Adaptation of modelling paradigms to the CIs interdependencies problem

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Research into critical infrastructure (CI) interdependencies is still immature. Such interdependencies have important consequences for crisis management. Owing to the complexity of this problem, computer modelling and simulation is perhaps the most efficient research approach. We present five facts that should be taken into account when modelling these interdependencies: 1) CIs are interdependent elements of a complex system. 2) Ever increasing interdependencies create new complexity. 3) Crises in CI are dynamically complex. 4) There is a need for a long term perspective. 5) Knowledge about CI is fragmented. These facts significantly condition the tools and methodologies to be used for modelling interdependencies, as well as the training and communication tools to transfer insights to crisis managers and policymakers. We analyze several modelling methodologies for applicability to CIs interdependencies problem

CIs are interdependent elements of a complex system

As CIs are not isolated from one another, we need a "system of systems" perspective to analyse them. Any one individual organization, concerned with its own problems, is likely to not have a complete understanding of how its actions affect other actors in the system. Hence, unexpected and unintended behaviour is likely to occur in CIs and dependent systems during crisis situations. Furthermore, owing to the last decade's trend of deregulation, these CIs are no longer centrally controlled. As such, we are dealing with a large number of tightly coupled networks in which there is a multitude of agents with differing goals. Thus, it may be more appropriate to talk about a "network of networks".

Ever-increasing interdependencies create new complexity

The ever-increasing connections caused by these additions can potentially be exploited by hostile attackers, or the extra complexity created may cause accidental failures. The new technologies and the evolving operational modes generate unfamiliar risks. The risks have "emergent character": they derive from interdependencies and circumstances that have not been anticipated by the designers and the users of CIs.

Crises in CI are dynamically complex

The stages of a cross-border crisis lifecycle may be asynchronous. Time delays in such crisis situations make it difficult to identify relations between causes and effects, and could lead to the implementation of solutions that only offer short term benefits. Delays also make it ifficult to capture data, as it will only be available for short periods during the occurrence of crisis. Furthermore, the longer a crisis is expected to last, the more difficult it will be to acquire relevant data, as data collection systems may not be in place in those parts of the system where unexpected consequences show up.

There is a need for a long term perspective

In contrast to familiar security crises, which are of short-duration and acute, CI crises - whether by failure or attack - could imply long-term, chronic disruption of vital operations. The strategic aspects of crisis management have to include the whole lifecycle of crises. With a lifecycle-view in mind, crisis management must encompass asynchronous management of the incubation periods, the physical manifestations of the crisis, the restoration periods and beyond.

Knowledge about CI is fragmented

Since the exact nature of risk in interdependent CIs is not well understood, an effort is necessary to bring about greater understanding. This lack of understanding translates to a lack of written and numerical records. Only when brought together in an environment that encourages interaction and exchange of information new knowledge about interdependencies in CI will be created. Hence, we should launch activities oriented towards the interaction of the different agents that could have valuable pieces of knowledge.

Adaptation of modelling paradigms to the characteristics of CIs interdependencies problem

Network Models and Derivatives: These models are built on mathematical network theory. CI is represented as a network of vertices (nodes) interconnected by edges (links). These networks represent systems that have certain non-trivial topological features that do not occur in simple networks. Their main contribution consists in showing what the network would be if a node was added or removed. Although network analysis is very useful in building robust CI networks it is unable to represent the transition from non-crisis to crisis to end-ofcrisis. Nevertheless, they are very suitable for capturing and communicating the "network of networks" perspective.

Input-Output Models: I-O models build on the premise that output from one industry sector is input for one or more others and that there is equilibrium conditions between these. I-O models consider the structure of the economy and the flow of resources between the different sectors. The main weakness of I-O models is their "data dependency". Data, in addition to being scarce, are most often calibrated to annual data and intend to capture permanent changes and long term trends, smoothing out short term dynamics. Additionally, equilibrium conditions are implied in I-O models. However, I-O models may be appropriate if the goal is to see which sectors of the economy might be affected

Agent-Based Models: A-B systems represent complex system behaviour as consequences of local interactions between agents and their environment. To construct an A-B model it is necessary to specify three main types of elements: agents, rules and the environment. The agents are people or entities of the artificial societies. The environment is the framework or abstract space where the agents can interact, and the rules are behaviour patterns for the agents and the environment. An insight of A-B models is that complex behaviour can arise from quite simple rules. Behaviour is said to be emergent, i.e. it arises endogenously. The main benefits of using A-B models are the possibility of representing heterogeneous agents, capturing emerging behaviour and creating a space where the agents interact according to distance.

System Dynamics Models: One of the main advantages of SD is its ability to effectively model socio-technical systems, which consist of human, organizational and technological parts. The philosophical stance behind SD models is that complex systems are in essence feedback systems. SD is used when the individual properties are not decisive and high-level aggregation is desired or required for management purposes. SD encourages not focusing on the isolated events but rather on the behaviour pattern that these events lead to. This high aggregation level makes it easier to analyse crises as evolutionary processes that could last longer periods of time. Another strength of SD is that the field has developed collaborative modelling methodologies where modellers work jointly with experts on the problem.

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