critical nature, in view of which current management practices have shown evidence of important limitations. UTS is a sociotechnical system whose resilience can be defined as the intrinsic ability to adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions (Hollnagel, 2011). Thus, UTS resilience is considered an emergent property and it refers to managing high variability and uncertainty in order to pursue successful performance of the system continuously. Answering to questions as:

- What type and sources of variability need to be managed?
- What type and level of resources are needed to cope with such variability?
- How to plan and deploy such resources?
- How to ensure that local adaptive mechanisms are synchronised at the system level?

is needed to understand the sources of operational variability, the mechanisms through which it may potentially propagate inside and outside and the impact on the system performance. The potential for resilience to emerge from UTS system performance can be assessed based on the "four resilience

---

[i] This paper is part of the IRGC Resource Guide on Resilience, available at: https://www.irgc.org/risk-governance/resilience/. Please cite like a book chapter including the following information: IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. *v29-07-2016*

cornerstones” (Hollnagel, 2011):

• **Responding** (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.

• **Monitoring** (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.

• **Anticipating** (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.

• **Learning** (Knowing what has happened): corresponds to the ability to address the “factual” by learning from experiences of both successes and failures.

The final aim is to dampen the performance variability of the functions composing the complex system considering their internal characteristics as well as their interdependencies.

Challenges in UTS resilience

Complex sociotechnical and interdependent systems are under-specified by nature. This means that, to a certain extent, system operations are unknown and therefore, potentially uncontrolled. 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. A list of challenges, needs and criticalities emerged from stakeholders:

- Over-specification of procedures and incremental development of rules based on past experience goes against the need for flexibility (local adjustment).
- Supply chain interdependency is not properly taken into account.
  Multi-decision-makers (civil protection, public administration, infrastructure managers, etc.),
- UTS users (citizens) with their conflicting micro-opportunistic behaviors, different risk perceptions, beliefs, skills, etc. should be included in the UTS resilience management
- 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.
- Fragmented and sometimes not clearly defined responsibilities among UTS actors.
- Local and general vulnerabilities with complex interdependencies aiming the system (ICs, People, Organizations, Business, etc.) composing the urban sociotechnical system.
- Needs to optimally manage the scarcity of resources in term of first responders, goods, and tools available before, during and after emergency
- Needs of a coordinate multi-channel communication strategy and a situation-aware communication delivery tools (e.g. localised and personalized early warnings, installation of variable messaging panels, etc.)
- Common attitude of the authorities to neglect the preparing and adapting phases in favor of the absorbing and reacting phases.

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

Moreover, since resilience is a complex and multifaceted concept there is the need to semantically disambiguate the meaning of the terms used through an active engagement of all the stakeholders. In fact implementing a measurement system for UTS resilience assessment has implications at political level because of its connection with the quality of life. Thus, in order to avoid any kind of "manipulation" of the measurement results in the political debate, the indicators require an agreement about their acceptance among all the actors involved in UTS, to achieve:

a) a clear understanding of the UTS adaptive capacity
b) a semantic reconciliation of the most ambiguous concepts and the identification of an official and widely accepted definition for them.
c) the development of sets of indicators and thresholds based on the agreed concepts
d) the identification of the sources to feed indicators with pertinent data.

Such approach should result into a semantic-aware Statistical Information System, to govern indicators development according to the transparency imperative. (Bellini & Martelli, 2012).

Florence UTS case study

The authors conducted a preliminary assessment of the resilience of the city of Florence UTS interviewing relevant actors as Civil Protection, City Mobility and ICT dept., Urban Policy, Public Transport operators, companies managing the road and rails infrastructures, small business operators. According to the preliminary results against the European Resilience Management Guidelines (Gaitanidou, Bellini, & Ferreira, 2016) several drawbacks in UTS resilience implementation and function coupling emerged for both predictable and unpredictable events. In fact, the Florence UTS is a multi-actor system that tends to be organised in silos with some technological and organizational barriers that prevent to manage resilience effectively. For instance, a decision to start a new yard in a specific part of the city is usually taken by the technical services department that is responsible for the roads maintenance. Since such kind of decision may have multiple implications, it requires that all the affected stakeholders should be timely informed (e.g. mobility department., citizens, business operators). In particular the mobility department needs to be aware of the status of the network to re-organize the service in the area (e.g. changing the road conditions). Unfortunately the need for such information sharing is neither officially defined with procedures nor technologically supported yet.

Inefficient function coupling among the UTS functions "maintenance" and "operation" increases the probability of an increment of their performance variability in changing conditions. In fact, if the information resource necessary for the "operation" function to adjust the service and organise new mobility strategy is provided too late or not at all, when an emergency occurs, the decision taken by this function will be totally unreliable, extending the performance variability of the system over its flexibility boundaries, potentially causing a catastrophe.

For instance, every traffic plan calculated in advance on the base of scenarios coming from the risk assessment activities, ends up to be ineffective in real condition, since it is based on hypothetical scenarios. Factors like the dynamic and intensity of the phenomena, the real-time status of the traffic, the real time position and direction of the people, etc. can frame a very diverse context, thus making good decisions with such level of dynamics and uncertainty is an open challenge.

To cope with such uncertainty, during an emergency, precious time is spent to gain a better understanding of the status of the UTS, collecting information from the operators on the ground (e.g. firefighters, urban police) or from citizens (calls to emergency call centre). In the meantime a number of decisions are taken separately by each actor involved causing overlaps in the interventions, human resources and means over/under spending, conflicting objectives, etc. affecting the absorb and recovery effectiveness. For instance an excessive use of resource during an emergency may prevent the capability of the system to respond to another emergency effectively for a while, increasing instantly its vulnerability.

It is clear that taking well-informed decisions to dampen performance variability in UTS during the four phases (planning/preparing, absorbing, recovering, adapting) requires new tools and methods based on data that should be timely, reliable and relevant.

New smart tools for resilience management

Today, thanks to the development of new technologies such as Internet of Things, network sensors, smart devices, big data analytics, and so forth, it is possible to go beyond the simulation based approach to resilience moving from technologies *in vitro* to technologies *in vivo*.

In fact, in order to sustain the adaptability of Florence UTS and to support decision makers in planning, preparing, absorbing, recovering and adapting phases, in the context of RESOLUTE EU project (www.resolute-eu.org) an Evidence-Driven Decision-Support System (EDDSS) is currently under experiment in the city (Bellini E. , Nesi, Ferreira, Simoes, Candelieri, & Gaitanidou, 2016). An EDDSS (Bartolozzi, Pantaleo, Nesi, Bellini, & Santi, 2015) is a computer-based information system that supports organizational decision-making activities. The objective of the EDDSS is to translate heterogeneous data into knowledge to provide evidence for making decisions for a problem by compounding experts' experiences and data and analysing them in an intelligent and fast way a human cannot do in reasonable time. The system is composed of a big data platform (KM4City) and the Collaborative Resilience Assessment and Management Support System (CRAMSS).

The **KM4City** platform (Bellini P. , Nesi, Rauch, Benigni, & Billero, 2014) implemented in Florence, is an advanced Big Data semantic aggregator of data generated by the Florence Smart City able to manage huge amounts of static and dynamic data streams generated by different actors (utilities networks position; citizens position, velocity, direction, social network data; hydrogeological risk maps; safe areas maps; presence of students at schools; public transport real-time position; Civil protection volunteers availability; weather forecast, etc.), and to connect such multi sources data flow to models of the complex system. Going beyond the theory and simulations, such a data-driven approach provides the means to assess the levels of criticality at evidence/quantitative level, while seeking to enable the capabilities of the system to take an appropriate decision at strategic, tactical and operational level (Bellini P. et al., 2014). Km4City also provides consumption APIs for 3rd party exploitation fuelling the Collaborative Resilience Assessment and Management Support System (CRAMSS).

The **CRAMSS is a System Thinkin**g and a Multiple Input – Multiple Output (MIMO) application having the capability of combining Communication, Data and Knowledge (Bartolozzi, Pantaleo, Nesi, Bellini,

& Santi, 2015) to track resource availability and support real-time allocation decisions to dampen function performance variability generated by internal and external factors (interdependencies).
Thus CRAMSS supports structured decision making for system adaptive management (Collier & Linkov, 2014) at several layers of abstraction (Strategic, Tactical, Operational level).
The output of CRAMSS will be then communicated according to the 4R: right information, to the right person, at the right moment, through right channels (e.g. situated message variable displays, traffic lights, personal smart devices).

Annotated Bibliography

Bartolozzi, M., Pantaleo, G., Nesi, P., Bellini, P., & Santi, L. (2015). Smart Decision Support System . *International conference on Smart City.* IEEE.
The article introduces the result of the Bayesian-based decision support system development. Such tool has the capability of decomposing each decision in components and evaluate each component separately with a connection to real data. The result of the value for each component is propagated in the Bayesian network to obtain the final decision.

Bellini, E., & Martelli, C. (2012). The role of the semantic approach to complex statistical information system planning and management. *Signal Image Technology & Internet Based Systems.* Naples: IEEE .
In the complex perspective developing an observatory means to get an unique and shared model of concepts starting from the analysis of the narrations collected during the collaborative step, to achieve: a) a shared description of reality, functional to social participation; b) the development of sets of indicators, referred to reality descriptions, oriented to sustain stakeholder opinions; c) the recognizing of sources to feed indicators with pertinent data. Competing definitions of a term are documented and referred to the indicator of reference.

Bellini, E., Nesi, P., Ferreira, P., Simoes, A., Candelieri, A., & Gaitanidou, E. (2016). Towards resilience operationalization in Urban Transport System: the RESOLUTE project approach. *ESREL.*
The authors present the Functional Resonance Analysis Method connected with the Big Data driven approach developed in the context of RESOLUTE EU project for the resilience operationalization of the UTS. See also http://www.resolute-eu.org/

Bellini, P., Nesi, P., Rauch, N., Benigni, M., & Billero, R. (2014). Km4City ontology building vs. Data harvesting and cleaning for Smart City service. *International Journal of Visual Language and Computing.* Elsevier.
The authors introduce KM4city, an extended OWL ontology capable of fusing heterogeneous data generated by the smart city into a unique knowledge base.

Collier, Z., & Linkov, I. (2014). Decision-Making for Resilience within the context of Network Centric Operation. *19th ICCRTS.*
In the article is reported how the Multi-Criteria Decision Analysis works with the Enhanced

Adaptive Management for Resilience to update selected courses of action as new events occur and conditions change

Gaitanidou, E., Bellini, E., & Ferreira, P. (2016). *European Resilience Management Guidelines.* Florence: RESOLUTE EU project.
The authors carried out an analysis of Critical Infrastructures to identify the desired functions and interdependencies and to provide recommendation on how to dampen function variability in changing conditions

Hollnagel, E. (2011). Epilogue RAG- Resilience Analysis Grid. *Resilience Engineering in Practice: a guidebook.* ASHGATE.
The author explains the for resilience cornerstone (monitor, anticipate, respond, learn) that is at the base of the resilience engineering research field.

RESOLUTE, a EU-funded research project coordinated by DISIT Lab, Department of Information Engineering, University of Florence, Italy, to define, develop and validate guidelines to operationalize the resilience concepts to urban transport systems http://www.resolute-eu.org