[EN-A-026] An approach for attribute- and performance-based evaluation of interdependent critical infrastructures

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Abstract: Notably, in engineering and behavioral sciences, the topic of resilience is being investigated broadly quantitively in technical systems like infrastructure or public transportation and qualitatively with respect to social and organizational aspects. Especially with regard to disturbances and crises in complex socio-technical systems, human operators play a pivotal role in ensuring the continuation of operations by adapting to the situation. An integrated framework for quantitative assessment as well as behavioral aspects in a socio-technical system is therefore essential to measure resilience and to compare different design approaches. The combination of quantitative and qualitative approaches is presented in this paper.

In the wake of a crisis often not only the system itself is affected but also interdependent systems. The resilience of those combined systems is the subject of this conceptual paper. Two objectives are pursued. Firstly, the creation of generic resilience management guidelines which are subsequently translated into operating procedures, strategies and practices in order to support individuals, systems and organizations in the face of crisis and to validate their cross-domain applicability.

The second objective of the paper is to contribute to closing the gap between formal descriptions of resilience in technical systems and the representation of the influence of the human operators. This is done by following an approach that combines serious gaming exercises of different scenarios, expert judgment and a simplified simulation of the involved systems which provides a quantitative assessment of resilience.

The ongoing work described in this paper is being carried out within the scope of the DARWIN project which has received funding by Horizon 2020. Preliminary results of the project that address the creation of resilience management guidelines will be presented.

Keywords: Resilience in ATM; crisis management

1. INTRODUCTION

Exceptional events, such as disturbances of great magnitude or of unusual character, can pose a significant challenge to critical infrastructure systems with respect to safety and operational continuity. In the aftermath of such events, the performance of these systems is reduced or even disabled over a certain period of time. The return of the system to nominal conditions is delayed or at worst, further implications of the disturbance will be amplified.

Involved actors are often unable to cope appropriately with an unfamiliar situation. The great number of stakeholders involved in the ATM system, interacting with each other under the constraints of different goals and competition for resources, illustrates the significance of social and organizational aspects of a socio-technical system and the problems arising in the face of a crisis. This is especially valid with regard to interdependent systems, which often display a confusion of responsibilities or inadequate synchronization between them [1]. In order to mitigate the consequences of exceptional events, affecting critical infrastructures, service providers aim to increase the resilience of the system. Two main directions of assessment of resilience in complex systems are currently subject of investigation [2]. On the one hand, performance based metrics are applied to directly measure the outcome of the system during a rebound. This is done by evaluating the system´s functionality, i.e. the state of the system, which is adapted to the particular research domain and scenario. The other aspect is attribute-related. Here, system attributes are explored which increase the resilience of the system. They often represent indicators that are gathered by subjective assessment. Resilience, as an inherit property of a socio-technical system, enables to anticipate and have readiness to respond to the implications of disturbances and to graceful extend essential functionalities when surprises arrive [3]. Both directions have become part of a broad range of research in recent years.

The project DARWIN develops resilience-enhancing measures intended to improve the response to expected and unexpected crises affecting critical infrastructures. In particular, DARWIN's measures consist of innovative training modules for crisis management practitioners and a set of resilience management guidelines. Intended as cross-domain reference guidelines, the latter can help organizations to operationalize various resilience concepts depending on the specific domain in which organizations operate. Thus, developed guidelines aim to serve as a set of generic recommendations in order to enable institutions to derive particular and domain specific instructions by applying a set of resilience concepts, found to increase resilience. The developed guidelines will be assessed by means of an integrated framework that considers attribute-based metrics as well as performance based approaches to evaluate resilience and considers two critical infrastructure systems, air traffic management and health care.

DARWIN will investigate its guidelines' effectiveness in two coupled domains, ATM and health care, and will do so by means of serious gaming exercises. The exercises will involve domain experts and will make use of cross-domain crisis scenarios, thus capturing relevant interdependencies between actors and resources. In order to detect bottlenecks to monitor and to perform what-if analyses, a computer-based simulation will be added. This simulation represents a simplified conceptual model of the relevant parts of the involved systems of a particular scenario. Workflows as well as available resources are depicted in here. Expert knowledge supports the creation of the conceptual model and the configuration of the implemented model into a discrete event simulation environment.

To quantitatively assess the impact of the guidelines on system resilience, the simplified model incorporates individually defined performance indicators for each particular scenario. The evolution of the chosen performance indicators over time (or the state of the particular system functionality) will serve to calculate the systems resilience, based on approaches made in [4], [5], [6] and [7]. Ref. [6] proposes a resilience factor by means of a sigmoid function.

$$f(t) = \frac{1}{1 + \exp\left(\pm \frac{t-\mu}{\tau}\right)}, \qquad (1)$$

Ref. [7] formalizes this approach by describing the course of the system functionality by a succession of three sigmoid functions, investigating the time series of occurring delay at an airport during an exceptional storm.

Fig. 1 illustrates the underlying concept of resilience quantification which is widely spread in the engineering domain and was introduced by [8]. The course of the system performance represents different phases in the aftermath of a disturbance. The stages can be described by the time constants of the particular sigmoid function. Due to a disturbance d, the functionality is being deviated from the former (static), reference state. Resilient systems would anticipate the event sooner and due to adaptive capacities, effective countermeasures c would be introduced to shorten the recovery phase as well as to limit the extent of performance loss. Depending on the resilience abilities of the system, the difference between the asymptotically reached new state and the reference state would be minimized.

The paper is divided into four chapters. Chapter 2 gives a short overview of relevant resilience concepts, as well as qualitative and quantitative assessments and modeling approaches found in resilience literature. The necessity to

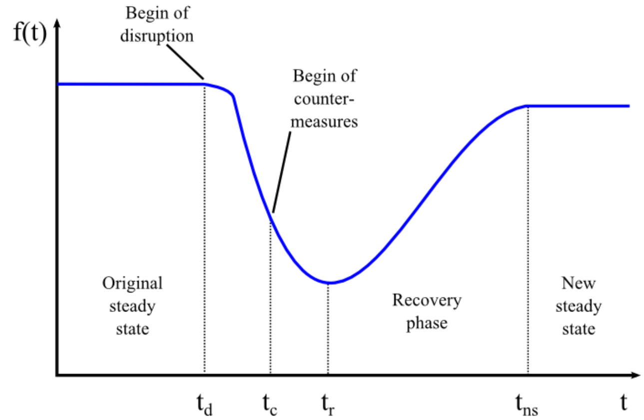

Figure 1: Systems functionality as a measure for resilience

consider both in a framework, attribute as well as performance based approaches will be discussed.

Chapter 3 presents (i) the process adopted by DARWIN to generate generic resilience guidelines and (ii) discusses the framework which is used for their evaluation. Chapter 4, discusses a scenario to illustrate the approach.

2. RESILIENCE CONCEPTS AND MOTIVATION FOR THE FRAMEWORK

Currently resilience is being investigated in a broad spectrum of research disciplines. This stretches from the beginnings in material sciences and psychology to ecology, environmental sciences and the engineering of technical systems.

A good overview over the distribution in different research domains is provided in [9]. Due to the variety of the domains, the terminology has not been evolved consistently over the years.

For example, the terms robustness and resilience are often used synonymously in different fields of research. An explanation of these terms, discussed in the light of the various definitions of resilience, is given in [5]. The described methodology relates to a performance based approach in ATM and proposes a differentiation between both terms. Depending on the system functionality and a predefined reference state, the abilities of a system to absorb disturbances as well as to bounce back in case of deviation from the reference state, are discussed against the background of a performance based ATM system. This stage of an envisaged ATM system is intended to operate on the basis of key performance indicators (KPIs). Performance based operations envisaged by SESAR [10] and quantified by means of ICAO performance indicators [11] can therefore be used to express resilience. Thus, resilient design principles might contribute to the shape of the future ATM system. Examples of performance based approaches of resilience in the ATM system, that incorporate KPIs, can be found in [12] and [13].

As stated before, with respect to the broader research community of resilience, different concepts as well as different approaches for assessment exists today. A widely used classification of resilience is the division into ecological resilience [14], engineering resilience [14] and, being a younger discipline, resilience engineering [15]. Ecological resilience can be described as the ability of an ecosystem to maintain equilibrium in the face of a disturbance, whereas different reference states are possible. In contrast to that, resilience in technical systems, such as in transportation or power infrastructure, refers to one reference state only. The aim of the resilient system is to return to this reference state as fast and with less cost as possible. Resilience engineering investigates sociological aspects in complex socio-technical systems by ensuring the safe operation of the system. Here, human and organizational aspects play a pivotal role.

Other concepts also address the various dimensions of resilience in socio-technical systems, such as the technical, organizational, economic or social dimensions, as proposed in [8] which also states, that a single measure cannot be applied on all four dimensions and that each dimension has to define appropriate means to assess resilience. Here, properties of resilience are denoted as robustness (ability to withstand a disturbance), redundancy (available substitutes of elements), resourcefulness (ability to manage resources during a disturbance) and rapidity (ability to reach a defined system state in a given time horizon). Ref. [6] provides a good survey of definitions of resilience in different research domains and suggests three capacities as fundamental properties of a resilient system. Absorptive (ability to withstand disturbances by means of proactive design of operations and resources for a minimal deviation from the system state), adaptive (ability to adapt to occurring disturbances in case absorptive capacity is exhausted by means of prediction of disturbances or restructuring) and restorative capacity (ability to return fast to the reference state) are to be optimized in order to increase the resilience of a socio-technical system. Though, both latter resilience concepts [8], [6], refer to a performance based perspective. That is, the system performance is being used to define measures of resilience with regard to the rebound from a disturbance.

With respect to resilience engineering (RE), which is a more attribute related method of assessment of resilience, Woods [3] proposes four concepts of resilience. Resilience as rebound ("how a system rebounds from disrupting or traumatic events and returns to previous or normal activities“), resilience as robustness ("expanding the set of disturbances the system can respond to effectively"), resilience as graceful extensibility ("how a system extends performance, or brings extra adaptive capacity to bear, when surprise events challenge its boundaries") and resilience as sustained adaptability ("the ability to adapt to future surprises as conditions continue to evolve"), advocating the latter two as foci for the development of the resilience concept in RE.

Considering the different approaches of resilience concepts, considerable overlapping of various aspects can be observed. This paragraph provides an example by means of the three capacities, introduced in the engineering domain by [6]. For instance, general resilience design principles, proposed by [16] can be associated to a particular capacity. For example, the proposed functional and physical redundancy, see [16], can be associated with absorptive capacity. Reorganization and human backup could be assigned to adaptive capacity. Ref. [17] provides further examples with respect to the three capacities. Here, absorptive capacity is associated to the design principle: "Design and prepare redundancy, backup and substitution to lower the interdependency impacts" and adaptive capacity is enhanced by "Adjusting and improving the organizational and administrative structure to increase early-warning awareness". As stated in [17], recovery capacity is related to "Design advanced decision support platform to quickly find the restoration sequences and priorities, optimum resource allocation strategies". This design principle is addressed by the simulation, which is part of the DARWIN framework. During the course of the crisis, the system state is presented to the participants, supporting for example the anticipation of bottlenecks, such as resource shortages, earlier or the comparison of different strategies, by the use of predictions.

Although there is a large variety of conceptions of resilience in socio-technical systems, stemming from organizational as well as engineering domains (the worldwide systematic literature review in [18] reveals roughly 300 definitions), to the best knowledge of the authors, no generally accepted definition of the concept of resilience for socio-technical system is available to this day.

Similar to the different concepts of resilience, evolving from behavioral and engineering disciplines, the evaluation of resilient systems also displays a variety of approaches. With regard to technical systems, such as public transportation or road infrastructure (domains which are tending to engineering resilience and are therefore performance based), a great number of approaches for resilience quantification can be found, see [1], [6], [19], [20] and [21]. A good overview of resilience quantification approaches is provided by [20]. A great number of approaches relates to the system functionality (see chapter 1) and its course over time. In this case, resilience is being described by the amount of loss of performance and time constants defining the phases of disruption and recovery. A first illustration is provided in [5]. Resilience engineering approaches on the other hand assesses resilience of socio-technical systems in an attribute-related manner. A prominent, widely known approach to assess resilience are four so called cornerstones (see [22]), to be considered by involved stakeholders. To anticipate, monitor, respond and adapt, learn and evolve is essential in order to constitute a resilient system. An assignment to adaptive and restorative capacity can easily be deducted, though when it comes to quantification of resilience different approaches between engineering resilience and resilience engineering are taken. For example, in contrast to the measurement of resilience by means of system functionality by engineering resilience, [3] constitutes, "that is not possible to measure resilience per se, but the potential for resilience", see also [1]. That is, in the field of resilience engineering current research investigates so called indicators which reveal potential to "remain resilient when challenging events occur" [1]. Several RE approaches have been proposed to identify and to apply those indicators of resilience potential, such as the Resilience Analysis Grid (RAG), the Functional Resonance Analysis Method (FRAM) or the Q4 Balance framework. Ref. [1] provides a good summary of available tools for assessment in the field of resilience engineering (RE). A SESAR project on RE [23] applied the application of resilience engineering concepts to the ATM system using a workshop- and human-in-the-loop-simulation-based concept evaluation approach for ATM safety assessment and design.. Brittleness is another aspect to measure resilience, since it describes "how rapidly a system´s performance declines when it nears and reaches its boundary conditions" [3]. Though, it should be noted, that a general formalization is hard to deduct and not yet presented.

In summary, it can be stated that quantifications of socio-technical systems focus rather on the rebound after a disturbance, thus neglecting influences of human operators, whereas socio-technical indicators that reveal resilience potential cannot easily be quantified. As an example of a misalignment of concepts of resilience engineering and engineering resilience might serve the recent approach to assign adaptive capacities only to the recovery phase and absorptive capacity only to the disruption phase, see [21]. Here the adaptive capabilities of human operators during the decrease of the performance, and even further back, before a crisis, are not considers appropriately.

Since the proposed framework of DARWIN includes a simulation to support human operators, aspects of its implementation will be addressed shortly. Ref. [17]discusses different modeling approaches for critical infrastructure systems (CIS). Agent based modeling as well as flow based techniques seem to be the preferred methods, keeping in mind CIS represent complex interdependencies of a variety of technical system, resources and human actors. Ref. [24] states that, as opposed to topological based modeling methods, flow based modeling methods cover all three resilient capacities. Ref. [24] also states the problem which arises regarding the available quantifications of resilience of technical systems with respect to the adaptive capacity, as part of a resilient system. Adaptive capacity cannot be measured explicitly. That is, when analyzing quantitative measures of the performance of the system, the human contribution is already inherent to system. Any quantitative assessment of the system functionality will incorporate adaptive capacity.

The aim of this project is firstly to provide resilience management guidelines to support organizations as well as individuals in critical situation and secondly, to evaluate their effectiveness by attribute- and performance-based approaches. It aims to contribute shorten the gap between resilience engineering and engineering resilience, by integrating measuring and modeling approaches of both perspectives in one framework.

The following chapter presents the approach to obtain the generic resilience management guidelines in DARWIN. It also introduces the developed evaluation framework.

3. RESILIENCE MANAGEMENT GUIDELINES

3.1 The DARWIN project

DARWIN is a project funded by the European Union's Horizon 2020 research program. It is part of the DRS-7-2014 [25] projects in which multiple consortia investigate crises and disaster resilience in order to operationalize resilience concepts. The rationale behind the call was to enhance the preparedness, response and recovery in the wake of man-made and natural disasters like the sinking of the Deepwater Horizon in 2010 and the eruption of the Icelandic volcano Eyjafjallajökull in 2010.

The consortium is led by SINTEF Digital from Norway. Other partners are the Technische Universität Braunschweig (Germany), Carr Communications (Ireland), Deep Blue Srl (Italy), ENAV S.p.A. (Italy), Instituto Superiore de Sanità – ISS (Italy), the Swedish Defense Research Agency – FOI (Sweden), Centre for Teaching & Research in Disaster Medicine and Traumatology – KCM (Sweden) and Ben-Gurion University of the Negev (Israel).

As introduced, the aim of the project is to improve the responses to expected and unexpected crises affecting critical infrastructures by the development of resilience management guidelines that cover the essential resilience abilities of the affected stakeholders. Adapted from Hollnagel [26], [22] and [27], these abilities are to be able to:

- **Anticipate:** The ability to understand how the situation at hand develops and how certain changes might influence the system positively or negatively.
- **Monitor:** This describes the active search for signs of what might happen in the near future – be it positive or negative.
- **Respond and Adapt:** This is the preparedness to react and to possess the resources to encounter a disastrous event in an efficient and flexible way.
- **Learn and Evolve:** The ability to learn from previous experiences to be more effective the next time a similar (or other) situation arises.

3.2 Approach of the project

Based on a systematic literature review covering multiple areas of research, a number of concepts for crisis management have been extracted [18]. This vast list has been condensed using interviews and a two-stage Delphi process with experts, both internal and external to the consortium [28]. As a result of this process, a total of 51 resilience concepts emerged which was assigned to eleven categories: 1) collaboration; 2) planning; 3) procedures; 4) training; 5) infrastructure; 6) communication; 7) governance; 8) learning lessons; 9) situation understanding; 10) resources; and, 11) evaluation [15].

During the development process, these concepts were transformed into a set of requirements [29] which builds the foundation to derive the generic resilience management guidelines. These aim at guiding organizations during the development and improvement of the capabilities and processes that support resilience, as described by the requirements. Resilience management guidelines, specific to their domain of operation are used to assess, improve and create such processes and tools, typically by roles at higher echelons in the organization. The guidelines provide the generic material based on which actors, in charge of policies and regulations in their domain develop domain-specific guidelines.

Fig. 2 depicts the project's hierarchical view of guidelines. The separation of users shown in Fig. 2 is a simplification, because actors often have roles at different levels (e.g., organization leaders can also be policy makers, as experts in their domain and primary stakeholders). It should also be mentioned that community leaders are part of the scope of DARWIN since community resilience is addressed (it is, however, not part of the examples discussed in this paper and therefore neglected in the description).

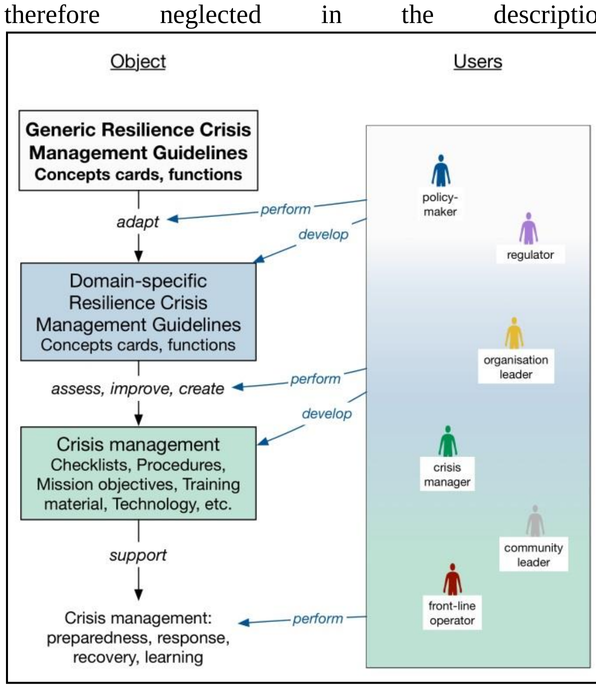

Figure 2: Applicability of the DARWIN resilience management guidelines for crisis management [30]

3.3 Concept Cards

The DARWIN guidelines are developed in the form of Concept Cards (CCs). These documents constitute mechanism by which DARWIN translates general resilience concepts into actionable guidelines. CCs propose interventions that can be implemented in order to reach the capabilities identified in crisis management practices and scientific literature. Many CCs are interrelated. The guidelines build on the CCs by organizing and relating them. This aspect of the guidelines is a consequence of the fact that resilience management capabilities are not independent. For instance, the management of adaptive capacity requires that coordination is properly supported between operational units; these two types of resilience management capabilities are different, but interdependent [30].

Each CC consists of a table that contains information on its purpose, relevant actors in the field of crisis management the CC is addressed to, expected benefits, propositions for implementation, and associated challenges.

Ways for implementation are described for utilization before, during and after a crisis and, when possible, are complemented by illustrative examples of best practices available in the literature, which provide additional guidance. Estimation of these practices' maturity in terms of technology readiness levels (TRLs) is also provided [30].

The first three Concept Cards developed include resilience management capabilities such as:

- Ensure that the actors involved in resilience management have a clear understanding of their responsibilities and the responsibilities of other involved actors.
- Noticing brittleness.
- Systematic management of policies involving policy makers and operational personnel for dealing with emergencies and disruptions.

3.4 First evaluation of concept cards

DARWIN adopts a two-phase evaluation framework consisting of an initial preliminary evaluation followed by a set of crisis simulation exercises. This incremental approach was chosen to maximize the success of the latter exercises, as these could benefit from lessons learnt and insights from the preliminary evaluation.

3.5 Evaluation framework and simulation

Serious gaming is being used to evaluate the resilience management guidelines, derived from the generic guidelines. The interacting of the participants from both domains paves the way to reveal emergent behavior, which serves redefining parts of the guidelines. Emergent behavior is likely to be expected due to the complex interdependencies of involved actors and organizations, roles, technical system or resources, between both investigated systems. For example, [32] indicates that in the case of a crisis emergent behavior of type 3 (multiple emergence) is likely to occur. This is characterized by "multiple negative and positive feedback loops" and unpredictability and might lead to even chaotic actions of the participants. In gaming sessions, communication and problem solving capabilities of experts, representing both domains and the first two levels of hierarchy (see Fig. 2), will be examined. The gaming sessions will make use of table-top exercises as well as of available domain specific simulation environments. During these pilot trials, coordinated solutions for problems, arising from the different scenarios, have to be devised among the participants. The achieved results will be evaluated by means of attribute focused metrics on the one and performance based metrics on the other hand. With respect to performance based quantification, an additional simulation of the particular scenario is being developed. A simplified model which is tailored to the particular scenario is being implemented into a discrete event simulation environment. As stated in [33], the simulation of examples in the network domain addresses schedules, capacities, resources and can reasonable be translated into a discrete event simulation (DES). Ref. [33] refers to a "middle level of abstraction" which can be applied to transportation and emergency departments by elements of a DES, such as resources, entities and flowcharts. Therefore DES is chosen as an adequate approach to provide insights into the performance of the particular participants.

Generally, the scope of a scenario is defined by boundaries to other systems, the number of involved actors and their roles, technical system and resources. The level of detail of those elements is also being outlined by the scenario. This conceptual model of the particular scenario aims to represents the relevant operational procedures and resources. The necessary abstraction of the particular elements of the system, to roles and resources, is being carried by the help of domain experts and can be represented by different means such as workflow depictions i.e. flowcharts. This is done in preparation of implementing the model. The flow based related modeling approach of the simulation denotes so called entities as commodities which flow through the system (or network) from node to node [17], such as aircraft (for example moving at the airport) or patients (for example moving around different departments at the hospital). The availability of shared resources define the particular process durations in which entities are being "kept up" till a further advancing in the network. Until now, TU Braunschweig has implemented the conceptual model of one scenario by means of the discrete event simulation environment SIMEVENTS, For other examples of the application of SIMEVENTS, please see [34]. The underlying method used in this environment is transaction based modeling. It depends on events which evoke the advancing of an entity in the network, such as the beginning or the end of a process or a rule based clearance of an involved actor. Currently additional functionalities for monitoring or configuring (of a particular scenario) by the participants are developed. This for example includes functionalities to easily model interdependencies between two systems. Important dependencies represent for example physical, geographical and cyber interdependencies; see [33]. Furthermore, functionalities to enable what-if simulations and the calculation of resilience are developed. The implemented simplified representation of the particular system supports the participants of the pilot trials to monitor the current state of the system and to perform projections of different operational options during the course of the crisis. It calculates the resilience of the system (as proposed in chapter 1), based on performance indicators selected for each scenario. The indicators are used to represent the system performance. Various time constants of the functionality will be calculated and will represent the performance based part of the resilience evaluation. Possible performance indicators could be the delay of flights and the capacity of the affected airport or other airports in the network, which are affected as well. Also, the number of casualties among the passengers could be a reasonable performance indicator. In the case of including a number of performance indicators, weighting factors will be applied in order to define the system functionality. The simulation is intended to support the gaming sessions during the debriefing phase. Events arising during the pilot trials, such as the assigning of resources to specific processes, the giving of clearances, or the start or end of processes, will serve as input for the simulation. During the debriefing, the performance of system, as well as development of resources over time, thus indicating possible bottlenecks in the system, will be discussed. The latter point relates to the identification of brittleness, which plays a crucial role with respect to the resilience engineering concepts, see [3].

The following chapter shortly discusses a scenario and a set of performance indicators as possible representations of the system functionality.

4. SCENARIO EXAMPLE

Four scenarios are used in the project [30]. They consist of:

- Aircraft crash in an urban area close to Rome Fiumicino Airport shortly after take-off,
- Total loss of radar information at Rome Area Control Centre caused by a cyber-attack,
- Disease outbreak during an incoming flight,
- Collision between an oil tanker and a passenger ferry on the Baltic Sea near Sweden.

This chapter will discuss the latter of above scenarios.

In this scenario, a small oil tanker and a ferry carrying about 1900 passengers collide in the Baltic Sea near Sweden and a number of injured persons need to be evacuated and transported to hospitals on land while the ferry remains afloat and moves slowly to the nearest suitable harbor.

For the evacuation, multiple sea rescue vessels and helicopters will be used and ambulances will be dispatched to transport the injured persons from the shore to the hospitals.

4.1 Modelling of the scenario and simulation

The simulation described in section 3 is adjusted to the scenario so that multiple distribution schemes for the differently injured persons as well as resource allocations of transport vehicles can be tested.

This results in estimates, of durations of the evacuation and the usage of hospital capacities or vehicles. Thus helping a participant to detect the bottlenecks in the system and assess the outcome of a particular course of action.

The following aspects could serve as examples of possible performance indicators to provide a quantitative assessment of resilience in this particular scenario.

- Capacity of the hospitals.
- Duration for transport of all injured persons to hospitals.
- Usage of particular vehicles

4.2 Using the simulation as a tool to evaluate concept cards

The simulation supports the evaluation of specific concept cards with its ability to conduct what-if simulations. During after-crisis reviews they can be used to determine how well the *adaption relative to events* could be applied by playing out different courses of action. The ability to detect bottlenecks and lack of resources during this example of crisis management helps to *notice brittleness*.

Fig. 3 shows the Graphical User Interface (GUI) of the implementation of this example. It depicts the map of the accident and related information on the available transportation resources and the patient allocation parameters.

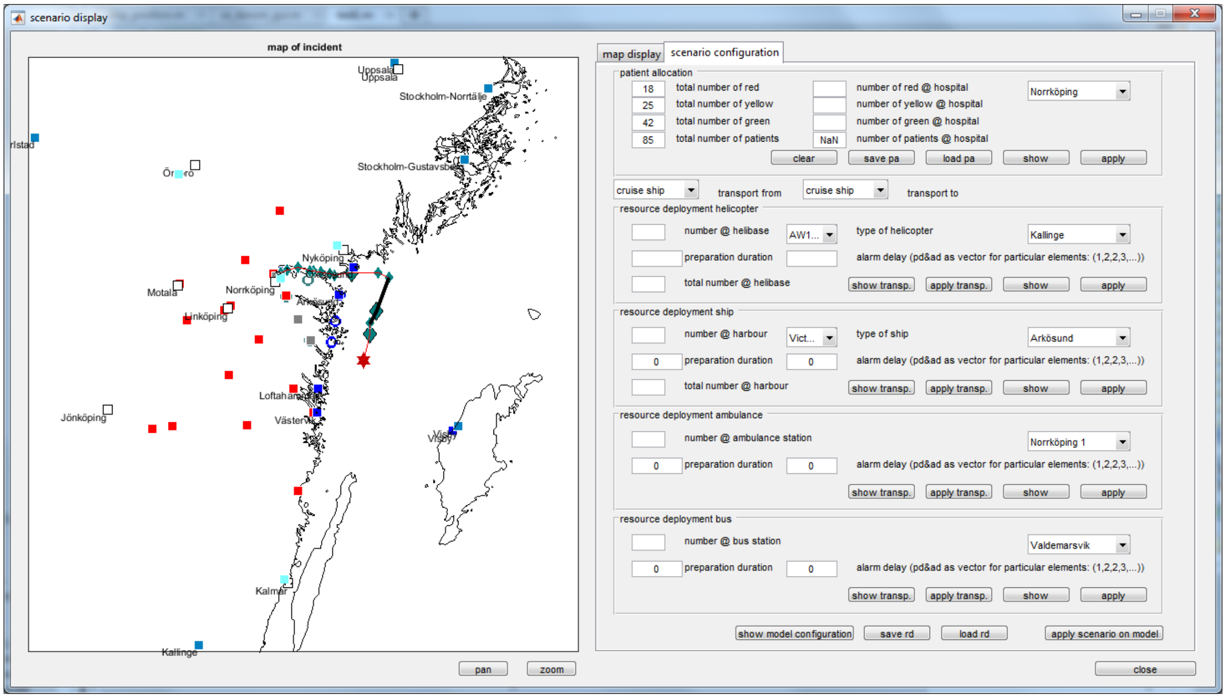

Figure 3: Graphical User Interface

5. OUTLOOK

The next step in the project will be the application of the generic guidelines to a particular domain by operational experts to derive domain specific guidelines. Afterwards, simulation runs of the different scenarios during the debriefing phases of particular scenarios will be performed, beginning in October.

The results will be presented to a group of external experts called "DARWIN Community of Practitioners (DCoP)". A group of experts which accompanies the consortium during the complete duration of the project and assures that the contents are closely related to practice.

Their feedback will be used to generate a revised version of the resilience management guidelines that will be published by the end of the project.

6. SUMMARY

This conceptual paper presents first results of generic resilience management guidelines, developed in the DARWIN project. The guidelines aim to support domain experts to adapt current operational procedures in order to increase resilience. Due to the general character of the guidelines, they will be applied to the ATM and the health care domain. Simulation trials, performed by operational experts in the form of gaming sessions, assess the effectiveness of the adapted operational procedures. Scenarios are developed which emphasize the organizational interdependencies between the two critical infrastructure systems. An evaluation framework is presented that aims to incorporate attribute-based as well as performance-based approaches, contributing to bridge the gap between the fields of engineering resilience and resilience engineering. With regard to engineering resilience, the performance of the system is described by the system`s functionality, using designated performance indicators. A simplified conceptual model of each scenario is implemented into a discrete event simulation environment in order to investigate the functionality of the system over the course of a simulation trial. The participants of the debriefing phase of an exercise are supported by the environment by means of monitoring and what if probing to assess their different courses of action. The aim is to improve the resilience of the system by participants reflecting on their actions during crisis management.

7. ACKNOWLEDGMENTS

The authors would like to thank the colleagues of the consortium working on the DARWIN project enabling this paper, especially the members of Ben-Gurion University, KMC and ISS for their contributions during the refinement of the resilience concepts and the definition of test scenarios.

The research leading to the results received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 653289. Opinions expressed in this publication reflect only the authors' view and that the Agency is not responsible for any use that may be made of the information it contains.

8. REFERENCES

[1] I. Herrera, T.O. Grotan, R.Woltjer, B. Nevhage, S. Nilsson, J. Trnka, B. Adini, O. Cohen, R. Forsberg and C.O. Jonson, “Applying resilience concepts in crisis management and critical infrastructures – the DARWIN project”, in Walls, Revie and Bedford (Eds.) “Risk, Reliability and Safety: innovating Theory and Practice”, Taylor & Francis Group, London, 2017

[2] E.D. Vugrin, M.A. Turnquist, N.J.K. Brown, “Optimal Recovery Sequencing For Enhanced Resilience And Service Restoration In Transportation Networks,” International Journal of Critical Infrastructures, 10(3/4), p.218-246. 2014. DOI: 10.1504/IJCIS.2014.066356

[3] D.D. Woods, “Four concepts for resilience and the implications for the future of resilience engineering”. Reliability Engineering and System Safety, Vol. 141, pp. 5-9, September 2015. http://dx.doi.org/10.1016/j.ress.2015.03.018

[4] D. Henry, and J. Emmanuel Ramirez-Marquez, “Generic metrics and quantitative approaches for system resilience as a function of time”. *Reliability Engineering and System Safety*, *99*, pp. 114–122, 2012, http://doi.org/10.1016/j.ress.2011.09.002

[5] O. Gluchshenko and P. Foerster, “ Performance based approach to investigate resilience and robustness of an ATM System”, Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), 2013

[6] R. Francis and B. Bekera, “A metric and frameworks for resilience analysis of engineered and infrastructure systems”. *Reliability Engineering and System Safety*, *121*, pp. 90–103, 2014, http://doi.org/10.1016/j.ress.2013.07.004

[7] N. Fürstenau, M. Mittendorf and K. Shumpei, “Nonlinear Dynamics Approach for modeling of air traffic disruption and recovery”, In: 7th Intern. Conf. on Research in Air Transportation (ICRAT), Philadelphia, PA, USA, 2016

[8] M. Bruneau, S.E. Chang, R.T. Eguchi, G.C. Lee, T.D. O’Rourke, A.M. Reinhorn, M. Shinozuka, K. Tierney, W.A. Wallace, and D. von Winterfeldt, “A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities”, 19(4), 733–752. 2003. http://doi.org/10.1193/1.1623497

[9] S. Hosseini, K. Barker, and J.E. Ramirez-Marquez, “A review of definitions and measures of system resilience”, Reliability Engineering and System Safety, 145, 47–61, 2016. http://doi.org/10.1016/j.ress.2015.08.006

[10] SESAR JU, “Concept Story Board”, SESAR JU, Brussels, Belgium, 2nd June 2009

[11] ICAO. “Manual on Global Performance of the Air Navigation System”. Doc 9883, ICAO, Montral, Canada, 2009.

[12] D. Pascarella, F. Gargiulo, A. Errico, and E. Filippone, “An Analytical Approach for Optimal Resilience Management in Future ATM Systems”, In: P. Novais, D. Camacho, C. Analide, A. El Fallah Seghrouchni, C. Badica (Eds) “Intelligent Distributed Computing IX. Studies in Computational Intelligence, vol 616” 415–425, Springer, Cham. 2016. http://doi.org/10.1007/978-3-319-25017-5

[13] J. Jung, S.A. Verma, S.J. Zelinski, T.E. Kozon, and L. Sturre, “Assessing Resilience of Scheduled Performance- Based Navigation Arrival Operations”, Eleventh USA/Europe Air Traffic Management Research and Development Seminar (ATM2015), 2015

[14] C.S. Holling, “Engineering resilience versus ecological resilience”, pages 31- 44 in P. Schulze (Ed.). “Engineering within ecological constraints”, National Academy Press, Washington, D.C., USA, 1996.

[15] E. Hollnagel, D.D. Woods, and N. Leveson, (Eds.), “Resilience engineering: concepts and precepts,” Ashgate, Aldershot, UK,. 2006.

[16] A.M. Madni, and S. Jackson, “Towards a Conceptual Framework for Resilience Engineering”, IEEE Systems Journal, Vol. 3, No. 2, 2009

[17] M. Ouyang. “Review on modeling and simulation of interdependent critical infrastructure systems”. *Reliability Engineering and System Safety*, 121, 43–60. 2014, http://doi.org/10.1016/j.ress.2013.06.040

[18] DARWIN, “ Deliverable D1.1 – Consolidation of resilience concepts and practices for crisis management”, Technical report, 2015, Retrieved 18/01/2017, from http://h2020darwin.eu/project-deliverables

[19] H. Baroud, K. Barker, J.E. Ramirez-Marquez, and C.M. Rocco, “Inherent Costs and Interdependent Impacts of Infrastructure Network Resilience”, Risk Analysis, 35(4), 642–662. 2015. http://doi.org/10.1111/risa.12223

[20] M. Ouyang, and L. Dueñas-Osorio, L., ”Multi-dimensional hurricane resilience assessment of electric power systems”. Structural Safety, 48, 15–24. 2014. http://doi.org/10.1016/j.strusafe.2014.01.001

[21] C. Nan, and G. Sansavini, G., “A quantitative method for assessing resilience of interdependent infrastructures”. Reliability Engineering and System

Safety, 157, 35–53. 2017. http://doi.org/10.1016/j.ress.2016.08.013

[22] E. Hollnagel, “Prologue: The scope of resilience engineering and Epilogue: RAG – The resilience analysis grid,” in: E. Hollnagel, J. Pariès, D.D.Woods, and J. Wreathall, (Eds.), “Resilience Engineering in Practice: A Guidebook”, Ashgate,Aldershot, UK, 2011.

[23] R. Woltjer, E. Pinska-chauvin, T. Laursen, B. Josefsson, “Towards understanding work-as-done in air traf fi c management safety assessment and design”, Reliability Engineering and System Safety, 141, 115–130. http://doi.org/10.1016/j.ress.2015.03.010 (2015)

[24] H.A.P. Blom and S. Bouarfa, “Resilience”. In: A. Cook, and D. Rivas (Eds.), “Complexity Science in Air Traffic Management”, Chapter 5, Ashgate publishing., 2015, ISBN 978-1-4724-6037-0.

[25] Horizon 2020, “Horizon 2020 Work programnme 2014-2015, 14. Secure societies – Protecting freedom and security of Europe and its citicens - revised”, consolidated version following European Commission Descision C (2015)2453 of 17 April 2015, European Commission, Brussels, Belgium, 2015

[26] E. Hollnagel, “The four cornerstones of resilience engineering,” in: C. Nemeth, E. Hollnagel, S. Dekker, (Eds), “Resilience engineering perspectives: preparation and restoration, v. 2” (pp. 117–133), Ashgate, Burlington (VT), USA, 2009.

[27] Herrera, I., “Resilience engineering and indicators of resilience”, in IRGC, ”Resource guide on resilience”, EPFL International Risk Governance Center, Lausanne, Switzerland, 2016

[28] DARWIN, “ Deliverable D1.2 – Evaluation and selection of resilience concepts and approaches”, Technical report, 2016, Retrieved 18/01/2017, from http://h2020darwin.eu/project-deliverables

[29] DARWIN, “ Deliverable D1.3 – Practicioner and academic requirements for resilience management guidelines”, Technical report, 2016, Retrieved 18/01/2017, from http://h2020darwin.eu/project-deliverables

[30] DARWIN, “ Deliverable D2.1 – Generic resilience management guidelines”, 2017

[31] D.D. Woods and M. Branlat, “Basic Patterns in How Adaptive Systems Fail”. In E. Hollnagel, J. Pariès, D. D. Woods, & J. Wreathall (Eds.), *Resilience Engineering in Practice* (pp. 127–144). Farnham, UK: Ashgate, 2011.

[32] S. Bouarfa, H.A.P. Blom, R. Curran, and M.H.C. Everdij, “Agent-Based Modeling and Simulation of Emergent Behavior in Air Transportation”. *Journal of Complex Adaptive Systems Modeling*, 1:15, Springer, 2013. DOI: 10.1186/2194-3206-1-15

[33] S.M. Rinaldi, 2004. “Modeling and Simulating Critical Infrastructures and Their Interdependencies”. In: Proceedings of the 37th Hawaii International Conference on System Sciences, 8 pp., Big Island, HI, USA, 2004. DOI: 10.1109/HICSS.2004.1265180

[34] A.A. Alsebae, M.S. Leeson and R.J. Green, “SimEvents - based Modeling and Simulation Study of Stop - and - Wait Protocol”. In: Proceedings of international Conference on Modelling, Identification & Control (ICMIC), IEEE, New York, NY, USA, 2013

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