Design of a multi-hazard collaborative system for scenario-based response planning

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Abstract: Recent natural and man-made disasters have affected multiple disaster management organizations, spanning multiple jurisdictions and countries. Examples are the extreme forest fires in France in 2016 and Portugal in 2017 and widespread flood events in Austria and the Czech Republic in 2013 and in Serbia and Croatia in 2014. Following the initial disaster event, cascading effects can further amplify the degree and complexity of disaster situations. This imposes a high demand of intra- and cross-organizational communication and cooperation - not only during the response phase, but increasingly also in the preparedness phase. An effective coordinated response requires a cohesive situation and risk assessment based on reliable information and a reasonable strategy and plan formulation. Our goal is to design and develop a system for improving response planning strategies and scenario building and facilitating organizational coordination among many actors. The designed solution includes a wide range of support tools to be used operationally by a large variety of stakeholders (firefighting units, medical emergency services, police departments, civil protection units and Command and Control Centres) and was designed with active participation of end users from these fields. In this regard, this work-in-progress paper presents and explains the design methodology chosen, the architecture and tools of the system developed in the ongoing EU H2020 project HEIMDALL.

Keywords: IT-supported crisis management, interoperability and standardisation, lessons learnt, multi-hazard system, response planning, scenario management.

1 Introduction

The management of complex crisis situations, with natural, accidental or even intentional origins, generally requires the participation and cooperation of multiple first responder organizations, including, but not limited to: firefighting units, police departments, medical emergency services, civil protection units and Command and

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Control Centres. This heterogeneous group of practitioners poses different challenges related to interoperability among the organizations and to situation awareness. Reviews of mid- and large-scale disasters have revealed communication problems in inter-organizational information exchange and disaster response [MB07], [WZL15], [Ba13]. From a socio-technical point of view, the variety of information systems that support decision making, verbal and electronic communication channels, procedures, and policies that are far from interoperable render collaborative disaster management a complex enterprise [Gu08], [CK06]. Different responders involved in multi-agency operations also develop different viewpoints of the same phenomenon depending on their organizational levels, roles, and strategic objectives [MB12]. In order to gain a situational understanding, actors will gather information chunks collected and assessed by other responders often unrelated to their objective. As consequence, situation awareness is hampered by a fragmentation of relevant information into pieces held by different stakeholders [FG16]. Therefore, efficient response planning and coordination systems should take into account this multidisciplinary context in order to provide efficient tools and technologies together with relevant information for the wide range of involved stakeholders.

A number of initiatives are aiming at improving disaster management at the European and National level, like for example, the EU Civil Protection Mechanism, the Copernicus Emergency Management Service (EMS) and several research projects within the framework of different European research programs. The efforts have been dedicated mostly to providing tools addressing IT solutions for disaster response, generally based on the generation of accurate and timely data and the combination of the derived information with modelling tools for supporting forecasting and decision making, cf. [GEO-SAFE], [PREFER], [LAMPRE], [FLOODIS], [PHAROS].

Mays et al. reflect an emerging shift in emergency preparedness from immediate-term response-oriented approaches to a more long-term view of disasters [MWS13]. Response-oriented approaches tend to focus on tactical and operational activities such as resource mobilisation and allocation and pre-planned decision and communication procedures. Furthermore, response planning involves a significant amount of long-term preparedness activities ranging from establishing appropriate strategies and processes for Disaster Risk Reduction (DRR) to evaluation and revision of response plans based on lessons learnt from disasters [eFIRECOM]. Many of these activities involve disaster scenarios [Fr18].

However, designing effective information systems for disaster preparedness requires us to better understand the dynamic and implicit ways practitioners define effective work [MWS13]. This is increasingly supported by different research initiatives, which require in their calls a better interlinking of the wide range of sectors, disciplines and actors involved in disaster risk management crucial for efficient response planning and the building of realistic multidisciplinary scenarios. A methodology for collaborative design in crisis response and management is given in [Pe15].

This work-in-progress paper describes efforts made so far in finding solutions for improved intra- and cross-organizational communication and cooperation, in particular for immediate and long-term response planning in the preparedness and response phases. It presents the design of the modular system architecture of a European Commission (EC) H2020 funded project on a Multi-Hazard Cooperative Management Tool for Data Exchange, Response Planning and Scenario Building [HEIMDALL], which started in May 2017. The project is ongoing but the presented architecture design is considered closed. Modifications are still expected on module level.

HEIMDALL aims at designing and implementing a multi-hazard integrated system to be used pre-operationally by the end users of the project and beyond which supports strategic response planning, multidisciplinary scenario building and sharing of information among multiple organizations. The design is done in close interaction with end users from several disciplines involved in emergency management acting as partners in the project. This ensures a strong base of multi-perspective expertise and knowledge in disaster preparedness. The main hazards considered for the time being are forest fire, flood, flash floods and landslides with the consideration of hazard interactions. The work conducted in HEIMDALL is based on results and findings of previous FP 7 projects and H2020 actions, cf. [Alert4All], [PHAROS], [RASOR].

The paper focusses in the first part comprising Sections 2 and 3 on presenting the collaborative design approach followed so far in order to identify major end user activities and needs for IT support. Section 2 outlines the selected methodology for collaborative design of the intended system for response planning and multidisciplinary scenario building. In Section 3, a consolidated response planning and decision making process for the HEIMDALL project is introduced which integrates different end user decision making processes with information products generated and potentials for system support. In the second part comprising Section 4, selected system concepts and functionalities including the resulting system architecture are elaborated in more detail. Section 5 summarises the results and future work to be conducted in the HEIMDALL project.

2 Collaborative design methodology for response planning and scenario building

HEIMDALL addresses the need for collaborative design of IT solutions for response planning and scenario building by following a detailed system engineering process. This process is based on an iterative version of the well-established Vee model for system engineering [Ha11] along with a close cooperation with the relevant end users (EU), comprising both consortium partners and an advisory board. Figure 1 depicts the interaction between the system engineering and the stakeholder management layers. The success of system engineering is built upon a deep understanding of the stakeholder's needs and challenges. Collaborative design is a methodology that involves people who will be affected by new technologies throughout all design phases, cf. [Pe15]. Unlike traditional approaches for developing information systems by having a fixed product and/or system idea that does not change or evolve as the development process takes place, an agile approach is a response to the need for a flexible and iterative process to be able to consider unexpected changes [KWM17]. Requirements and solutions evolve through collaborative design in an agile design and development methodology and therefore these techniques should lead to satisfying results when working together with end users as partners in the project.

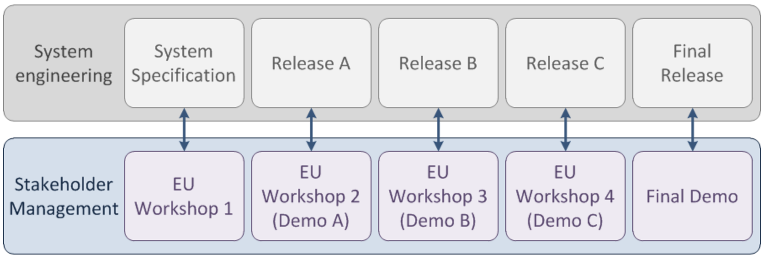

Figure 1: HEIMDALL collaborative design methodology

Another example for of the applied methodology of collaborative practitioner involvement is the identification of common, cross-organizational information elements needed in a conceptual scenario model to improve major response planning activities in complex multi-hazard crisis situations [Fr18]. These activities include situation assessment, risk and impact assessment, scenario matching, the analysis of possible futures, cross-stakeholder cooperation and communication and the evaluation and revision of response plans. Taking into account the diversity of end user partners and advisory board members in the HEIMDALL project the model should most probably be compliant with disaster scenario concepts of other end user organizations in Europe.

3 Decision Making Process

We have examined the decision making processes of the end user partners in the consortium to find opportunities for technical support in situation and risk assessment, strategy and plan formulation, scenario building, and intra and inter-organisation communication and cooperation. For this, end users have supplied us with their decision making models and processes they base their activities on. These include the JDM Decision Model and the Decision Control Process (DCP) [CBH15] and the M-OODA Model [RB04]. It is worth noting, that HEIMDALL does not intend to improve processes of individual organizations by providing research on better suitable decision making models, or to replace any existing system currently in use by end-user organisations but in fact strives to find functional and technical ways of supporting existing processes.

All provided models have been analysed in order to identify commonalities and differences between them and to define IT processes which could support them. The JDM model identifies phases of activities while the DCP model perceives the resulting products as major pillars. The M-OODA model adds focus on a cyclic behaviour/feedback loop. In normative decision making models, it is further assumed that decision makers assess the current situation, formulate plans, and then execute the plans. Normative decision making models typically identify three key phases: situation assessment (SA), plan formulation (PF), and plan execution (PE) [CBH15].

At first, consolidation of understandings has been assessed by both the end users and the technical partners in the consortium as crucial for "being on the same page" during the collaborative design process. In addition, a consistent terminology and transparency in design add to sustainable services and products. For this purpose, we elaborated a general decision making model which is based on the five consecutive activities of JDM allocated to the three key phases SA, PF and PE. The model combines the activity-centric view of the JDM model with the cyclic behaviour of the M-OODA model and the product-centric view of the DCP model.

The resulting JDM model extension is shown in Figure 2. The cornered boxes show the five steps of JDM followed by rectangular boxes with the outcome of each step. For instance, the outcome of the "gather information and intelligence" step is a situation or a simulation whereas "identify options and contingencies" results in a plan or a decision. The conceptual scenario data model enables different groups of users to collect the outcomes which are relevant for the scenario at hand in a consistent manner. Furthermore, the decision making model integrates system functionalities supporting the steps and the information products generated together with interactions between these three entities. It presents a general multi-perspective idea of the HEIMDALL concept without detracting from the idea by implementation details, information product/format multiplicities, technologies used, etc.

The three phases of the normative models, SA, PF and PE, are shown in the background of the modified JDM model. The SA phase corresponds to the gathering-of-information step and includes the assessment of risk. The development of the working strategy is an interaction of the SA and PF, while the PF persists until a decision is taken. PF is followed by the PE which corresponds to taking and coordinating the action, i.e. the execution of the decision. To close the cycle, information on the outcome of the action is gathered and consequently the SA starts again.

For example, assume a forest fire situation where the fire is reported by a citizen or detected by in-situ sensors. At that point, we would be in the "gathering of information and intelligence" step. HEIMDALL data sources, like Earth Observation (EO) data, highlighting for instance the extent of burnt areas and fire hotspots, or various in-situ sensors help to get a clear picture of the situation. Fire-fighters arriving at the scene can use the HEIMDALL app to upload their information directly to the platform making it immediately available to the Command and Control Centres. HEIMDALL will also include several interfaces to external systems, e.g. meteorological data and weather forecasting services, Copernicus Emergency Management Service, cf. [EFAS], [EFFIS], [EMS-Mapping], along with simulation tools to create a forecast of the disaster evolution. The major focus of the platform in this step is to provide a situational picture fed by a variety of data inputs from different stakeholders.

As the next step in the JDM model, risk assessment is carried out and a working strategy is developed. To this end, HEIMDALL situation assessment functionalities can be used to analyse scenarios, mitigating actions and possible future scenarios (what-if analysis) by the use of simulation and impact assessment tools. Impact assessment can be performed to determine the effect on people and critical infrastructure. For instance, a what-if analysis may consider different sets of weather phenomena and other circumstances such as day-time and night-time. For the different options simulation and impact assessment may result in different scenarios forming the base for potential alternative working strategies. With the scenario matching functionality, decision makers can find similar historic and fictive (e.g. best-case, worst-case) situations in a database and look for the response measures and decisions taken, their outcomes and lessons learnt to evaluate suitable strategies.

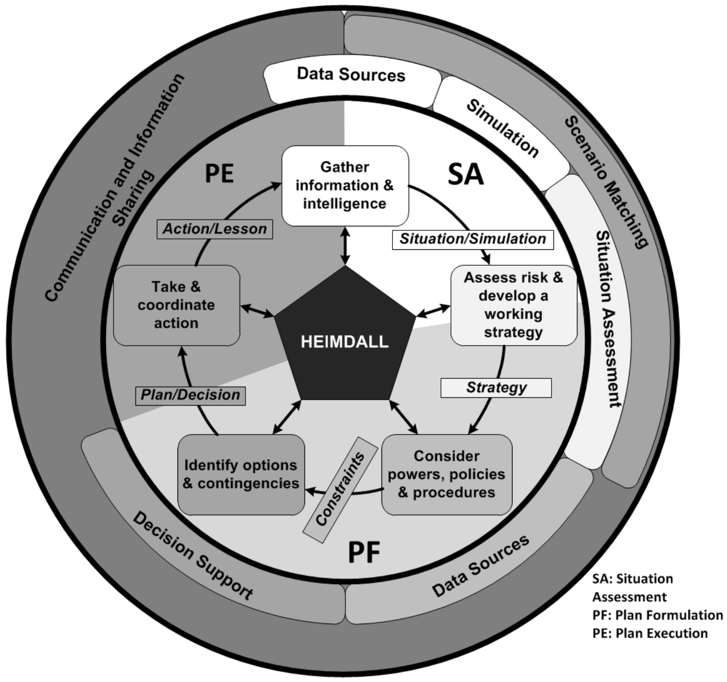

Figure 2: Generalised decision making model

The incident commander will then consider what procedures/policies and powers exist: what is the procedure for fighting the type of fire involved? Is the authority available to evacuate buildings if necessary? Here, HEIMDALL data sources can pose a solution. In the system database policies and procedures can be saved and checked. Similar information sources that are already in use by authorities can be integrated as additional information sources. The communication functionalities ensure that policies and resources can be communicated with other authorities and within their own organization.

Before the action is taken, the next step is to consider what contingencies are needed and what options exist: if the fire escalates, what is required? If casualties are recovered, is there somewhere to take them? HEIMDALL offers decision support functionalities for this. For instance, optional locations are shown as possible target areas for evacuation.

The final step is to take action. This is where the HEIMDALL communication and information sharing systems are crucial to communicate response plans and decisions. The cycle then starts again by monitoring the results of the actions; if new information is discovered such as changing weather conditions, the HEIMDALL system incorporates this information for the next iteration of the cycle. The architecture of the HEIMDALL system is described in the next section.

Once the disaster situation has passed, those involved can identify new lessons learnt if applicable, and use them to plan and prepare for the next event. As mentioned before, all data collected during and after a disaster situation can be stored using the scenario model data structure. In addition, fictive scenarios can be created, e.g. for training. A database of disaster scenarios consisting of information on the incident evolution, environmental and weather conditions, risk assessment, Command and Control decisions, response plans and lessons learnt forms a comprehensive data basis for future scenario-based response planning activities. Standards-based information sharing functionalities allow for accessing scenarios hosted by other organizations, e.g. in other countries.

4 System Architecture

In Figure 3 the system architecture of a HEIMDALL Local Unit is shown. The design of the architecture is closed, however, the project is proceeding and modifications could be introduced. Modifications on module level are expected. On the left-hand side the system inputs are displayed that are used within the HEIMDALL system to provide products. HEIMDALL itself will develop and include EO data services for fire and flood monitoring and detection, data from an autonomous swarm of drones for fire detection and in-situ sensors for terrain movement monitoring and detection.

The main HEIMDALL system products are generated by the modules at the centre of the figure. Three Simulators, one for forest fire, one for floods and one for landslides offer multi-hazard capability and allow forecasting the behaviour of the hazard

[HEIMDALL19]. The output of the Simulators is used by the Risk Assessment, the Impact Summary Generation and the Decision Support modules to provide assistance. Core module is the Service Platform that interconnects all the modules and, together with the Graphical User Interface (GUI) and the user and role management modules, enables the orchestration and usage of the system.

A pivotal component is the Scenario Management module which supports the practitioners in scenario building and matching [HEIMDALL18]. Core element for effective situation assessment and plan formulation prior and during an incident in HEIMDALL is a scenario. It assembles all related information that has been collected. Based on a scenario practitioners can generate situation reports for analysis, reporting and archiving purposes and for sharing them with their colleagues or other agencies. The Scenario Management module provides functionality to access and manage scenarios, response plans, lessons learnt, decisions and measures.

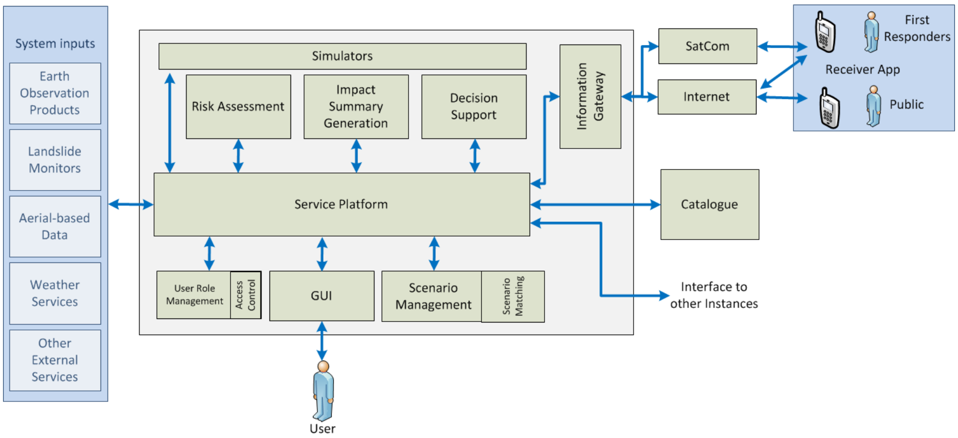

Figure 3: HEIMDALL Local Unit architecture

The right-hand side of Figure 3 shows modules related to communications. Two aspects of communication are considered in our development: First, information and data sharing among different actors within an organization, i.e. among Command and Control Centres, Forward Command Posts and first responders in the field, and second, the information can be shared with other authorities. For the first case, the HEIMDALL system can be accessed by a GUI from a web browser. Also, a mobile version is being developed for connecting to the system using a smartphone. In this way, information can be shared platform-independent and from remote locations. HEIMDALL makes use of common data formats, mostly based on open standards, in particular, standards such as EDXL-CAP [OASIS10], EDXL-SitRep [OASIS15] and TSO/EMSI [Gu08], [ISO15] for operational situation report messages. Furthermore, a messaging platform supports rapid information exchange by either forwarding text messages or multimedia content. In cases where there is no internet connection or the communication infrastructure was destroyed during the disaster, we provide Wi-Fi connection backhauled by a satellite connection.

For the second case, to interlink multiple authorities, we take the modular structure from the PHAROS project [PHAROS] as basis and interconnect multiple instances of the so called Local Units in a federated architecture, where each instance would represent an authorised organization. Recent projects for improving the interoperability of disaster management organizations follow a cloud-based approach [FG16], [Po16]. However, while collecting requirements we found that some organizations have legal constraints that can block end users from uploading data into a cloud drive and sharing it in this way with other actors: some data can be quite critical and sensitive especially in an international context. At any point in time, end users need information and control about who can access which data. The HEIMDALL approach makes use of a federated architecture based on content-oriented design, which offers efficient communication and at the same time ensures security.

Figure 4 shows an example with two connected Local Units, one for user A and one for user B. However, the setup can in principle be extended for multiple users. The data and service catalogue helps with the information discovery and the connection to other authorities. The catalogue controls the data sharing and offers the necessary services. The interface connected to the HEIMDALL Service Platform, is then used to actually transmit the data in peer-to-peer mode.

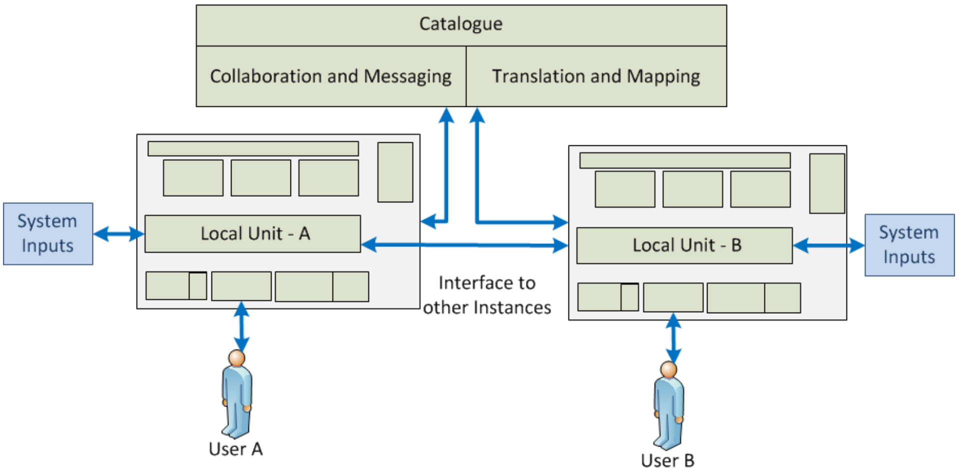

Figure 4: HEIMDALL federated architecture

Another stakeholder that needs to be considered with regard to interoperability and communication is the population at risk. With increased public awareness, damage caused to lives and property can be decreased. HEIMDALL offers for this a service to keep the general public informed. This is done in the first instance with standards-based alerting means with multi-channel capabilities and automatic translation to take into account tourists and non-native speaking people [PMC16].

5 Conclusion

In this paper, we have presented the collaborative design methodology used to find the best consolidated solution for the HEIMDALL system and the system architecture. We have subsequently elaborated the system functionalities in detail. The HEIMDALL system aims at supporting a wide range of practitioners in their cooperative response planning and multidisciplinary scenario building. In order to identify how IT tools can provide the different stakeholder profiles with an effective integrated solution, the normative decision making processes of practitioners involved in the project have been analysed. Based on those, we have derived a consolidated process and have shown how different HEIMDALL functionalities can support the process completion. First implementations of the system components have been trialled in user-centred exercises in real-environment conditions giving the technical partners and the end users the possibility to reflect on current solutions, to validate these and to identify problems. As the system architecture, case studies, and also the technical solutions are evolving during the project, we expect these to mature iteratively. The current experiences show that the collaborative, agile approach is more demanding on the development and technical coordination side but promises excellent results satisfying user needs, especially given the variety of end users from different disciplines whose perspectives need to be considered.

6 Acknowledgements

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