

Towards a Context-Aware Systemic Risk Management Framework for the Crisis Response

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ABSTRACT

Crisis response is, as any other collaborative networked organization, challenged by changes and vulnerabilities. Moreover, as a complex system with distributed activities and numerous interdependencies, considering the risk of such an organization at a systemic level, including time and space dimensions, is necessary. Systemic risk management is a topic traditionally studied in the finance area. Even if a few researches now focus on the supply chain management area (a more relatable domain regarding crisis response), there is even fewer literature regarding systemic risk management for the crisis response. Thus, this paper proposes first to define systemic risk related to the case of the crisis response. Then, a framework for context-aware systemic risk management is presented, to support the design as well as the follow-up of the crisis response, meeting one of the challenges of the Sendai Framework for Disaster Risk Reduction.

Keywords

Context-Awareness, Risk Analysis, Risk Evaluation, Knowledge Base, Systemic Risk.

INTRODUCTION

It is now acknowledged that crisis management and more specifically crisis response is seen as a collaborative process. Various stakeholders, with different technical and non-technical competencies, are involved into this collaborative process at various levels (crisis cell, crisis cell sub-cells, on-site teams). They perform management, coordination and operational activities to solve (or at least reduce) the crisis situation by outsourcing their service or activity, then completing the detecting process and responding process together. In the crisis situation, the after-crisis risk always detected from the service or activity provided by stakeholders.

However, a crisis situation is an unstable phenomenon that challenges the crisis response which has to be agile (Barthe-Delanoë et al., 2014). The consequences are unpredictable because between the crisis event and after-crisis risks, there are always repeated and inter-related small events, which are hard to find. The analysis of the mechanism is a systemic risk problem. If we could allocate the inter-relations of small repeated event and inter-linked risks, we can predict consequences. In addition, calling for multiple actors may lead to lower the reactivity to changes regarding the crisis response. Moreover, as underlined in (Poljansek et al., 2017), one of the challenges of such collaborative organizations is the interdependency of systems. The vulnerability of one system may be dependent on how resilient another system is, even located in a far distance.

A risk is defined as the combination of the probability of occurrence and the impact of hazard (Edwards and Bowen 2005). The Sendai Framework for Disaster Risk Reduction 2015–2030 goes further by integrating the spatial and time dimensions to define the systemic risk (McGlade et al., 2019). The systemic risk is created by (and/or can be magnified among) different systems as they interact, across different geographic or spatial scales. There is a need to understand and manage the interdependent and multidimensional variables of risk, beyond the historical risk metrics. Now, most of the studies regarding systemic risk are focused on the finance area, following the 2007–2009 financial crisis (O’Halloran and Nowaczyk, 2019).

In this regard, integrating the context (geographical, temporal, economic, cultural, etc.) and its multiple levels of modeling (micro, meso and macroscopic) into risk mitigation can be a way to tackle the issue of the interlinking of potential systemic risk impacts.

Our research question is to find out the risk consequence and prevent it in a changing crisis situation. We propose a context-aware framework for systemic risk management within networked organizations, and specifically crisis response. The paper is structured as follows: first, a literature review of existing systemic risk mitigation methodologies and tools is done. A definition of systemic risk for crisis response management is proposed, followed by the presentation of the framework before concluding.

SYSTEMIC RISK MANAGEMENT TODAY

As stated in the Sendai Framework for Disaster Risk Reduction, risk management is supported by models that are mostly based on historical data and observations. It relies on the idea that the past is a guide for the present and the future. But the global warming, the increasing number of human beings, the global connectedness of individuals, communities and societies render this assumption obsolete. The Global Assessment Report for Disaster Risk Reduction (McGlade et al., 2019) also underlines the need to shift from a focus on individual hazards to cascading hazards (Schauer et al. 2019) and/or multiple hazards crossing in either time and/or space leading to a larger disaster.

Looking at networked organizations, such as crisis response, (humanitarian) supply chains, it is then necessary to manage risk from a global point of view, to take into account the interlinking of risks among different entities and the ripple effect, within both their local context and the global context of the network.

Context-awareness (Castillo, 2016) is crucial to get an accurate view of the situation in which the network evolves: weather, environment, markets, etc. It helps to detect changes and evolutions, even the slightest ones, that can challenge the network behavior. Context-awareness is supported by many data sources (Open Data, social networks, sensors, reports from stakeholders, local and national policies, etc.). During the last decade, technologies that emerged regarding real-time processing of measurements and information like Complex Event Processing (Etzion et al., 2015) are now mature enough to be integrated into context modelling frameworks (Fertier et al., 2019).

Context-awareness is not limited to the monitoring of physical and technical characteristics (SAS-085, 2014). It has also to capture the social and cognitive aspects that can challenge the network's behavior, from rumors and misinterpretation to cultural differences. For example, (Byington and Felps 2017) in trust management, (Zhu et al. 2017) in KFC case, (Pecujlija et al. 2017) in war situation, (Morakabati et al. 2017) in tourism domain, (da Silva and Souza 2017) in water supply system, (Bertoncel et al. 2018) in smart factory, (Pompei et al. 2019) in family firms, (Teffali et al. 2019) in Algeria terrorist as so on.

Researches on systemic risks are mainly conducted in the finance area, which is subject to the inter-connectedness of different levels or layers of financial systems. Systemic risk in a banking system describes how a failure can create a chain reaction leading to the failure of the entire system. Researches on networked organizations disruption propagation are usually conducted for the supply chain area and focus on isolated or limited points in the supply chain. Few recent research works are studying supply chain risk management through the lens of systemic risk, making a parallel with the finance area. For instance, (Yang et al., 2016) studied disruption through interconnected logistics services into a Physical Internet structure. However, this study focuses on measuring the impact on the performance of the supply-chain rather than on how to identify the systemic risk. (Scheibe and Blackhurst, 2019), after having defined three aggregated dimensions of the systemic risk, underlines that one of the challenges of managing the systemic risk is taking into account the context. Indeed, context-awareness in systemic risk management may prevent supply-chains (or any other networked organization) from cyclical linkages that increase the risk of self-sustaining disasters (Ackermann et al., 2007). A cyclical linkage happens when a problem in node X can lead to a problem in node Y where it propagates onto node Z. Node Z may, in turn, have a feedback effect on node X (Eisenberg and Noe, 2001).

About risk analysis framework, (Paraskevas and Quek 2019) provides risk intelligent framework, they consider risk management is an important part of resilience. The framework defines risk management as sensing the risk landscape, risk assessment, risk treatment, crisis response, crisis recovery in a cycle. (Loriette et al. 2019) makes a review of risk management steps. They all cover identification of situation, organization, reaction and efficient management. (Loriette et al. 2019) also provide their own framework which is a cycle and interconnected elements of discovery of warning signals, preparedness and prevention, mitigation and damage limitation, restoring activity and learning. (Zhang et al. 2018) extends organization to organizational adaptation. It also admits that risk management is a cycle of several phases and the assessment of risk is vulnerable. (Yan and Kim 2018) adds

continuous scan for information and causation model compared to others, the causation model also provides a prove of inter-relation of risks. (Caroleo et al. 2018) collected crisis events and provide a prediction of cascading effect. They also consider risks as chain, but they did not provide evidence. (Itria et al. 2017) considers crisis management as situation detection, event fusion, processing and actions. (Bode and Macdonald 2017) adds relevant risks and (Pecujlija et al. 2017) add risk detection in crisis management. To summarize, context is the starting point of crisis management, researchers believe that risks are inside the management of crisis and the risks are inter-connected, but they did not know the way of interconnection.

The literature clearly shows that identifying and managing the systemic risk within a dynamic context is still an open question, especially in the area of crisis management. This calls for a shift from the sole use of risk assessment tools and frameworks (see Figure 1). Risk Chain Analysis (Cao et. al, 2019) and Danger-Risk-Consequence Chain analysis (Li et al., 2018) are previous works of our team. The second explain how we consider the definition of danger, risk and consequence. The first paper provides an application case on heavy-haul railway system. They complete the risk detection and risk analysis work, but they did not complete the use of risk-chain model. As shown in figure 1, we connect risk-chain model with context (present by collecting different data) and try to provide a research framework to complete the risk evaluation and risk response phase.

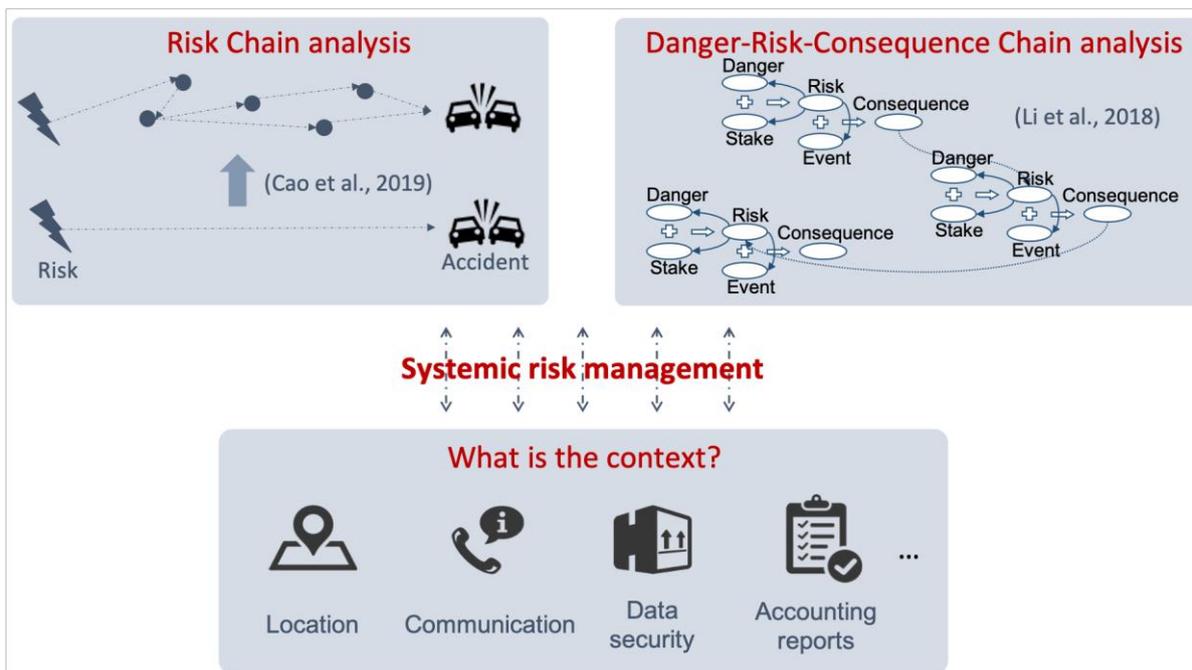


Figure 1. Context-aware systemic risk management, an open question

A FRAMEWORK FOR CONTEXT-AWARE SYSTEMIC RISK MANAGEMENT OF THE CRISIS RESPONSE

Systemic risk of the crisis response

First of all, systemic risk of the crisis response has to be defined. Based on the above definitions, systemic risk can be seen as a function describing the probability of occurrence and the impact of hazard *given a context*. The context is given by several dimensions, depending on the available data, but it must at least represent the time and location dimensions. So, instead of having the traditional two-dimensions {consequence-likelihood} matrix to value the risk, there is now a at-least four-dimensions space to value the systemic risk, as depicted on Figure 2: likelihood, consequences, location and time. The represented dimensions are limited to four for sake of clarity, but they can be as numerous as needed (social habits, individual behavior, weather conditions, etc.). To our knowledge, only the NASA developed a multi-dimensional risk matrix, though it is limited to four dimensions and is domain specific (McCollum et al. 2015).

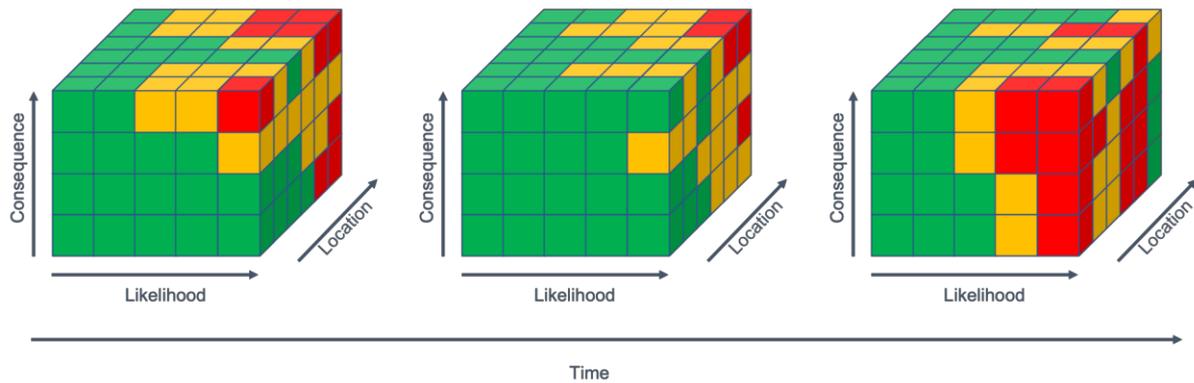


Figure 2. Representation of the risk value as a (minimal) four-dimensions space.

This definition of the systemic risk can be related to the Danger-Risk-Consequence Chain analysis framework described in (Li et al., 2018), applied to the collaborative organizations area (Figure 1 right-above part). A Danger is any specific dangerous characteristic of the context. A Stake is an element of an organization (item, thing, entity) valuable for the organization and that is susceptible to the above defined Danger. A Risk is then a realization of a Danger onto one or several Stakes. An Event represents a change in the context that triggers Risk, leading to a Consequence (set of negative impacts of the risk occurrence).

Despite the fact they do not consider explicitly the time and space dimensions in their risk definition, it is interesting to note that they aim to describe risk-related contexts and the interlinking of risks to identify risks within a collaborative network.

Analyzing their work against our systemic risk definition, some context dimensions could be expressed through the Danger and Event concepts. For example, regarding the Event concept: an event is something that happens (Etzion and Niblett, 2011). It is produced by devices (e.g.: pressure sensor, weather forecast, log files), by people (e.g.: social media content, reports) regarding both the crisis environment and the crisis response. As defined by (Etzion and Niblett, 2011), the minimal information embedded by an event includes a timestamp (i.e. time dimension) and the event source (i.e. location dimension), which fits with the characteristics of the systemic risk as defined in this paper.

Systemic Risk Identification

The proposed framework for context-aware systemic risk management for the crisis response covers both systemic risk identification and systemic risk evaluation, mainly through knowledge management and simulation.

Systemic risk identification is the first part of the proposed framework. As illustrated by Figure 3, the whole knowledge about contextualized systemic risks is collected and organized using the Danger-Risk-Consequence Chain model from (Li et al., 2018). This knowledge comes from the past crisis responses feedback. This step never ends as the knowledge base must be continuously fed with incoming feedback on systemic risk on past and present crisis responses.

As shown in Figure 3, the theory starts from crisis response processes simulation (discrete event simulation). The crisis response processes are simulated several times, generating report files about the results of the processes' activities, time queues and delays, dead ends, etc. Simulations are conducted by changing context characteristics. This can be slight changes on apparently insignificant context elements (weak signals) as well as disruptive events. It is interesting to note that these simulations can be run on two different timelines. In the first one, Number 1 in Figure 3, the simulation report file sends out and combines with Danger-Risk-Consequence Chain knowledge base. They can support preparation phase to deduce crisis response planning as well as training. In this case, the context-awareness is simulated using data based on expert knowledge and/or past events. The second timeline is the crisis response phase of crisis management. In this case, the context-awareness is ensured through data collection from the field and the crisis response itself. From a technological point of view, data collection for context-awareness can be done using the Event-Driven Architecture principles, allowing to gather events from multiple data sources, including real-time data as well as historical data (Etzion and Niblett, 2011).

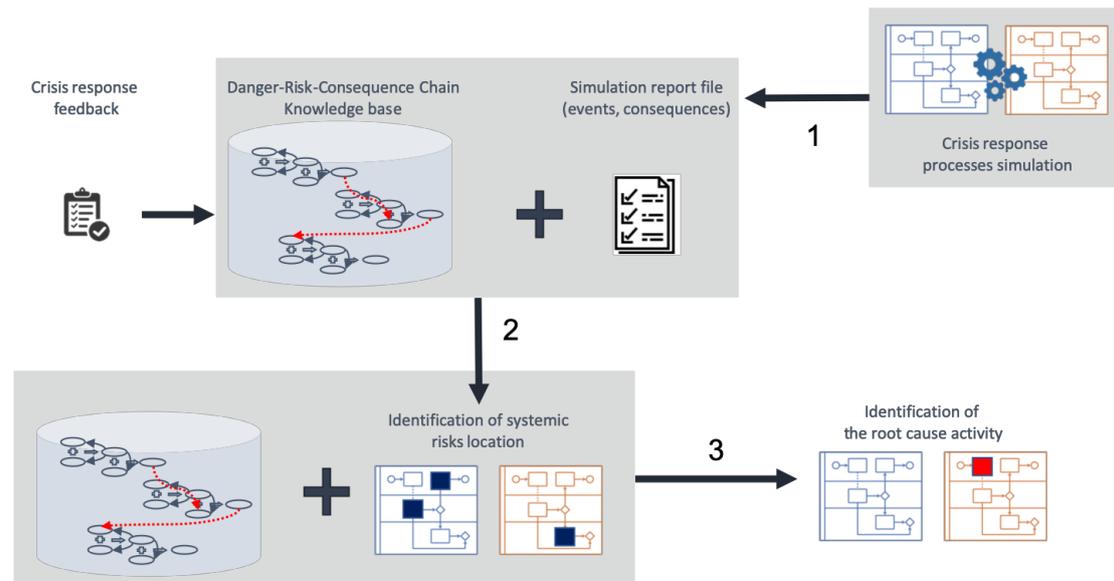


Figure 3. The proposed framework, step 1: systemic risk identification

The completed knowledge base is then transferred (Number 2 in Figure 3) to the phase of risk locations phase. It is used to support the identification of systemic risks onto the crisis response processes, using the report files. A matching is done between the results of the report files and the consequences and events of the knowledge base. It is important to note that the systemic risk concern the whole process (ripple and/or cascading effect), not a sole activity. At this step, it is crucial to identify the data source that highlighted the existence of the systemic risk (e.g. a supplier log file, a tweet from a governmental account, a weather forecast report, etc.).

This way, the first two dimensions of context-awareness are available: time (through simulations), location (through data sources). The knowledge base is used again to identify the root cause activity (Number 3 in Figure 3) of the systemic risk into the crisis response process.

Systemic Risk Evaluation

After having identified the systemic risk and its root cause into the crisis response process, it is necessary to evaluate the root cause to decide how to solve (or at least reduce) this systemic risk.

The systemic risk evaluation starts from the root cause which is embedded in the response process as shown in Figure 4. An activity can be identified as a root cause due: to its input, its output (the cause is then related to the activity performance), the stakeholder performing this activity; or to the input, the output, the stakeholder of another activity. This last case can highlight a cyclical linkage: if the input of an activity failed, then that means that the output of another activity failed, etc. In the case additional information is lacking to define the true root cause activity of this cyclical linkage, it will be necessary to define a criterion to do so.

All above information is stored in a data table. The data table is linked to business data and risk knowledge base. With the analysis of real business data and risk knowledge base to ensure the risk level and the location of the detected risk in the whole systematic risk chain. The risk knowledge base is the same one as mentioned in Figure 3. But in the evaluation phase, the key point question is how to locate the risk instance in the knowledge base, which is the graph searching technique in knowledge graph field. So, we change the presentation of knowledge base to graph language: a directed acyclic graph. Here we planned to use graph searching algorithm to complete the location of risk-chain.

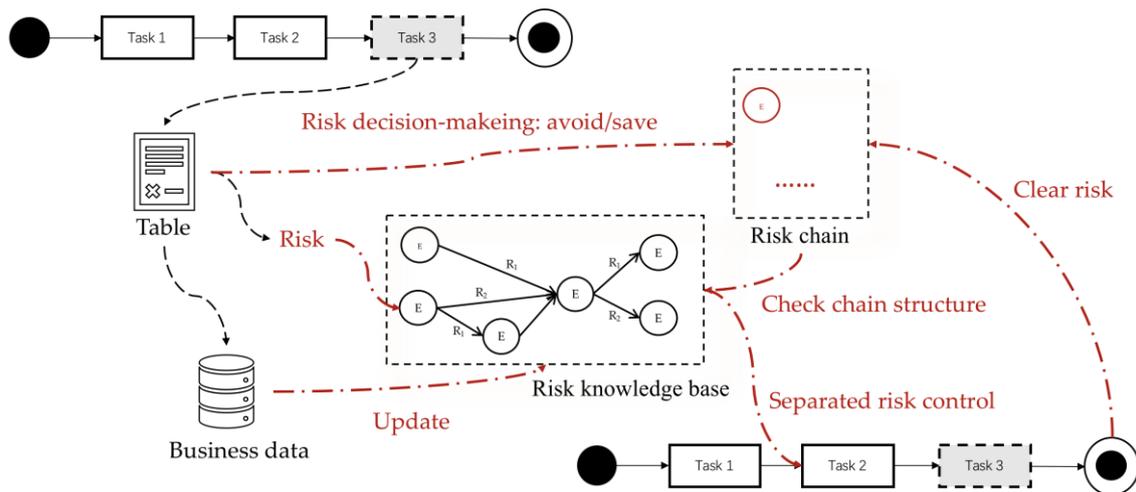


Figure 4. The proposed framework, step 2: systemic risk evaluation

After the detected risk is located in the knowledge base. The detected risk will be temporarily stored in a “risk-chain” queue (The risk “E” stored in the box of risk chain in Figure 4). There is a decision to make. If the consequence is not acceptable and if it is possible to adapt the process, the concerned process part is modified by adding a control activity, then the controlled risk will be cleared after the response process. Otherwise, if it is a low-level risk, or if it is a low-level consequence, then it is possible to accept them and to let the process in its current state, without adding anything (i.e. no adaptation is performed). With the queue, we will check if it can be connected to next detected risk as the time going and to make the decision again.

Regarding the time dimension of the systemic risk, it is interesting to note that as a dynamic function of time, a risk may naturally evolve from a high level of risk to a lower level of risk. Hence it could be interesting to simulate the evolution of a systemic risk during a given period of time to evaluate the benefits of adapting the process or not (considering the required resources and the required time to conduct this adaptation). Finally, decision-making results regarding systemic risk evaluation are collected and organized into the knowledge base to support further systemic risk identification.

CONCLUSION

In this paper, the concepts of the first version of a framework are presented to support context-aware systemic risk management for crisis response. First, a definition is proposed to define systemic risk for the crisis response domain. Systemic risk is a dynamic function, defined over at least four dimensions, including time and space. It also extends the traditional valuation of risk as a matrix to a multi-dimensional space. Based on this definition, the general concept of the framework is proposed, to identify, collect and analyze the systemic risks of a crisis response. This framework relies on two major steps: systemic risk identification and systemic risk evaluation.

One can question the issues raised by relying so much on the context to manage the systemic risks in a complex system, as context-awareness based on crowdsourced data is not fool-proof. Recently, a German artist fooled Google Maps by using ninety-nine smartphones in a cart driven at pedestrian pace into an empty street to cause Maps to register false traffic jams (Weckert, 2020). As a result, nearby users have been diverted to other routes even though the street in question was actually empty. If this “hack” had little consequences, one may wonder the results in a supply chain, a crisis response, etc. This trust issue is then two-folded: (i) how reliable crowd-sourced data are? (ii) how much can the context of a complex system be changed to induce an autonomous change of this system’s behavior? In other words, how resilient a process is facing influence or context manipulation?

Future works include the implementation of this framework, ranging from defining risks as dynamic functions of time, space as well as any other relevant dimensions to developing a systemic risk knowledge base and a proof of concept to assess the methodology, while tackling the trust issue of context-awareness.

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