Spatial Data and Service Infrastructures to Support Inter-Disciplinary Modeling of Disaster Cascades and Resilience Assessment

Vassilios Vescoukis[(1)], Panagiotis Galanis[(2)] and Ioanna Theologou[(1)]

[(1)]National Technical University of Athens, Greece [(2)]ETH Zurich, Switzerland

Correspondence: v.vescoukis@cs.ntua.gr

Abstract

Artificial systems that support human activities are constantly becoming more complex and interconnected to each other as well as to natural phenomena. This gives ground to new services addressed to individuals and societies, that facilitate many aspects of life; typical examples include multi-modal urban transportation and close-to-real-time natural disaster alerts. However, it is important to realize that either an external factor such as a natural disaster, or a failure of any element of such a system, could start a chain of cascading events that may affect other elements of the same or other interconnected, both natural and artificial systems. Risks, ranging from natural hazards to random or systemic failures of structures and networks, may produce severe cascading effects to external systems, including social and economic systems.

This calls for a holistic, inter-disciplinary approach in the study of social and economic impacts of disaster scenarios, which needs to be done in each geographical, economic and social context. Focus should be placed on how to relate the social and economic impacts of a disaster scenario to its potential effects on macro and micro economic indices such as the Gross Domestic Product (GDP) or the Consumer Price Index (CPI). Furthermore, another important part of the assessment of the impacts of disasters to the economy is the quantification of the consequences, along with the estimate of the recovery rate of a socio-economic system after a shock. This becomes noticeably difficult for multi-hazard scenarios that include cascading effects between hazards and networks/systems. The need for socioeconomic resilience becomes evident, especially in those areas of the world that suffer from the increasing frequency and severity of natural disasters. According to this concept, every system should be evaluated based on its potential loss of resilience after a disaster as shown in Figure 1, where resilience could be any quantity ranging from network functionality, GDP percentage or any other social and economic index, which needs to be evaluated locally, but also at a national level, as the aggregate effect of a disaster and its cascading effects to the national economy.

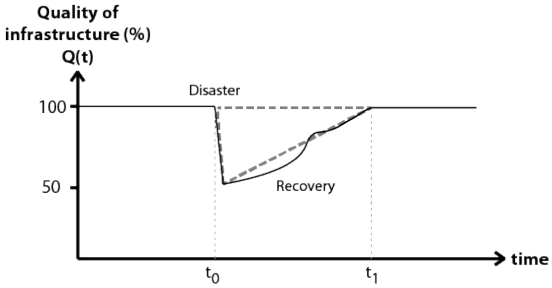

Figure 1. Resilience Triangle

Therefore, risks need to be approached by researchers in a holistic way. To enable inter-disciplinary analysis of cascading effects, we need to take into account inter-dependencies of structures and networks to each other and to the physical environment; to do that, we need information system infrastructures that allow the modelling of both semantic and quantitative links among data and services related to systems under consideration. Such an approach would allow the assessment of the consequences of, for example, a natural hazard to the failure of the transportation utility and telecom networks, and, consequently, to the local GDP, land and building values, etc. This, in turn, would provide the ground for the assessment of resilience and the improvement of preparedness and response planning, ranging from emergency response to the minimization of time for total economic and social recovery, including the covering of insurance claims.

To achieve the above, effective Spatial Data Infrastructures are required. The design and operation of such infrastructures becomes a challenge, as data that need to be analyzed come from heterogeneous sources in a variety of formats and they need to be geo-referenced. These data need to be processed using methods from different disciplines, including simulation of engineering and physical processes (such as dynamic structural response, CFD, environmental simulation, etc.), network analysis (e.g. transportation, power, communications), loss assessment, resilience analysis, and more. Currently, researchers involved in risk analysis use data and methodologies to produce results within the scope and terminology of their own discipline.

In order to represent cascading effects related to multi-hazard risks, inter-disciplinary research needs to take into account the existing multiple dependencies among systems, with regard to different types of structures, networks or activities. To facilitate this, we need a common, application-agnostic spatial information infrastructure (SDI) that integrates all kinds of data, in a way that makes them available to be processed by any discipline in a context of shared scenarios of cascades. Furthermore, the results of processing in the context of each discipline must be accessible in any other discipline, to further analyze the effects of risks from other viewpoints, create models for cascading effects, economic analyses and more.

This paper discusses the requirements and architecture of geo-information data and service infrastructures that enable an inter-disciplinary approach of different kinds of risks and hazards, to produce multi-faceted results that correspond to the complex inter-dependent nature of modern systems to each other, as well as to the physical and social space. The proposed geo-information data and service infrastructure will allow researchers and decision makers alike, to account for cascading effects on urban and semi-urban infrastructures, as well as transportation, power, and telecommunication networks. Modeling of the dependencies and possible interactions between the functionalities of different structures and networks, facilitated by the proposed SDI architecture, enables the quantification of the recovery cost and time at a community or national level. These types of analyses are targeted to creating resilient communities against a variety of exogenous threats. This way, a holistic approach to risk management and resilience can be enabled, to provide decision support, enhance preparedness and improve resilience in the operational as well as in economic and social contexts.

A case study where the proposed data and service model is applied, is also presented. The study focuses on the modeling of the cascading effects of several flood scenarios to the transportation network in the city of Alexandroupolis, a city of 73,000 population, located in Northern Greece. A combined integrated study of the effects of floods to the direct and indirect cost of road transportation in the post-flood situation, can be of considerable complexity, as the flood-related parameters need to be eventually mapped into transportation loss indexes. Therefore, this study involves elements ranging from flood modeling, to transportation simulation and loss assessment. Considering that transportation networks are particularly susceptible to external influences, while floods are a complex combination of many causes and conditions, the understanding and modeling of interactions between these two dynamic systems as cascading effects, becomes a challenge as it also involves human behavior. In this context, 10 flood scenarios are examined, ranging from tsunamis to floods caused by river overflows; each scenario comes with different assumptions regarding how the quantitative attributes of the flood parameters can be translated in quantitative operational indexes of the city's transportation network, which, in turn, can be translated to losses, insurance cost estimates, as well as recovery (resilience) time and cost.