Title of the research project
Disaster inside a disaster: modeling the occurrence and effects of major seismic sequences during epidemic crises using multi-risk analysis and complex multi-agent systems.

Keywords
Risk analysis; complex systems; epidemics; natural hazards; control theory

Supervisors:

Supervisor 1
Mario di Bernardo, MERC PhD Board Member – control theory, dynamical systems, complex systems

Supervisor 2
Iunio Iervolino, MERC PhD Board Member – structural engineering, risk analysis

Project description
The COVID-19 pandemic hit the world particularly hard showing the limitations of current plans to deal with the pandemic and forcing policy makers and stakeholders to reconsider their ability to face such an event and improve their resilience. During the pandemic, natural hazards continued to be a threat in many parts of the world and recently it has become increasingly clear that multiple hazards can manifest at the same time [1]-[4]. A notable example is that of wildfires happening in California at the same time as the COVID-19 epidemic was spreading through the state [1,6] or the recent earthquake that struck Croatia in the middle of the pandemic crises [3]-[4] as well the volcanic eruption on the Carribean island of St Vincent [2] that drove up the number of COVID-19 cases on the island. This causes an interaction of the hazards which can substantially affect the consequences and requires ad-hoc management strategies.

A pressing open problem is to assess the risk of a seismic event happening at the same time of an epidemic, that is, modeling the effects on the epidemic dynamics and the management of the emergency.

The crucial research questions we want to address are:

- What are the chances of Italy being struck by an earthquake and an epidemic at the same time?
- How does the occurrence of an earthquake and its type affect the epidemic spread in the region or country?
- What are the adjustments to be taken in order to manage the pandemic effects in such circumstances?
- How can the effects of the earthquake be managed in the case of long lasting seismic sequences while also taking measures to alleviate the epidemic spread.
To our knowledge, the study we propose has not been conducted yet and is therefore a pressing open problem in the literature.

**Objectives**

(i) Investigate the risk of the next pandemic occurring at the same time as an earthquake in Italy;
(ii) Derive a hierarchy of increasingly complex network models of Italy to describe an epidemic spread at the regional level and to evaluate the risk and impact on the epidemic of an earthquake happening concurrently;
(iii) Use available data on available concurrent events (e.g. Croatia) to parameterize from data the set of models derived at step i);
(iv) Develop possible mitigation strategies at the regional level to manage the risk and mitigate the epidemic;
(v) Evaluate the impact on the economy and on the resilience of the various regions/areas of Italy of the proposed strategies.

**Methodology**

To understand how a seismic event can impact the epidemic spread, we will analyze data from the recent earthquake that struck Croatia [4] during the COVID-19 pandemic and use the data to extend and parameterize the network model of Italy developed in [5] to take into account the effects of a concurrent crisis. To simplify the epidemic spread analysis we will first consider a model where Italy is divided in macroareas (e.g. North, Centre, South) and then increase the number of compartments to comprise all the Italian regions or provinces, increasing the granularity of the model and/or specializing to specific areas most prone to natural hazards such as the Campania region which could be modelled in terms of its provinces and areas.

Data-driven model identification methods will then be used to parameterize the models from real data taking the COVID-19 pandemic as a case of study capturing the effects of seismic events on the epidemiological model parameters. Concurrently a multi-risk stochastic model will be derived to assess the risk of a seismic event occurring at the same time as an epidemic [7].

We will then try to combine the complex system model predictions based on ODEs with the risk model of the country in order for one to inform the other and viceversa. Possible mitigation strategies will be then identified to affect both the economic impact of the epidemic and to alleviate its effects on the health systems. A crucial methodological challenge will be how to reconcile the two modeling frameworks so that they can effectively interact with each other.

As a starting case of study, we will investigate the hypothetical scenario of the COVID-19 epidemic occurring during the Central Italy seismic events that happened in 2016-2017.

**Relevance to the MERC PhD Program**

Briefly describe how this project fits within the scope of the MERC PhD program describing its interdisciplinary aspects, relevance in application and beneficiaries.

This project combines both aspects of Risk and Complexity crucial to the MERC PhD program. It is highly interdisciplinary involving both risk analysis and the analysis and control of complex systems. It also requires tools from data-analysis and data-driven models and could be extended...
into the use of AI based techniques for both analysis and control in real time scenarios.

Applications and Impact

The results of the proposed project will be extremely relevant for policy-makers and local authorities to evaluate and assess the risk of multiple concurrent events in Italy and other countries with a similar pseudo-federal structure. In particular the models we will derive can be useful both to assess the impact of such concurrent events but also to devise strategies for their mitigation and to enhance resilience against them. The results can also be easily extended to other concurrent events (e.g. tsunami and earthquakes like in Fukushima, Japan). From a methodological viewpoint the combination of risk analysis models with complex systems model will be of utmost importance to obtain dynamic complex multi-risk assessment and mitigation models easily adaptable to other situations and deployable even in real-time during an emergency.

Key references


Joint supervision arrangements

The student will meet regularly with both supervisors, more than once per week (if needed) with at least one of them.

Location and length of the study period abroad (min 12 months)

Give details of the foreign research institution where the student will be host together with the full name and contacts of the foreign host. Please indicate if the foreign institution has already agreed to host the student and when the student is expected to travel abroad.

The location of the period abroad of 12 months will be decided according to the development of the research activities within the network of contacts of the two supervisors that include
Stanford, Bristol, NYU among other institutions. Collaborators will be sought internationally who are developing or have developed models of scenarios similar to the one of interest even if in different contexts.

Any other useful information

Involvement of stakeholders:
Protezione Civile Nazionale – Consorzio ReLUIS