Mitigating Escalation of Cascading Effects of a Payment Disruption across other Critical Infrastructures: Lessons Learned in 15 Simulation-Games

Joeri van Laere[1] ✉ [0000-0003-0488-6841], Björn J.E. Johansson[2] [0000-0002-8701-8689] , Leif Olsson[3] and Peter Määttä[4]

[1] University of Skövde, Sweden
joeri.van.laere@his.se
[2] Linköping University, Sweden
[3] Mid Sweden University, Sweden
[4] Combitech, Sweden

Abstract. A disruption in one critical infrastructure can quickly lead to cascading effects in several other ones. Much research has been done to analyze dependencies between different critical infrastructures, but little is known about how to mitigate escalation and cascading effects across several critical infrastructures, i.e. how to develop collective critical infrastructure resilience. This research presents the results of 15 simulation-games where groups of 6 to 8 field experts from different sectors were challenged to collaboratively manage a disruption in the payment system that quickly affected food distribution, fuel distribution, transport, health care et cetera. Teams discussed possible strategies, which next were implemented in a computer simulation. Teams could influence the sequence of events on 4 decision points during a 10 day scenario, and play the same scenario several times to test alternative solutions. Each simulation-game session lasted a full day. Data analysis involved the recorded team discussions as well as computer simulation logs of the implemented decisions and their impacts. The results show how escalation and the severity of cascading effects largely depends on the quality of the early crisis response and not so much on the initial disruption. Also, it is shown how cross sectorial collaboration is required. Responses where groups focus too much on cascading effects in one area lead too poor overall performance for society at large. Groups tend to overbalance their mitigating strategies initially, until they arrive at a more balanced strategy that covers challenges in several different critical infrastructures from an integral perspective.

Keywords: Critical Infrastructures, Cascading effects, Resilience, Gaming-simulation, Cross-sectorial collaboration.

1 Introduction

Resilience of interdependent infrastructures increasingly depends on collaborative responses from actors with diverse backgrounds that may not be familiar with cascade effects into areas beyond and outside the own organisation or sector. Our ongoing research project aims to create insight in how critical infrastructure disruptions that create cascading effects in several other critical infrastructures can be collaboratively mitigated. The context of our study is disruptions in the payment system. A severe disruption of the payment system may cause that citizens experience problems to acquire food, fuel or medicine. In addition, transport companies may also be dependent on the payment system to get hold of fuel. When these immediate issues are not addressed or when the measures are not properly communicated, uncertainty may grow in society, which may create further escalation such as hoarding or an increased risk of safety and security problems. As the exact interplay between these cascading events is both uncertain and dynamic, affected actors such as food stores, petrol stations, pharmacies, transport companies, security companies, government and media may have a hard time to develop a well-aligned response.

A simulation-game has been developed to gain a deeper understanding of how cascading effects of a payment solution develop; to explore what mitigating actions can be identified as well as to learn how these mitigating actions interrelate and impact the escalation of the disruptions scenario as a whole. A particular challenge for societal actors is that their response might worsen escalation.

In earlier publications of our study, the focus has been on the development of the scenario (i.e. which cascading effects might occur) [1], what important design choices were identified when developing the simulation-game [2] and how they have been handled [3, 4]. This publication is the first paper where output of the simulation-games is presented regarding what kind of mitigating actions have been identified and how their combined impact influences the escalation scenario.

Innovative collaborative responses have been identified in the playing sessions that might be valuable in a real disruption. Challenges in the cross-sectorial response involve arranging availability of payment options, securing good flows, performing crisis communication and maintaining safety and security.

The outline of the paper is as follows. After presenting related research on cascading effects across different critical infrastructures and studying critical infrastructure resilience with simulation games (section 2), our research design is presented (section 3). The 4th section contains the research results. Finally a discussion (section 5) and conclusion (section 6) complete the paper.

2 Background

2.1 Cascading effects of critical infrastructure disruptions

Societies rely on well-functioning critical infrastructures such as Energy, Information and Communication Technology, Water Supply, Food and Agriculture, Healthcare, Financial Systems, Transportation Systems, Public Order and Safety, Chemical Industry, Nuclear Industry, Commerce, Critical Manufacturing, and so on [5]. When one or more critical infrastructures break down or provide only limited service, large numbers of citizens, companies or government agencies can be severely affected [6, 7]. Breakdowns can be caused by internal factors (human or technical failure), external factors (nature catastrophes, terror attacks) or by failures of other infrastructures as there are many dependencies between critical infrastructures [7]. Energy and Information Technology or Telecommunications are well-known event-originating infrastructures that generate cascading effects in many other infrastructures, as has been shown in different types of analyses [7, 8]. In times of increasing digitalisation and an ever increasing development towards a digitally interconnected society, security experts argue for more awareness for digital vulnerabilities, more attention for cyber security and a need to educate professionals and citizens on these matters [9].

Resilience of interdependent infrastructures increasingly depends on collaborative responses from actors with diverse backgrounds that may not be familiar with cascade effects into areas beyond and outside their own organisation or sector [10]. In [6] and [7] it is argued that there is limited empirical evidence of cascading effects across many infrastructures, which makes it hard to foresee which interactions may occur across sectors. Risk analysis, business continuity management and crisis management training are often performed within the context of a single organisation or sector and are seldom addressing the holistic analysis of multiple infrastructures [7].

More research is needed to understand collective resilience in the context of critical infrastructure management. In this study, a contribution is made by focusing on one application area, i.e. how payment disruptions impact other critical infrastructures. Despite the long term efforts of public and private actors in the financial sector in Sweden to identify, analyse and understand risks and to develop routines for preventing and mitigating serious disruptions in the payment system in Sweden, there is still a lack of insight into how the proposed action plans exactly need to be executed and how numerous other actors in society (e.g. citizens, food stores, gas stations, voluntary organizations, governmental agencies and so on) will act in case of a temporary or complete breakdown of the payment system [1].

2.2 Exploring collective critical infrastructure resilience in simulation-games

Gaming-simulation is defined as a specific form of simulation. Simulation in general aims at designing a model of a system in a complex problem area in other to be able to experiment with the model. Deeper insight in the behavior of the system is created by evaluating various operating strategies against each other in one ore multiple scenarios.

Gaming-simulation differs from other forms of simulation in that it incorporates roles to be played by participants and game administrators, implying that people and their (goal-directed) interactions become part of the simulation [11]. Gaming-simulation is especially relevant when the "*how and why*" of the interaction processes between the participants are of interest and when these interactions cannot easily be incorporated in computer simulation models. In addition, it creates a deeper learning opportunity, as simulation-game participants literally are active participants in the simulation, rather than passive observers of a computer simulation.

In our case, the reason to choose for simulation-gaming is to combine the benefits of role-playing (open system analysis) and computer simulation (closed system analysis). A role-playing game (without the computer simulation) would not be able to address the uncertain, complex and dynamic interaction between mitigating actions and escalations of cascading effects. On the other hand, a computer simulation (without active participation of societal actors) would require a comprehensive insight in all actions, effects and their interrelations, whereas a gaming-simulation can incorporate the creativity and knowledgeability of the playing experts who can come up with innovative out of the box solutions to mitigate the situations occurring in the computer simulation model.

There exist several examples where simulation-gaming has been applied to study dependencies between critical infrastructures or the management of critical infrastructures [12, 13, 14] indicating that this is a viable strategy to study critical infrastructure dynamics and resilience. As discussed in [2] our simulation-game design differs considerably from these other approaches and can thus create new insights on how to study the mitigation of cascading effects of critical infrastructure disruptions that escalate across multiple critical infrastructures.

3 Research Design

3.1 Research method

Our research design is based on an inductive research strategy and a qualitative research method. A clear theory on how the many involved actors collaboratively could manage disruptions that create cascading effects across multiple critical infrastructures is lacking. As such, there is a need for theory building rather than theory testing, which leads us to an inductive research strategy [15]. From an interpretative perspective, we are interested in exploring the many different interpretations of actors involved regarding what challenges disruptions can pose and how they could be handled collaboratively across the affected infrastructures. A simulation-game can be a safe environment where participating actors can experiment with different action alternatives, and demonstrate the core values they hold through their choice and motivation of resilience strategies.

3.2 The payment disruption simulation-game

The purpose of the game is to learn about consequences and cascading effects a payment disruption and to explore the pros and cons of different sets of mitigating actions. Game-play involves a group of 6 to 8 representatives from different societal sectors. They play as a team and have universal control over all actors in a fictive society. The objective for the team playing is to mitigate the consequences of a 10-day payment disruption in the best possible way.

The fictive society modeled in the computer simulation represents a typical Swedish region with a large city, some smaller cities and villages on the countryside and is created with Anylogic modeling software. The society contains 77 food stores, 59 petrol stations and 440.000 citizens. The team aims to influence performance on about 35 resilience indicators. Players can come up with any imaginable action that will be implemented instantly (open system design). The first version of the game included 15 different action alternatives. As each playing team has generated new ways to address the scenario, currently about 60 different action alternatives are included. When players suggest an action that is not implemented in the computer simulation, the behavior or impact of that actions is mimicked instantly by influencing computer simulation model variables during runtime.

The scenario starts on Day 1 with the event that card payment disappears as a payment option. The expectation is that the disruption only will take some hours. On Day 2 it is revealed that the disruption cannot be fixed easily and will last several days (not clear how many). The team goes through the scenario and can influence the sequence of events during 4 decision points (day 1, 2, 4 and 6). At each decision point the playing team gets feedback on the situation and the effect of their previous actions. Next they discuss for 20-30 minutes and implement new actions. The team plays the scenario twice and can as such fine-tune their set of actions or test a completely new approach in the second playing session.

A more detailed discussion of the game design is presented in [3] and [4].

3.3 Data collection and data analysis

The game has been played on15 occasions. Groups playing the game consisted of 4 to 8 professionals representing various sectors of society. Data has been gathered by recording the discussions of the players while playing, by logging their implemented actions (and the effects of their actions in the computers simulation), by 2 observers taking notes, by questionnaires the players filled in, and by recording the oral debriefing.

Data analysis consisted of a qualitative analysis, where themes appeared based on relevance, rather than on frequency. As the scenario in each game sessions is dynamic, i.e. totally depending on the actions that the group who plays chooses, not all challenges have appeared in all game sessions, or they have appeared at different moments. A challenge that only appeared in one game session, but generated very interesting reasoning, can be equally valuable as sequences of events and accompanied reasoning that have been repeated in multiple sessions.

4 Results of the 15 simulation-game sessions

This chapter summarizes the main challenges that the participating groups have been struggling with. Teams pondered about what sets of actions could be effective to arrange for alternative payment alternatives (4.1), to perform crisis communication (4.2), to secure goods flows (4.3) and to warrant safety and security (4.4). The final subsection of the results chapter elaborates on tackling the interdependencies between these four areas of attention (4.5).

Whereas these four areas of attention were consciously incorporated in the game design, following a thorough scenario validation based on expert opinions from around 37 workshop participants and 6 interviewees combined with 33 analyzed reports [1], this game design consisted primarily of 'effects of the initial disruption' and 'cascading effects when not addressing the initial disruption'. During playing the 15 simulation-game sessions mitigating actions (and their envisioned impact) where generated by the players. They could not choose from a list of available actions, but started suggesting actions given the situation they encountered in the fictive society. As a result, all actions discussed below (and their combined application) are output of the gaming simulation sessions played.

4.1 Challenges with regard to arranging alternative payment alternatives

As the scenario starts with the breakdown of card payment transactions, a first point of attention for participants is logically to open up for alternative payment options in different types of shops. When the scenario develops, the participants argue and reason about how to realize this practically and learn (from each other and from the simulation outputs) about limits and drawbacks of different payment options. For instance, too heavily relying on cash payments might create a quick emptying of ATMs, even when withdrawal amounts are limited or when the capacity of collecting and distributing cash is increased. As card payments take about 90% of the payment flow in Sweden today, cash collection and distribution can be increased to a certain extent, but not fully cover the lost capacity of card payments. Moreover, a heavy use of cash in society creates security challenges like potential robberies (see 4.4) as large amounts of cash are concentrated at stores or at civilians. A heavy use of mobile payment solutions are initially a promising solution, although they are not available for all people in society. Again, capacity is a problem, and too heavy relying in this option results in a technical breakdown due to overload of the services somewhere in the chain of service providers involved. Next, the final major payment option, paying by invoice, raises after a while the question how to handle liquidity problems at stores and the question who will take the credit risk if not all claims are met. Game participants ponder whether the credit risk can be taken by individual shops, by factoring companies or by central government.

A recurring theme in the discussions is that not all payment options are viable for all shops/companies and all citizens. Participants argue that it will be hard for companies that not already have certain payment options installed to install them when crisis hits. First it can be hard to make arrangements with banks or other financial institutions to launch new services when everybody is contacting them, and next it can be hard to

create workable routines on the fly. Civilians are faced with similar challenges, not all of them can collect cash before ATMs are empty, not all of them have mobile payment services and not all of them are eligible to buy goods by invoice.

Even those shops, who have alternative payment options 'lying on the shelf' that can be activated rather instantly, are faced with unfamiliar routines that may cause delays at pay desks, irritation amongst customers facing waiting times or denied transactions. This will create a heavier burden on shop employees the longer the disruption lasts.

A final theme that appears in different forms are all kind of juridical issues. While coping with the payment disruption scenario companies, banks and local government representatives give numerous examples of small and more severe legislative issues that will be ignored by themselves of their customers in order to be able to sell as usual. For instance, more capacity is needed to transport and handle cash and staff might be involved that is not really accredited to handle cash. Mobile payments may be accepted on private accounts rather than the company account if the company does not have an existing account. The latter means that the transaction is not registered according to the cash register law. Although these are hypothetical behaviors, professionals playing the game are quite convinced that such behaviors will arise on a small or larger scale. They argue that clarity from governmental institutions is required considering which deviations will be tolerated.

4.2 Challenges with regard to performing crisis communication

In close connection to arranging alternative payment options, almost all groups argue from the start and throughout the scenario that intensive communication is required. This can involve recommendations to postpone less urgent consumption, information about what payment alternatives are available at different points of sale, or other information about either desired behavior or taken measures. Implementing communicative actions in the game leads to changes in behavior of civilians and consumers in the fictive society that is simulated. Different communicative actions have different impacts on multiple variables (arrivals, hoarding, stealing) & and the communication may be more or less effective. Finally communication might have a certain short time impact and a rather different long term impact. For instance, when informing about the disruption early on this will decrease arrivals of consumers initially, but lead to a rather big increase on the 3rd or 4th day when certain groups start to run out of products they need.

Participants debate rather intensely about the duality of communication. On one hand it can mitigate escalation of the disruption (if people trust public agencies and private companies and follow their instructions). On the other hand the same communication might make things worse: rather than calming down the system, it might evoke panic and/or hoarding if the public interprets that bigger threats are around the corner and that they need to get hold of things before a total breakdown of the consumption system occurs.

A complicating factor is that many points of sale may reason in different ways and might go out with contradicting recommendations. When society at large does not manage to coordinate communications, instructions might be perceived as chaotic, leading to lower trust and more panic. Another way out suggested by participating players is to

actually argue for diversity as a resilient strategy, i.e. emphasizing in communication that a rich diversity of solutions is the best strategy (rather than one major alternative which becomes the next Achilles heel).

4.3 Challenges with regard to securing goods flows

Depending on the type of payment options that will be activated and the type of communication that will be used to promote certain consumer behavior, different points of sale can be confronted with different types of problems. One potential consequence may be a dramatic drop in sales with short term economic consequences and also a risk to have to throw away perishable products that are not sold. On the other hand, shops can also be confronted with a dramatic increase in visits, queuing, stealing and hoarding when the degree of panic and chaos increases in society. Increased visits and hoarding will not result in completely empty shops, but rather empty shelfs for certain types of products, whereas other types of products are not sold at all. Dramatic fluctuations in demand are challenging for today's 'just in time- logistics' that heavily relies on predictable patterns to be able to deliver goods with minimal resources and a slimmed fleet. Irregularities in demand and supply are not only dependent on available payment options and the effects of communication, but also on how the challenges of fuel supply are mastered. Other points of sale can have fantastic solutions in place, but deliveries or consumption might be affected when either customers, or transport companies that supply goods. or both, cannot pay for fuel.

4.4 Challenges with regard to safety and security

When the disruption lasts longer and longer, more and more customers get disappointed, lose faith and get annoyed. As a result, issues like hoarding, threatening behavior towards shop employees and shop lifting may become more and more common. Teams discuss how addressing such issues of safety and security can be managed in different ways. One way is to keep up a positive atmosphere, by offering free coffee or treats. Another way is to increase the presence of employees and guards. Especially when teams start discussing introducing limits to hoarding (i.e. a maximum amount of certain groceries or fuel per customer) they realize that extra personnel is needed to actually be able to enforce such limits. As discussed earlier, a higher circulation of cash requires also measures to limit the chances of robberies.

4.5 Relations between the earlier discussed sets of challenges

From the preceding discussions it is evident that there are many interactions between introducing alternative payment options, impact on goods flows, necessity of communication and managing safety/security. When more payment options break down, or when more goods are out of stock (due to hoarding or delivery problems), people get less attentive and less responsive to official communication instructions, and safety and security challenges become larger. The other way around when communication or security measures fail early on, and are interpreted as a sign of government and commerce losing control, consumers might overload one payment option, worsen the logistics of

goods distribution by hoarding some products and not buying others, and might create hostile situations in shopping areas. As many actors already are involved in each of the four discussed areas of attention, coordination challenges become immense when even interdependencies across those four areas need to be addressed.

5 Discussion

Whereas the current analysis is based on a qualitative analysis of the performed game sessions thus far, and does not yet incorporate an analysis of the quantitative performance of different teams in the computer simulation model, some interesting observations have been recurrently discussed in the simulation-game evaluations when participating teams and game facilitators reflect on the lessons learned. What is judged as good performance, bad performance, interesting or challenging in the game session experiences is based on common understanding of players and game facilitators.

5.1 The need for a cross-sectorial coordination at multiple levels

Our game sessions confirm the well-known insight that a coordinated cross-sectorial response is needed, because a disruption of one critical infrastructure quickly may affect other critical infrastructures, and because mitigating actions of one actor/sector may influence the sequences of events in other sectors. This sounds self-evident, but from the reasoning in the game sessions, some challenges come forward on a more detailed level. First, game participants acknowledge that they on a general level know that dependencies exist between their sector and other sectors, but while playing have become more and more aware how tight and critical these dependencies are when disruptions start to reproduce. The trickiest challenge which arises from this first insight is how to accomplish cross-sectorial collaboration in practice. How can many sectors that not necessarily communicate in a big forum on a day to day basis, suddenly gather and tackle strategic and operational assignments on a local, regional, national and international level? Clearly, it is unrealistic to think that all kind of workgroups first need to sit together before any action can be undertaken. That would lead to an all too passive response (see also 5.2). Instead, actors in any sector and at any level in society need to be able to instantly act independently – and simultaneously start to coordinate bilateral and in larger work groups. When acting instantaneously individually, actors need to be aware of their role in the larger system, and what presumable responses are of other actors and sectors, i.e. collaboratively creating a well-integrated response based on individual holistic understanding. The same holistic understanding is needed to initiate relevant bilateral contacts and cross-sectorial work groups. Note that the kind of actions and the kind of cross sectorial collaboration can differ from disruption to disruption which implies that this cannot be a fixed organization, but needs to be a flexible organism. A final challenge observed frequently is that actors initially may be passive as they have the expectation that "*there must be some national actor that will fix this major disruption*". Our game design was prepared for this phenomenon. As the players were responsible for all actors in society they had to name which actor needed to do what, or argue for that not any actor should act. Still, it appeared that many actors have large

expectations on resources outside their organization and learn (after others have answered that their resources are limited) that they need to act themselves rather than waiting for others coming to solve their problems.

5.2 The need for a fast and determined response, but not too fast

A typical course of events during a game session is that the playing group in the first game round has a relatively passive response (and are surprised by some unexpected cascading effects they did not addressed), whether they in the next round often move many of their actions to an earlier point in time to timely address issues that will happen later. Some groups overcompensate and end up with a response that is too fierce and too early, which then becomes counterproductive. Instead of being interpreted as a fast and adequate crisis response, the public in the fictive society sees the early forceful actions as a sign that societal actors are panicking and have lost control. Rather than listening to governmental instructions to limit consumption, the 'too early' response evokes a bank run and hoarding of food, fuel and medicine.

In evaluative discussions, players emphasize that communication becomes a challenging balancing act. What actually is too early, too slow, too passive or too forceful is largely situation dependent. Recommendations for practitioners cannot be summarized as "*act as follows on day 2 at 15.15 ...*", but rather on a more general level like "*be aware that a crisis response can be activated too late and too early and monitor therefore thoroughly signals that would indicate a too early or too slow response*".

5.3 The need for a different type of exercises illuminating system dynamics

Many participants in the simulation-games were surprised or even initially reluctant to the fact that they would not play "*themselves*" or "*their own organization*". Several of them readdressed this in the evaluative debriefing discussions. It is quite common in the simulation gaming field to let professionals change perspectives. The pedagogical idea of letting them play their adversary is to get a deeper understanding of the larger system, i.e. subordinates and managers could learn how their respective jobs are not as easy as may be assumed by an outsider. In negotiation games, for instance considering rural planning of a limited geographical areas where many stakeholders want to achieve their goals, switching stakeholder roles (i.e. let the industry play the nature protection role and vice versa) can result in either innovative win-win solutions or less extreme standpoints. The common idea is to arrive at a more holistic understanding of the problem at hand and the role and position of yourself in it. The fact that crisis management professionals in our games were insisting so much on playing their own role – rather than adopting a holistic perspective, might indicate that their training culture is rather conservative. Consequently, it would be recommendable to initiate a discussion amongst practitioners whether a larger variety of training forms with different goals are needed. Given the challenges of critical infrastructure resilience – more education forms aiming at understanding overall system dynamics are needed.

In a similar way, participants repeatedly commented that they desired to be put under more time pressure: "*It is a crisis training, but I did not feel that way; we should be put under more pressure and receive more demanding time constraints*". Again, the game

design team observed that they consciously have created a game design where participants have plenty of time to discuss. The aim of the game is too collaboratively explore consequences and potential mitigating actions in depth. A risk of putting the participants under time pressure is that they start guessing – rather that carefully arguing for their choices. The learning gains of the game are in the collaborative discussions (why does this happen?), rather than in game figures (if we do action A, variable q goes down and r goes up). For after all, in the next disruption action A might cause variable q to go up and r to go down, and the challenge is to understand why this happens rather than just remembering what happens. The assumption that you need to be put under pressure to be able to learn about crisis management, might indicate a rather narrow learning culture. Apart from learning to act under stress, many other qualities can be developed which are relevant for crisis management professionals. For critical infrastructure resilience, understanding complex system dynamics is such a necessary quality!

6 Conclusion

More research is needed on ***how to manage*** disruptions that are reproduced across many other infrastructures. Much current (equally relevant) research focuses on understanding dependencies between existing infrastructures, and on how disruptions spread. The important next question is how mitigating actions influence cascading effects of an ongoing disruption, and to what extent these actions evoke new disruptions. Simulation-games are one method that incorporates both quantitative decision modelling as well as qualitative analysis of experts discussing what actions to implement and why. Results from our 15 game sessions have both generated overall insights considering what needs to be addressed in a crisis response mitigating a disruption in the payment system, and concrete examples on possible strategies. One challenge in such a crisis response is the amount of actors that need to coordinate their actions, and how they quickly can adapt their response strategies to one and another. As that will be hard to realize on the fly, individual actors need to build up holistic system dynamic understanding of all infrastructure systems on beforehand. The latter requires new education and training forms that illuminate holistic system understanding rather than training individual competencies.

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