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An advanced decision support system for European disaster management: the feature of the skills taxonomy

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Abstract Mankind has faced a huge increase in severe natural and man-made disasters worldwide in the last few years. Emergency responders on a strategic, tactical, and operational level can be assisted by decision support systems (DSS) to enhance disaster preparedness, response, and recovery. Policy makers are in need of an advanced, resilient and integrated incident command and control systems for emergency responders that incorporates health care-related features. To address this need, a DSS was developed in the European Union (EU) project named Securing Health.Emergency.Learning.Planning (S-HELP). Improving the health care delivery process through health care-related DSS features, the identification of key emergency responders and their associated tasks performed in preparedness, response, and recovery-related interventions is absolutely necessary. Thus, we establish a skills taxonomy for the S-HELP DSS Toolset "Decision Making Module" to interlink key emergency interventions/tasks with main national emergency responders supported by international emergency responders with a special focus on the EU. Furthermore, we provide an overview of which key emergency interventions/tasks can be covered by EU Civil Protection Modules by incorporating availability, start of operation, self-sufficiency, and operation time. This skills taxonomy for the S-HELP DSS Toolset "Decision Making Module" improves the interoperability of emergency responders when they cope with major disasters such as mass flooding, chemical spills, and

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biological-hazards policy scenarios that impact on health care. In the future, operation research models related to fields such as humanitarian logistics or disease control could be incorporated into or benefit from the S-HELP DSS.

Keywords Disaster management · Decision support systems · Skills taxonomy · Emergency management interventions · Emergency management responders · EU Civil Protection Modules

1 Introduction

In an emergency response, decision makers are required to make rapid high risk decisions based on the information that is available and accessible. These decisions are made with both short and long term consequences in mind. In the short term, resources needs to be allocated and casualties prioritized (Bharosa et al. 2010). In the long term, the effects of the incident needs to be minimized to reduce damage to human life, property, and the environment, and to ensure a full recovery after the impact (Johnson 2000). In support of these activities, the emergency services use decision support systems (DSS) to make better and more effective decisions based on the best information available.

In the past, DSS have been used across the emergency management (EM) lifecycle, which consists of four phases: mitigation, preparedness, response, and recovery (Egli 2013; Whybark 2015). One such example is the use of spatial DSS in the rescue and relief operations during the World Trade Center disaster, which "ranged from micro-level risk assessments (shifts in the debris pile and temperature hot spots at the site) to the spatial status of lifelines (electric, water, telephone, transportation networks), all of which changed almost daily" (Cutter 2003 p. 441). Existing disaster management systems provide graphical representations of disaster-relevant data but are limited by the fact that they do not provide *active decision support* with capabilities such as resource allocation that include optimized schedules of available resources to improve the identification and management of response assets during an incident (Kondaveti and Ganz 2009). Thus, decision support systems bridge the gap between traditional disaster management systems and the decision-making needs of emergency responders.

The purpose of a DSS is to augment a decision-makers capacity (not replace it) and provide a mechanism with which to approach semi-structured problems through computer analysis complemented with the decision-makers own reasoning and judgement (Cioca and Cioca 2010). For emergency management, these systems need to integrate multiple components varying in capabilities, including: geographic information systems (GIS), storm tracking tools, damage projection and flooding models, as well as models for evacuating an affected population (Tufekci 1995). When evacuating an affected population, for example, decisions are made based on: the number of people who are at risk, an assessment of the most appropriate places to evacuate people to, and consideration of the methods available for transporting casualties during the evacuation, to name a few (Carver and Turoff 2007). Emergency responders need real-time data and modelling tools to best assess specific scenarios. Hence, DSS are necessary to help facilitate decision-making under complex and constantly evolving conditions

(Tufekci 1995). Unfortunately, due to the extreme nature of disasters coupled with unpredictable outcomes (Turoff et al. 2008), the decisions made are often based on completely unique and unforeseen circumstances, with much of the preparation work bearing little relation or relevance to the issues emerging during a new crisis (Boin and McConnell 2007).

One example of an essential feature for an advanced emergency management DSS to best cope with medium and large scale disasters, is to identify crucial national and international emergency responders which have to be well-trained to best plan, perform, evaluate, and improve their joint emergency interventions/tasks in preparedness, response, and recovery activities by enhancing their interoperability (i.e., cooperation capability). Furthermore, main emergency interventions/tasks have to be identified and classified. Both emergency responders/skills and emergency interventions/tasks have to be interlinked.

This paper presents such a classification and interlinkage of main national emergency responders/skills (supported by international emergency responders) and emergency interventions/tasks by using a taxonomy as a classification methodology (called skills taxonomy). This new approach also closes a gap in the literature.

The aim of the skills taxonomy is to improve the interoperability and cross-border communication of emergency responders from different countries to best cope with major disasters by identifying main national emergency responders needed for key emergency interventions. A special focus is given to general disaster scenarios on a medium to large scale national or cross-border emergency level in Europe. We also account for EU disaster response tools regarding type, availability, start of operation, self-sufficiency, and operation time. The EM interventions/tasks that can be covered by EU disaster response tools (European Parliament and the Council 2013) are illustrated. We also explain how the system matches the offers and requests of EU member states under the emergency Civil Protection mechanism. The general EU Emergency and Crisis Coordination Arrangements (European Commission 2010b, 2014b; European Parliament and the Council 2013) are briefly illustrated. Furthermore, the paper presents and discusses how the skills taxonomy is digitized and implemented in the Securing Health.Emergency.Learning.Planning (S-HELP) DSS which aim to assist emergency policy makers to better cope with preparedness, response, and recovery of major disasters by allowing ready access to the taxonomy content.

In Sect. 2, we briefly describe the research methodology and features of the S-HELP DSS. Particular attention is given to the Decision Support Module which operationalizes the skills taxonomy presented in this paper. We also illustrate which potential application fields of Operations Research could be incorporated in, or benefit from, the S-HELP DSS in the future. Section 3 explains the research methodologies used by the skills taxonomy covering the taxonomy approach, the interoperability approach, and the skills terminology concept. Next, the data collection for the skills taxonomy is described in Sect. 4. Emergency interventions (cf. Sect. 4.1) play a crucial role in disaster management since a rapid reaction/action of national and international key emergency responders (cf. Sects. 4.2 and 4.3, respectively) is required in different stages of an emergency. EU Civil Protection Modules (European Parliament and the Council 2013; European Commission 2014a) play an important role for supporting national emergency responders to cope with major disasters as outlined in Sect. 4.4. In Sect. 5,

we present the skills taxonomy by interlinking key emergency interventions and main emergency responders by identifying related tasks and incorporating EU Civil Protection Modules. To illustrate this skills taxonomy, we outline the main tasks of national emergency responders involved in two selected emergency interventions: (1) general emergency management (Sect. 5.1) as well as (2) search and rescue (Sect. 5.2). In Sect. 5.3, we provide an overview map that summarizes which of the key emergency interventions are performed by whom of the main emergency responders, while another overview map summarizes which key emergency interventions are supported by the EU Civil Protection Modules (Sect. 5.4). Section 5.5 explains how the skills taxonomy is incorporated into the S-HELP DSS Toolset regarding the Decision Making Module. The concluding Sect. 6 provides policy implications and further research.

2 Research methodology and features of the S-HELP DSS

To address the challenges facing decision makers in an emergency situation, as outlined above, the S-HELP DSS aligns with the current needs of emergency management policy makers and bridges the capability gaps in existing disaster management systems. The S-HELP DSS supports rapid and effective decision-making across all stages of the emergency management lifecycle (i.e., mitigation, preparedness, response, and recovery). The S-HELP Toolset has function-specific modules that can integrate with existing legacy systems and tools. This is important because the development of such systems does not occur in a greenfield setting, hence it is necessary to take into account the legacy systems already in place that are well established for emergency management, so that new solutions can integrate with existing infrastructure and value can be added through advanced capabilities and functionalities. The S-HELP DSS also focuses on the challenges associated with a cross-border multi-agency response. As disasters do not respect borders, it is often necessary for independent agencies to work together coordinating and sharing information and resources during and after a response (Bharosa et al. 2010; Mendonça et al. 2007). This is an added complication in an already complex situation, and often these agencies have no working history, lack a shared vocabulary, and have an over reliance on internal structures and processes (Lee et al. 2011; Manoj and Baker 2007; Carver and Turoff 2007). This leads to a number of operational inefficiencies and delays, detrimental in these time-critical extreme events.

Hence, the S-HELP DSS applies a holistically framed approach to address the challenges of emergency management in general and specifically the challenges associated with cross-border disasters, as well as the issues around decision-making and the use of decision support systems. This holistically framed approach integrates a number of components for consideration in the development of an EM decision support system, such as interoperability standards (cf. Waugh and Streib 2006), modular end-user focused tool development (cf. Carver and Turoff 2007), real-life emergency scenarios (cf. Reznek et al. 2003), end-user training in decision making (cf. Alexander 2003; Kowalski-Trakofler et al. 2003), as well as risk communication through information communication technologies and social media (cf. Sutton et al. 2008; Veil et al. 2011). Moreover, for the design of the decision support tool-set, concepts such as spatial modelling and mapping (cf. Cutter 2003), psychological frameworks, and informa-

tion processing for user interface design have been investigated and incorporated (cf. Chen and Lee 2003). As a result, the S-HELP DSS enhances the existing knowledge base required for the development of a user-centred decision support tool-set in the event of emergency situations and provides an essential skills taxonomy to promote interoperability across agencies. By applying both industry and research practice, the S-HELP DSS harnesses this collective knowledge to identify current capability gaps and constraints in existing EM solutions.

Extant literature and emergency management policy makers have highlighted the areas for improvement in terms of solutions that address overlooked EM activities and in terms of supporting and integrating activities across the entire EM lifecycle (as opposed to serving just one phase in isolation) (Altay and Green 2006). Consequently, the S-HELP DSS seeks to improve on other emergency management projects and existing tool-sets, by addressing the gaps in the literature and by developing a solution that serves the entire EM lifecycle with added functionality based on emergency management policy makers requirements. An interoperability standard was defined to support coordination and communication capabilities during multi-agency response to mitigate challenges associated with different geographical areas, cultural settings, and language barriers. This solution consists of an end-user driven tool-set for application in the context of a varied user base across a number of countries. The tool-sets were tested, evaluated, and enhanced through end-user designed real-world emergency scenarios and S-HELP's holistically framed approach to improve preparedness, response, and recovery in emergency situations will advance the design and application of EM solutions and provide a set of tools/approaches that can be reworked and remixed for application in different contexts.

To summarize, the S-HELP DSS is a strategic decision support tool for emergency management that aims at (Neville 2017):

1. coordinating multiple agency response,
2. collaborating across agencies,
3. facilitating better decision making,
4. integrating best practice and end-user focus, and
5. accounting for a people process technology approach.

The S-HELP DSS is a holistic system that integrates multiple decision support tools across an integrated interface. Figure 1 displays the key features of the S-HELP DSS which are categorized via: context, boards, and tools (Neville 2017, p. 9). The situation module (context) provides an overview of all current and historical situations. Next, the Information Management Boards guide the decision-making process and provide users with a common operational picture. The S-HELP DSS Boards contain: (1) the Situation Log, (2) the Current Recognized Situation (CRS), (3) the Strategic Aims & Priorities, and 4) the Action Board.

The S-HELP DSS Toolset (Tools) offer modules to provide additional emergency management support capabilities based on the recognized current situation (Neville 2017, p. 9). The S-HELP DSS Toolset includes: (1) a Casualty Module, (2) Decision Support Module, (3) a Crisis Communication Module, (4) a Data and Reporting Module, (5) a Geographic Information System Module, (6) a Knowledge Management

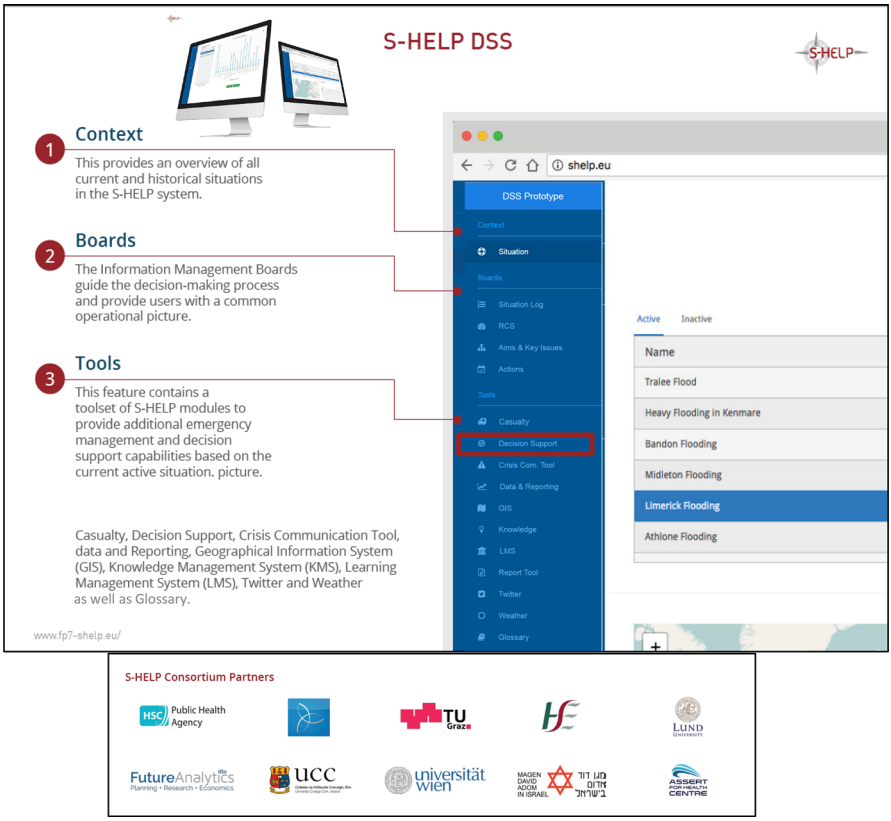

Fig. 1 The S-HELP DSS features: context, boards, and tools. Adapted from Neville (2017, pp. 8–9)

System (KMS), (7) a Learning Management System (LMS), (8) a Report Tool, (9) a Twitter, and (10) a Weather Module.

The S-HELP approach to interagency and cross-border collaboration is exemplified by the decision support module illustrated by the tools in Fig. 1. The underlying taxonomy provides a mechanism for clearly identifying task, interventions, and resources required throughout the various phases of emergency management. Moreover, it provides a shared context for incident commanders operating across jurisdictions and provides a valuable resource for resource planning and decision making. For example, the KMS and LMS S-HELP Tools are described in detail by Steen et al. (2016). The Glossary S-HELP Tool contains part of the strategic management disaster WIKI (cf. Rauner et al. 2016).

The S-HELP DSS can also be useful for gathering essential emergency information and data as well as for gaining insight into the disaster such as the overall situation of the disaster, the resources available to manage the disaster, and, in general, how to best cope with it. S-HELP could then be the backbone for developing Operations Research (OR) policies and Management Science (MS) models in the field of e.g. facility/ambulance location, inventory management, and routing for emergency management (cf. Leiras et al. 2014). Also humanitarian logistic models could be

incorporated (cf. Van Wassenhove 2006; Gupta et al. 2016) with a special focus on multi-criteria optimization models to facilitate multiple objectives in disaster operations of different stakeholders (cf. Gutjahr and Dzubur 2016; Gutjahr and Nolz 2016). For additional literature reviews on further OR and MS models that have successfully provided decision support in disaster management including several real practice applications, we refer the reader to the reviews of Altay and Green (2006), Caunhye et al. (2012), Kunz and Reiner (2012), Manopiniwes and Irohara (2014), Galindo and Batta (2013), as well as Hoyos et al. (2015). General issues on disaster management are summarized in Lettieri et al. (2009).

For specific examples, OR policy models that best triage patients and best handle limited resources in mass casualty incidents gain in importance (cf. e.g., Dean and Nair 2014; Mills 2016; Sung and Lee 2016). Ambulance allocation and reallocation policy models/DSS comprise an additional key application field (cf. e.g., Moeini et al. 2015; Schneeberger et al. 2016). Aringhieri (2009) used a general mathematical programming model to best compose medical crews with equity and efficiency for the Italian emergency medical service. Furthermore, training staff and simulation–optimization based strategies for emergency medical services using disaster management games play an essential role for improving decision making (Niessner et al. 2017). To best determine depot locations in disaster relief operations, Rath et al. (2016) developed bi-objective stochastic programming models. In the current time of the refugee crisis as well as major and multiple disasters together with political instabilities it would also be essential to account for the element of beneficiaries' choice in location-routing policy models for disaster relief logistics as proposed by Burkart et al. (2017). The S-HELP DSS can also be used in the future to incorporate OR policy models for controlling emerging infectious diseases which have the potential to become pandemics with worldwide devastating humanitarian and economic effects (Anderson et al. 1992, Vynnycky and White 2010).

3 Research methodology used by the skills taxonomy

In general, the skills taxonomy is based on international scientific literature and practice with a special focus on international norms and European guidelines. Therefore, we incorporated the expertise of different emergency policy makers of several countries (such as Austria, Ireland, Israel, Italy, The Netherlands, and the United Kingdom). For the development and further improvement of the skills taxonomy, total quality management (TQM) principles and International Organization for Standardization (ISO) 9001 norm were applied (ISO 2015a). We used a taxonomy approach to build the skills taxonomy (Sect. 3.1) by accounting for a certain interoperability approach (Sect. 3.2) and skills terminology concept (Sect. 3.3). The research methodology used for the embedment of the skills taxonomy in the S-HELP DSS is outlined in Sect. 5.5, while the general research methodology of the S-HELP DSS was explained in Sect. 2.

3.1 Taxonomy approach

The use of taxonomies and classification systems to categorize "an apparently perplexing variety of elements of a scientific field or specialty" is well established as

demonstrated by the widespread adoption of the Periodic Table and International Classification of Diseases (Heidenberger and Roth 1998, p. 337). Such taxonomies are useful for policy makers "in a systematic search for hitherto unknown, and hopefully better" components, structures, and systems of a given domain (Heidenberger and Roth 1998, p. 337). Such taxonomies can be "extracted or identified along multiple dimensions and ordered to result in a coherent frame of reference. This frame of reference facilitates the recombination of the essentials of previous approaches and may result in new approaches of enhanced analytical power" (Heidenberger and Roth 1998, p. 337).

As further examples for taxonomies in disaster management, Tatham and Spens (2011) develop a taxonomy to support the development of a body of knowledge in support of the logistic response to natural or man-made disasters. Burkle and Greenough (2008) emphasize that disaster frameworks should account for the relation of public health emergencies and modern disasters. Rake (2003) provides a literature review and taxonomy regarding on-scene command with a special focus on decision making, under uncertainty, in emergencies.

3.2 Interoperability approach

A successful cooperation in disaster management requires the will and capability of the participating emergency responders to work together in an optimal way (Guédria et al. 2015). The concept of "interoperability" is often used as a measure of the cooperation capability. Interoperability both enables the use/exchange of information and the ability to perform a function on behalf of another entity (Vernadat 2003).

Three main aspects of interoperability are considered (Interoperable Delivery of European eGovernment Services to public Administrations, Businesses, and Citizens, IDABC 2004):

- organizational interoperability (standardization of goals and processes),
- semantic interoperability (understandability of exchanged information), and
- technical interoperability (interlinkage of computer systems and services).

The skills taxonomy plays a major role in improving the semantic and organizational interoperability of emergency responders from different countries. The embedment of the skills taxonomy in the S-HELP DSS enhances the technical interoperability of emergency policy makers.

For the skills taxonomy, standards for interoperability are defined based on ISO norms ISO (2011, 2015a) and EU guidelines (European Parliament and the Council 2013, European Commission 2014a). For command-related national emergency responders, we have used the ISO 22320 Societal Security—Emergency Management—Requirements for Incident Response (ISO 2011) and ISO 22351 Societal Security—Emergency Management—Message Structure for Exchange of Information (ISO 2015a). Special focus in the skills taxonomy is given to the EU disaster response tools regarding type, availability, start of operation, self-sufficiency, and operation time (European Parliament and the Council 2013; European Commission 2014a).

3.3 Skills terminology concept

In general, two main groups of skills can be distinguished (Comfort 2007; Comfort and Wukich 2013): (1) meta-skills which can be mainly applied on the strategic level (e.g., problem-solving competences), and (2) domain-specific skills which mainly relate to the tactical and operational levels (e.g., expertise). Meta-skills exceed expertise of a certain domain.

The skills taxonomy deals with domain-specific skills that consist of expertise and capability of emergency responders which mainly relates to the tactical and operational levels with a main focus on the EU, while Steiner et al. (2015) and Technical University of Graz (2014) especially investigate meta-skills for decision making in emergencies. We classify main groups of national emergency responders supported by international emergency responders. Currently, international emergency responders, are only incorporated on a general strategic level in the skills taxonomy as two groups: (1) international organizations and (2) the European Union. To obtain cross-border or inter-EU organizational interoperability in disaster management, we also account for main components of incident command control systems based on ISO 22320 (ISO 2011).

The EU Skills Panorama (2015) contains an essential glossary for definitions of key skills-related terms and concepts. Please note that the classification of a broad number of different emergency responders involved in the skills taxonomy of the S-HELP DSS is crucial to incorporate a generic structure for the multitude of relevant skills as well as differences in education and legislation among countries.

4 Data collection for the skills taxonomy

Figure 2 illustrates the main three components of the skills taxonomy. It is part of the S-HELP DSS Toolset and is incorporated in the Decision Support Module (illustrated in Fig. 2). We focus on a general, non-country-specific level from a strategic, long-term perspective in the skills taxonomy. Country-specific emergency responders are gathered for the three S-HELP policy scenarios (mass flooding, chemical explosion, and biological-hazard) which occur in different countries (e.g., Ireland, Northern Ireland, United Kingdom, Israel, and Austria) which is summarized by University of Vienna (2016). Further features of the S-HELP DSS related to taxonomies include the resources taxonomy and the skills/disaster taxonomy (University of Vienna 2015b, c, 2016). The strategic disaster management wiki (Rauner et al. 2016) is incorporated into the Glossary of the S-HELP DSS.

For decision making, well-structured and well-performed emergency interventions play a crucial role in disaster management since a rapid reaction/action of key emergency responders is required in different stages of an emergency (cf. Fan et al. 2015; Salmon et al. 2011). Collaborative disaster management among interdisciplinary emergency responders is of utmost importance (Bharosa et al. 2010; Noran 2014). Consequently, the negative impact of a disaster on humans, fauna, flora, and infrastructure can be lowered. Furthermore, the health care delivery process can be enhanced. Therefore, in the component "emergency interventions/tasks", we focus on data collection of

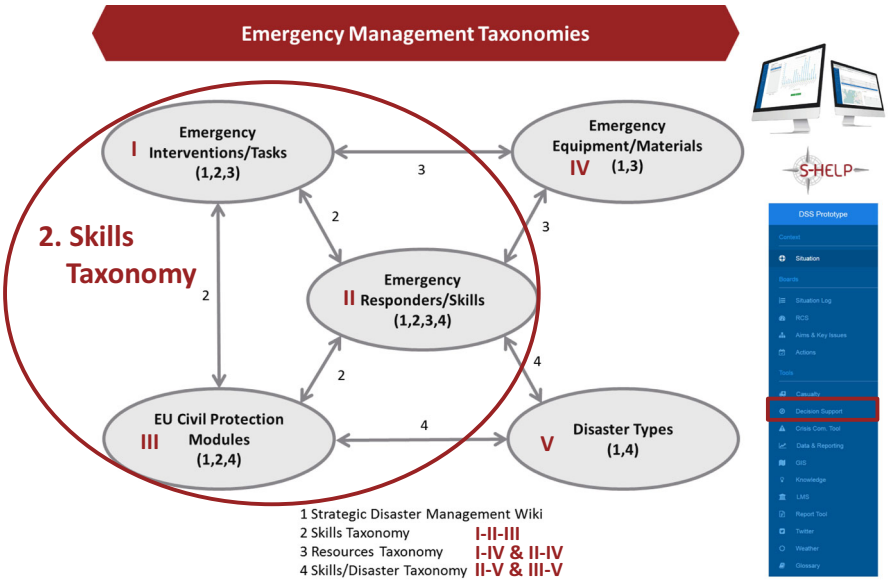

Fig. 2 The components of the skills taxonomy incorporated into the S-HELP DSS

preparedness, response, and recovery-related emergency interventions for emergency responders (part I of Fig. 2; cf. Sect. 4.1) oriented on Alexander (2012).

Furthermore, we concentrate on cross-border disasters in which national emergency responders (cf. Sect. 4.2) of different countries are involved (part II of Fig. 2). An example of this includes the potential scenario of a chemical spill across the border of Northern Ireland and Ireland. Furthermore, assistance by international emergency responders has become essential for major disasters (cf. Sect. 4.3). In Sect. 4.4, we illustrate the role of the European Union as an example for an important international emergency responder. For example, the EU provides EU Civil Protection Modules (part III of Fig. 2) that contain human and material resources of one or more member states and are able to perform pre-defined tasks in the areas of response (European Parliament and the Council 2013).

4.1 Preparedness, response, and recovery-related emergency interventions

The skills taxonomy presents main emergency responders needed for key emergency interventions and related tasks which are performed in the emergency management cycle. The emergency management cycle consists of two phases, namely a pre-disaster phase (mitigation and preparedness) and a post-disaster phase (response and recovery) (Alexander 2012). We mainly focus on the preparedness and response phases as well as partly on the recovery phase due to the focus of the S-HELP DSS.

Preparedness can be explained as "the readiness of an organization and/or community to respond to an emergency/disaster/crisis in a coordinated, timely, effective, and efficient manner. It involves equipping responders, decision-makers, and the public

with the tools and mechanisms necessary to increase their chance of survival and to minimize losses." (S-HELP 2013, p. 7). For the preparedness phase, the S-HELP DSS offers training of emergency management policy makers in general decision making (which has an impact for all phases of the emergency management lifecycle) and other essential emergency management tasks such as the donning and doffing of protective equipment which are important in preparing for biological-based incidents.

Response covers the "sum of decisions and actions taken during and after the event of an emergency/disaster/crisis to reduce or eliminate the impact of the disaster in order to prevent further health suffering, financial loss, or a combination of both" (S-HELP 2013, p. 7). In the policy scenarios of the S-HELP DSS, isolation of infected individuals is one example of a measure under consideration for the response phase. Other tools help model the effects of a variety of incidents, such as the potential areas vulnerable during a flooding event, plume modelling for predicting affected areas during a chemical explosion, and help with predicting the spread of disease during a biological incident.

Recovery "involves returning victim's lives back to the normal state they were before the disaster. This usually begins immediately after the incident but it can last for months or even years" (S-HELP 2013, p. 7). In the S-HELP DSS, the priority for recovery includes the reconstruction of critical infrastructure after a major disaster has occurred (e.g., the biological-hazard policy scenario or chemical explosion policy scenario). Existing vendor solutions do not fully address first responder challenges such as: response under time pressure, lack of data, human factors (cognition, emotions, interpersonal relationships), the activation of social service for recovery (public mental health), trust-building across groups, definitions or conflicts in incidents, and debriefs (Neville et al. 2013).

The S-HELP DSS interoperability standard fully leverages resources, lessons-learned and best practices across the EU. The standard improves shared preparedness, response, and recovery from disasters and enable EM knowledge transfer and faster response times by health care end users. The interoperability framework is created to incorporate the management of incident information, learning, and development as processes to ensure more effective and efficient decision-making in EM. The framework will ensure that S-HELP DSS supports the integration and analysis of diverse incident data along with provisioning for multi-factor (fire and a flood) decision-making. Moreover, S-HELP DSS incorporates findings from current research and practice while considering broader socio-technical factors in design, development, and use. The solution allows for gradual evolvement of decision-making capabilities through simulations and 'what-if' activities, facilitating regional and international preparedness, response, and recovery. In practice, all of the phases are intermixed and are performed to some degree before, during, or after the disaster. Thus, disaster management tends to exist in a continuum, with the recovery starting at the same time as the response or for the actual response to begin well before the disaster actually happens (Coppola 2011).

For the skills taxonomy, we identified the following main eleven emergency interventions across the preparedness, response, and recovery phases (Alexander 2012) as illustrated in Fig. 3 (University of Vienna 2015a, b). General emergency management, emergency communication, forewarning, and evacuation management play an essen-

Fig. 3 Emergency interventions with a special focus on preparedness, response, and recovery (University of Vienna 2015a, c)

tial role in the preparedness, response, and recovery phases of the emergency cycle. For the response phase, impact response as well as search and rescue are crucial emergency interventions. Both response and recovery interventions include: emergency transportation, emergency engineering, emergency shelter, emergency food program, as well as care of vulnerable and secure groups. We illustrate key tasks of two of the above eleven emergency interventions in Sect. 5: (1) general emergency management as an intervention example for the preparedness, response, and recovery phases as well as (2) search and rescue as an intervention example for the response phase.

4.2 Main national emergency responders

Each of the main eleven emergency interventions discussed in Sect. 4.1 consists of key tasks provided by different main general national emergency responders (cf. Sect. 4.2.1) who are supported by international emergency responders (cf. Sects. 4.3, 4.4). The incident command and control process is performed by an incident commander and supporting heads on a national level (cf. Sect. 4.2.2). The incident command-related national emergency responders are differently regulated in each country.

4.2.1 Main general national emergency responders

The emergency response aims at dealing with the hazardous consequences of an emergency and at assigning suitable emergency responders to strategic, tactical, and operational emergency interventions/tasks in accordance with their authority and competence. First, we investigated general national emergency responders in the international literature (e.g., Digital Humanitarian Network 2014; FLOODsite 2007; Ginter et al. 2013) for the skills taxonomy by merging and improving available classification schemes. Figure 4 illustrates our current classification scheme for main general national emergency responders who can be grouped into: (1) core responders, (2) non-core responders, and (3) co-operating bodies (cf. University of Vienna 2016).

The first column of Fig. 4 represents the most important group called main national core responders. For example, government plays a critical role in civil protection. Emergency planning, warning/advising the public, and assessing the risk include key responsibilities of this strategic core responder. Health care organizations (e.g., primary providers, secondary providers, other health care organizations) are highly demanded during an emergency situation for caring and treating patients (Ginter et al. 2013). They work in liaison with other emergency services.

Emergency services are first responders with predominantly domain-specific skills and are mostly employed at the scene of an accident for operational interventions/tasks (e.g., FLOODsite 2007; Digital Humanitarian Network 2014). Especially, emergency medical services, search and rescue teams, the fire brigade, and the police closely

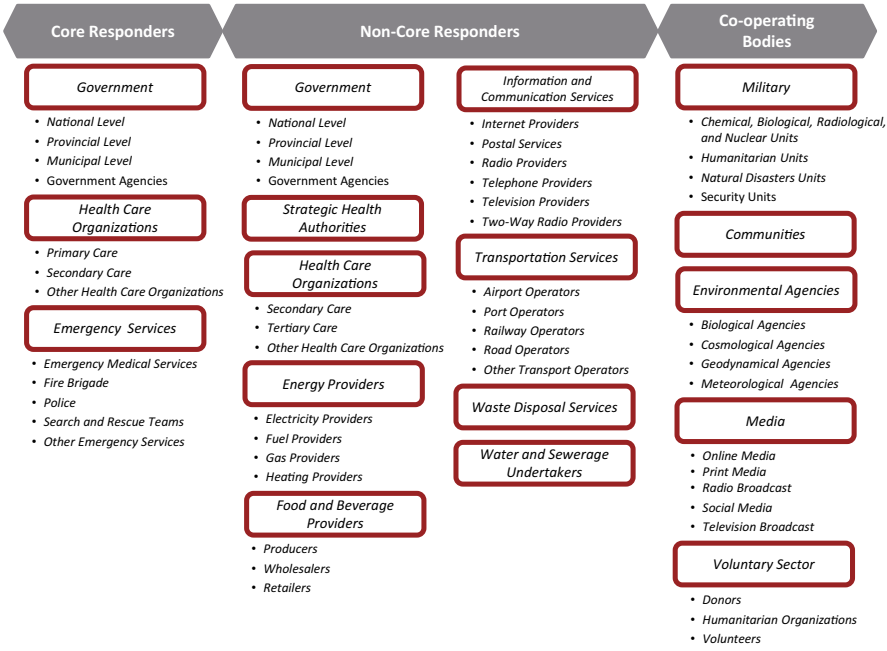

Fig. 4 Main groups of general national emergency responders (University of Vienna 2016)

work together in order to search for and rescue trapped and injured people. They also coordinate activities of emergency responders around the scene and assign personnel and equipment/materials needed. This is important for damage containment and leads to a faster overall recovery after the incident.

The second group of main national emergency responders is titled non-core responders (e.g., FLOODsite 2007; Digital Humanitarian Network 2014). Government and strategic health authorities have in this category only advising or supportive functions such as monitoring impact response or funding health services. The main part of non-core responders is represented by the private sector and non-profit sector. These emergency responders are in charge for restoration of crucial services and critical infrastructure (e.g., energy providers, information and communication services, transportation services, waste disposal services, water and sewerage undertakers). Furthermore, food and beverage providers help ensure sufficient and adequate food and water supply for humans and animals which is vital in all emergency situations.

The last category of main national emergency responders consists of co-operating bodies. They act as a helping hand during an emergency situation and are not directly involved in impact response (e.g., FLOODsite 2007; Digital Humanitarian Network 2014). Their main duties are among others: (1) providing helpful information to core responders, military, and the public (media, environmental agencies), (2) supporting emergency services on-site such as the military, and (3) offering assistance at different levels of impact response (voluntary sector). In addition, communities might also offer their support. For example, a sport club could provide infrastructure for short-term shelter to victims.

4.2.2 Incident command-related national emergency responders

Effectiveness and efficiency in emergency response can be enhanced by comprehensive incident command systems (Jensen and Thompson 2016; Rimstad and Braut 2015). The incident command and control process is performed by an incident commander and supporting heads on a national level (ISO 2011, 2015a). For the entire emergency incident, the incident commander is the final authority in decision making regarding the incident command and control process. Therefore, decision making on a strategic level, the communication of objectives and strategies, as well as the authority to delegate are the main tasks of the incident commander. As the incident commander and his or her co-commanders who are called "heads" are crucial for policy making on site, they are also incorporated.

National emergency responders have to implement incident command and control systems which comply with national, EU, and international legislation/regulations as well as the requirements of the ISO 22320 standard (ISO 2011). Because this ISO 22320 standard is highly essential to enhance the interoperability in international and cross-border incidents, we have implemented the ISO 22320 standard in the skills taxonomy of the S-HELP DSS.

The incident command and control roles and responsibilities recommended by the ISO 22320 standard (ISO 2011) are presented in Fig. 5 (cf. University of Vienna 2015c). The incident commander is supported by the following heads who are responsible for: (1) personnel, administration, and finance, (2) situational awareness and

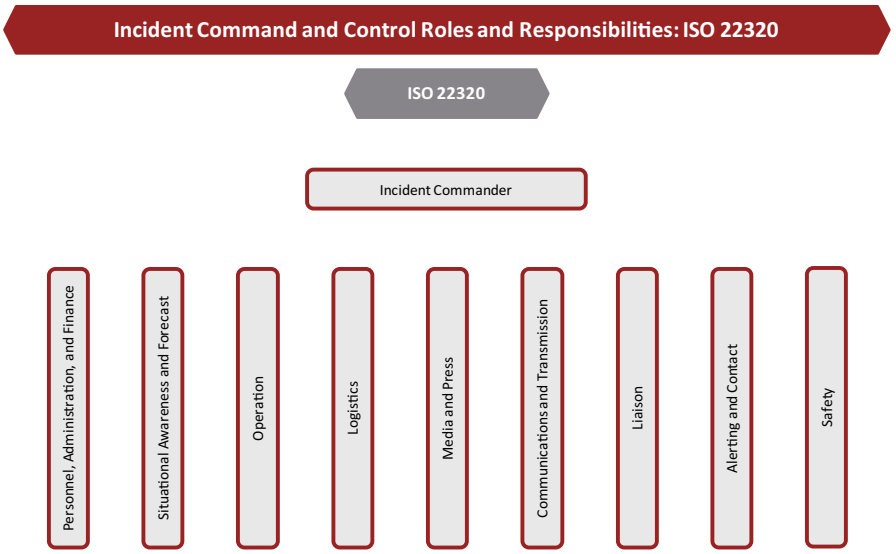

Fig. 5 The incident command and control roles and responsibilities recommended by the ISO 22320 standard (ISO 2011; University of Vienna 2015c)

forecast, (3) operation, (4) logistics, (5) media and press, (6) communication and transmission, (7) liaison, (8) alerting and contact, as well as (9) safety.

For a summary table of the incident command tasks and responsibilities according to ISO 22320, we refer the reader to University of Vienna (2015c) and briefly describe two examples below: (1) head of operations and (2) head of logistics.

In contrast to the incident commander, the head of operations is the final authority regarding operational decisions (ISO 2011, 2015a; Bundesamt für Bevölkerungsschutz und Katastrophenhilfe 1999). The head of operations implements decisions that are taken by the incident commander. This emergency responder bears the overall responsibility for managing and supporting an incident at the operational level. The main tasks comprise planning the operation, making decisions on the operational level (such as life-saving decisions for population at risk); monitoring and recording the operation; and implementing decisions that are made on the strategic level.

The head of logistics is in charge of the provision of resources but is also responsible for evaluating and planning required resources and carrying out the use of resources (ISO 2011, 2015a; Bundesamt für Bevölkerungsschutz und Katastrophenhilfe 1999). The main objective of this emergency responder is to provide adequate resources in the right spot at the right time.

The incident command and control level needs to escalate according to the geographical scope of the incident. The larger the incident is, the more incident command and control levels are needed:

- For smaller incidents, a pure on-site incident command and control level might be sufficient (Austrian National Crisis and Disaster Protection Management 2007).

- If an incident consists of two or more incident sites, a local incident command and control level will be needed for coordination among the incident sites.
- If two or more areas/districts are impacted by an incident, a regional incident command and control level will have to be established.
- In case of two or more regions being hit, a national incident command and control level will be required.

The previous examples demonstrate the variance and complexities in command and control structures while also illustrating the need for flexibility when designing systems that support decision makers during disasters.

Each incident command and control level has to communicate and interact with the existing incident command and control level(s) below and/or above (Irish National Steering Group 2006). For example, means of communication/interaction include: (1) personal contacts, (2) telephones, (3) radio communication, and (4) standardized information technology (IT) systems (including DSS). Furthermore, each incident command and control level has to cope with informing media, press, and the public on their own but in a coordinated way.

4.3 Main international emergency responders

For a major emergency incident, the national incident command and control levels of each country affected will have to be coordinated together with international emergency responders for further support. We have identified main groups of international emergency responders (cf. Fig. 6) based on international literature (African Union 2002; Coppola 2011; Federal Emergency Management Agency, FEMA 2015; Global Corps 2015; Thomas and Fritz 2006).

We categorize main international emergency responders into two groups (cf. University of Vienna 2015a): (1) governmental and (2) non-governmental organizations (NGOs). The United Nations has a global mandate for disaster assistance and acts in all four main phases of a disaster. The following five governmental organizations mainly focus on providing regional assistance. They might be active in other countries as well, if there is an assistance call from the respective country (Coppola 2011, pp. 549).

With regards to disaster management, NGOs may be defined as "non-profit, civilian-based, staffed organizations that depend on outside sources of funding and materials (including funding from governments) to carry out a humanitarian-based mission and associated goals in a target population" (Coppola 2011, p. 484). There are countless organizations involved in every phase of the disaster management process. We illustrate most important NGOs which are active in the impact response phase.

International emergency responders, are only incorporated on a general strategic level in the skills taxonomy of the S-HELP DSS as two groups (cf. Sect. 5): (1) international organizations and (2) the European Union. We separately focus on the role of the European Union in emergency response because they provide special EU Civil Protection Modules as explained in the next section.

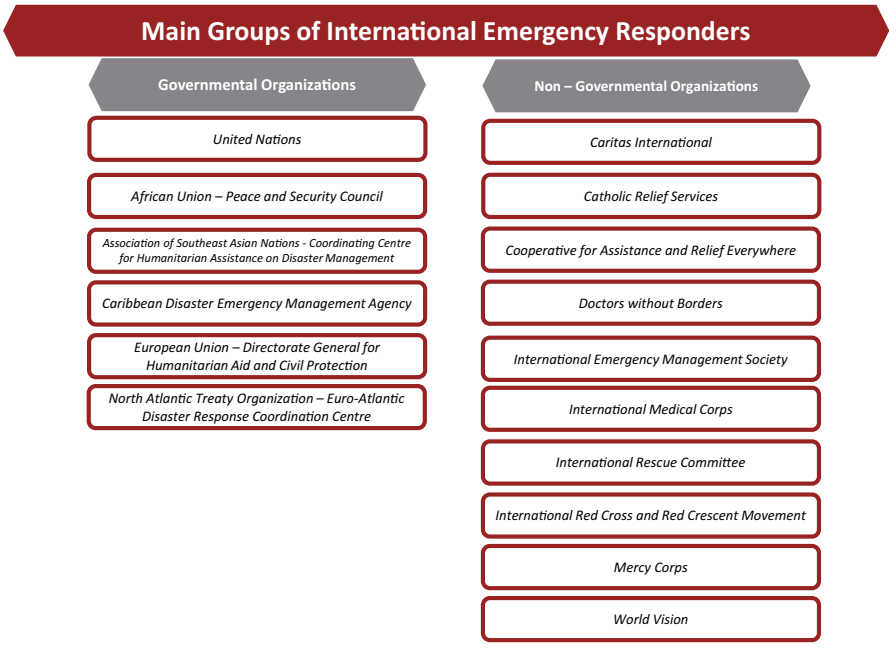

Fig. 6 Main groups of international emergency responders (University of Vienna 2015a)

4.4 The role of the European Union as an international emergency responder

In case of a severe crisis, a Member State (MS) of the European Union might not be able to handle a crisis without external help (European Commission 2010b, 2014b; European Parliament and the Council 2013). Figure 7 (cf. University of Vienna 2015a) shows that for a most severe crisis with a wide-ranging impact or political significance, a coordinated EU response is required on a political level. To support, complement, and facilitate the coordination of member states' actions in the field of civil protection, the EU has set up a civil protection mechanism (European Parliament and the Council 2013). The protection should cover people, environment, property, and critical infrastructure against all kinds of natural and man-made disasters occurring inside or outside the EU. Member States should immediately convey information on any breaking emergency or crisis to the Emergency Response Coordination Centre (ERCC).

The EU civil protection mechanism supports the mobilization and coordination of assistance interventions. It is based on the following structure (European Parliament and the Council 2013):

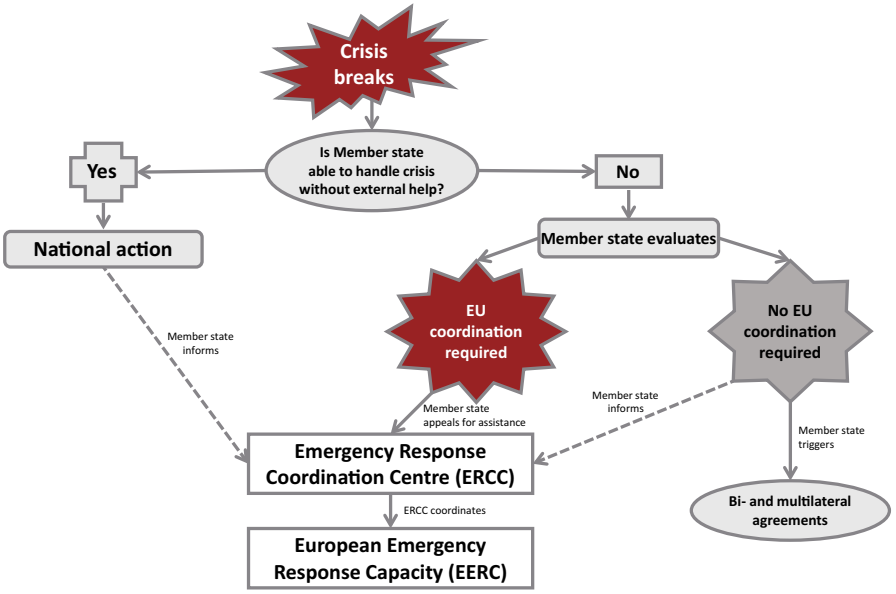

Fig. 7 EU Emergency and crisis coordination arrangements modified based on the European Commission (2010b, p. 6), European Parliament and the Council (2013), and European Commission (2014b)

- an Emergency Response Coordination Centre (ERCC),
- an European Emergency Response Capacity (EERC) in the form of a voluntary pool of pre-committed capacities from the member states ("EU Civil Protection Modules"),
- trained experts (e.g., technical experts, assessment experts, co-ordination experts, team leaders),
- a Common Emergency Communication and Information System (CECIS), and
- contact points in the EU member states.

EU Civil Protection Modules contain human and material resources of one or more Member States and are able to perform pre-defined tasks in the areas of response (European Parliament and the Council 2013). They can be dispatched at very short notice following a request for assistance through the ERCC and work self-sufficiently and autonomously for a given period of time. This is why, the skills taxonomy of the S-HELP DSS provides emergency management policy makers with an overview of which key emergency interventions/tasks that can be covered by EU disaster response tools (cf. Sect. 5). As a first step, emergency management policy makers need strategic information on the general availability, start of operation possibility, self-sufficiency, and operation time of the EU Civil Protection Modules which is presented below.

Table 1 (cf. University of Vienna 2015a) gives an overview on the different types of available EU Civil Protection Modules (Austrian Federal Ministry of the Interior 2014; European Commission 2010a). Some of them support nearly all disaster types and are titled "General Modules", while others focus on specific disaster types and are titled "Scenario-Specific Modules" for earthquakes, floods, and forest fires. The numbers in brackets indicate the quantity of specific EU Civil Protection Modules.

Table 1 EU Civil Protection Modules: overview and general availability (University of Vienna 2015a)

Module Name	Abbreviation	General Modules		Scenario-Specific Modules			
		Technical	Medical	Chemical, Biological, Radiological, and Nuclear	Earthquake	Flood	Forest Fire
Advanced medical post	AMP		x [11]				
Advanced medical post with surgery	AMPS		x [4]				
Aerial forest firefighting module using airplanes	FFFP						x [3]
Aerial forest firefighting module using helicopters	FFFH						x [0]
Chemical, biological, radiological, and nuclear detection and sampling	CBRNDET			x [18]			
Emergency temporary shelter	ETS	x [2]					
Field hospital	FHOS		x [2]				
Flood containment	FC					x [3]	
Flood rescue using boats	FRB					x [5]	
Ground forest firefighting	GFFF						x [8]
Ground forest firefighting using vehicles	GFFF-V						x [21]
Heavy urban search and rescue	HUSAR				x [11]		
High capacity pumping	HCP					x [24]	
Medical aerial evacuation of disaster victims	MEVAC		x [4]				
Medium urban search and rescue	MUSAR				x [31]		
Search and rescue in chemical, biological, radiological, and nuclear conditions	CBRNUSAR			x [6]			
Technical assistance and support team	TAST	x [10]					
Water purification	WP	x [5]					

x [number of registered modules]

Table 2 EU Civil Protection Modules: time-related availabilities (University of Vienna 2015a)

Module Name	Abbreviation	Departure to Country Affected (hours)	Start of Operation in Country Affected (hours)	Self-Sufficiency (days)	Operation Time (days)
Advanced medical post	AMP	12	1	4	-
Advanced medical post with surgery	AMPS	12	1	4	-
Aerial forest firefighting module using airplanes	FFFP	3	-	-	-
Aerial forest firefighting module using helicopters	FFFH	3	-	-	-
Chemical, biological, radiological, and nuclear detection and sampling	CBRNDET	12	-	4	-
Emergency temporary shelter	ETS	12	-	4	42
Field hospital	FHOS	168	12	4	15
Flood containment	FC	12	-	4	10
Flood rescue using boats	FRB	12	-	4	10
Ground forest firefighting	GFFF	6	-	4	7
Ground forest firefighting using vehicles	GFFF-V	6	-	4	7
Heavy urban search and rescue	HUSAR	-	48	4	10
High capacity pumping	HCP	12	-	4	21
Medical aerial evacuation of disaster victims	MEVAC	12	-	-	-
Medium urban search and rescue	MUSAR	-	32	4	7
Search and rescue in chemical, biological, radiological, and nuclear conditions	CBRNUSAR	12	-	4	-
Technical assistance and support team	TAST	12	-	4	-
Water purification	WP	12	-	4	84

For example, eleven units of the EU Civil Protection Module "Advanced Medical Post (AMP)" are currently registered at the EERC.

For a mass flooding emergency policy scenario, the EU Civil Protection Modules titled "Flood Containment (FC)" (three modules available), "Flood Rescue Using Boats (FRB)" (five modules available), and "High Capacity Pumping (HCP)" (24 modules available) could appropriately assist (European Commission 2014a). For a chemical spill emergency scenario, both "Chemical, Biological, Radiological, and Nuclear Detection and Sampling (CBRN)" (18 modules available) and "Search and Rescue in Chemical, Biological, Radiological, and Nuclear Conditions (CBR-NUSAR)" (six modules available) are relevant.

In case of a major disaster, the country affected should request assistance from ERCC as fast as possible. Nearly all EU Civil Protection Modules are ready for departure within a maximum of 12 h and can therefore be deployed at the disaster site very quickly (European Commission 2014a). Table 2 (cf. University of Vienna 2015a) shows crucial time-related availabilities of the EU Civil Protection Modules for policy making provided by the S-HELP DSS including:

- the maximum time until the departure to country affected,
- the maximum time until the start of operation in the country affected,
- the number of days for which the module is fully self-sufficient (self-sufficiency), and,
- the number of days which the module can operate at the disaster site (operation time).

For example, the EU Civil Protection Modules titled "Flood Containment (FC)" and "Flood Rescue Using Boats (FRB)" are ready to depart within 12 h, can work for 4 days completely self-sufficient, and can operate for 10 days (European Commission 2014a). These modules can be demanded for a flooding emergency policy scenario. For a chemical spill emergency policy scenario, both of the two modules for chemical, biological, radiological, and nuclear incidents are ready for departure within 12 h and have a self-sufficiency of 4 days.

The general information for emergency management policy makers of Figs. 8 and 9 (cf. Sect. 5.5) on the EU Civil Protection Modules are incorporated by the S-HELP DSS. In the next section, we illustrate how the skills taxonomy interlinks key emergency interventions and main emergency responders supported by EU Civil Protection Modules.

5 Skills taxonomy of main emergency responders needed for key emergency interventions

For each of the eleven emergency interventions (cf. Sect. 4.1), we have developed an overview table that shows all national emergency responders (cf. Sect. 4.2) supported by main international emergency responders who are international organizations and the EU (cf. Sect. 4.3) that are relevant to perform specific emergency tasks under consideration of the EU Civil Protection Modules (cf. Sect. 4.4). To illustrate this skills taxonomy of the S-HELP DSS, we present key tasks of main emergency responders involved in two selected emergency interventions: (1) general emergency management

(Sect. 5.1) as well as (2) search and rescue (Sect. 5.2). Please note that for certain emergency interventions, we have added supportive emergency responders in addition to the classification scheme of Sects. 4.2 and 4.3 because they might be provided by several other emergency responders.

The skill taxonomy enhances the semantic and organizational interoperability among emergency management (Interoperable Delivery of European eGovernment Services to Public Administrations, Businesses, and Citizens, IDABC 2004). They can better understand the exchanged information (semantic interoperability) and goals and processes can be standardized (organizational interoperability). To further enhance semantic interoperability, we developed a strategic disaster management wiki for the S-HELP DSS to provide emergency management policy makers with a list of controlled vocabulary and a general structure for the main areas of strategic disaster management (cf. University of Vienna 2014; Rauner et al. 2016). For example, Allen et al. (2014) elaborates how essential information sharing is for interoperability in the case of major incident management.

In each of the eleven overview tables of the skills taxonomy, the general national emergency responders required, who are supported by international organizations and the EU, are listed in the upper rows of each table. Next, incident command-related national emergency responders are specified. Finally, tactical/operational national emergency responders are enumerated. While strategic emergency responders are hierarchically listed, tactical/operational emergency responders are displayed in alphabetical order.

In the lower rows, the EU Civil Protection Modules (European Commission 2014a) are specified and their coverage regarding specific emergency interventions/tasks is illustrated. In the columns of each overview table, specific emergency interventions/tasks depending on the eleven sub-section-related general emergency interventions are chronologically or alphabetically ordered. In addition, all rows and columns of a table are numbered. For example, the overview table for general emergency management (cf. Table 3) consists of 27 rows and 13 columns and one linkage to an EU Civil Protection Module. An "X" in a cell indicates that a specific emergency intervention/task is performed either by certain emergency responders (upper rows) or covered by certain EU Civil Protection Modules (lower rows).

In Sect. 5.3, we provide an overview map that summarizes which of the key emergency interventions are performed by whom of the main emergency responders (alphabetically listed), while another overview map summarizes which key emergency interventions are supported by the EU Civil Protection Modules (Sect. 5.4). Section 5.5 explains how the skills taxonomy is incorporated into the S-HELP DSS Toolset regarding the Decision Making Module to enhance the technical interoperability of EM policy makers.

5.1 General emergency management

General emergency management is the subordinated strategic level of the entire emergency management cycle (ISO 2011). The main objective is to ensure adequate impact response, recovery, and preparedness. Emergency responders of general emergency

Table 3 General emergency management: interaction between key emergency interventions/tasks and main emergency responders (including EU Civil Protection Modules) (University of Vienna 2015a, 2016)

General Emergency Management *Interaction between Emergency Interventions/Tasks and Emergency Responders/Skills (including EU-CP Modules)*			Emergency Interventions/Tasks$_j$											
			Preparedness			Response							Response Recovery	Recovery
			1	2	3	4	5	6	7	8	9	10	11	12	13
			Developing an Emergency Plan	Modelling and Testing of Scenarios	Providing Training and Exercise	Gathering and Evaluating Available Information	Assessing the Situation and Delivering Forecasts	Defining Objectives, Procedures, and Standards	Sharing Useful Information and Defined Procedures Internally	Coordinating Agencies	Directing Personnel and Assigning Equipment/ Materials	Implementing Decisions	Cooperating With Media and Coordinating Public Relations	Monitoring and Evaluating the Management Process	Restoring Conditions, Services, and Activities of a Community
Emergency Responders/Skills$_i$	1	Government	x	x	x	x	x	x	x	x	x	x	x	x	x
	2	International Organizations	x	x	x	x	x	x	x	x	x	x	x	x	x
	3	European Union	x	x	x	x	x	x	x	x	x	x	x	x	x
	4	Incident Commander	x	x	x	x	x	x	x	x	x	x	x	x	x
	5	Head of Communications	x	x	x	x		x	x	x	x				
	6	Head of Liaison	x	x	x	x		x		x					
	7	Head of Logistics	x	x	x	x		x	x		x	x	x		
	8	Head of Media and Press	x	x	x	x		x					x		
	9	Head of Operations	x	x	x	x		x	x			x		x	x
	10	Head of Personnel, Administration, and Finance	x	x	x	x		x			x				
	11	Head of Public Information	x	x	x	x		x					x		
	12	Head of Safety	x	x	x	x		x			x				
	13	Head of Situational Awareness and Forecast	x	x		x	x	x							
	14	Communities	x	x	x										x
	15	Emergency Medical Services	x	x	x										x
	16	Energy Providers	x	x	x										x
	17	Environmental Agencies	x	x	x										x
	18	Fire Brigade	x	x	x										x
	19	Food and Beverage Providers	x	x	x										x
	20	Health Care Organizations	x	x	x										x
	21	Humanitarian Organizations	x	x	x										
	22	Information and Communication Services	x	x	x										x
	23	Media	x	x	x										x
	24	Military	x	x	x	x	x	x	x	x	x	x	x	x	x
	25	Other Emergency Services	x	x	x										x
	26	Police	x	x	x										x
	27	Search and Rescue Teams	x	x	x										x
	28	Strategic Health Authorities	x	x	x										x
	29	Transportation Services	x	x	x										x
	30	Waste Disposal Services	x	x	x										x
	31	Water and Sewerage Undertakers	x	x	x										x
EU-CP Modules		Technical Assistance and Support Teams				x			x						

management have the capability to capture and process data in order to provide timely, relevant, and accurate information for guidance and decision making. This acquired information together with command and control, coordination, and cooperation establishes the framework for general emergency management.

Table 3 (University of Vienna 2015a, 2016) displays main strategic emergency responders and their corresponding key emergency interventions/tasks which are involved in general emergency management based on literature and guidelines (Alexander 2012; European Commission 2014a; ISO 2011, 2015b). General emergency management is applied in every stage of the emergency cycle and plays a crucial role for planning actions and for preventing a disaster and/or mitigate its aftermaths. The national government, international organizations, the EU, and the incident commander are responsible for all relevant emergency interventions/tasks in general emergency management due to their authority and competence. For the preparedness phase in general emergency management, emergency interventions/tasks such as developing an emergency plan, modelling/testing of scenarios, as well as providing training and exercise are vital precautionary measures. Providing training and exercise is mainly coordinated by the head of logistics; the head of personnel, administration, and finance; as well as the head of safety.

For the response phase, the head of situational awareness is responsible for assessing the situation and delivering forecasts under consideration of the severity and risk of a disaster. The head of communications, the head of logistics, and the head of operations have to ensure that useful information and procedures defined are internally shared. In addition, agencies involved have to be coordinated by the head of communication and the head of liaison in order that they operate efficiently. It is also important to direct personnel and to assign equipment/materials where they are needed the most. Moreover, the safety of personnel and the proper functionality of the equipment/materials used have to be considered. For these emergency interventions/tasks the head of communications; the head of logistics; the head of personnel, administration, and finance; and the head of safety are jointly responsible.

During an emergency situation, rumours circulating about the incident can quickly cause panic among civilians. Therefore, it is of highest importance to control the impact of shared information to the public. Consequently, the head of public information acts as a spokesperson and has the duty to closely collaborate with media and coordinate public relations to secure that only useful and proper information is externally shared. In the S-HELP DSS, these risk communication mechanisms are incorporated too.

Finally, the recovery phase consists of two vital emergency interventions/tasks which include monitoring and evaluating the management process as well as restoring conditions, services, and activities of a community. These emergency interventions/tasks are in the area of responsibility of the head of operations from a tactical/operational point of view.

Referring to EU Civil Protection Modules (European Commission 2014a), the module titled “Technical Assistance and Support” covers both strategic and tactical/operational emergency interventions/tasks for general emergency management.

5.2 Search and rescue

In the response phase of a disaster, the intervention "search and rescue" of injured humans and animals is a most critical intervention for emergency management policy makers. There are different types of search and rescue measures depending on location, namely urban, rural, underground, and marine (Alexander 2012). The search and rescue process further differentiates among aerial, ground-based, and underground. While aerial surveys are conducted by emergency aircrafts, marine search is performed by either emergency watercraft or aircraft. Aerial surveys are preferred for rapid identification of large objects, although this task is limited to daylight and good weather conditions.

Table 4 (University of Vienna 2015a, 2016) gives an overview of various chronologically listed key emergency interventions/tasks of the search and rescue process based on literature and guidelines (Alexander 2012; European Commission 2014a; ISO 2015a). First of all, the entire search and rescue process has to be coordinated. In addition, the danger zone has to be secured because the relief units need non-hazardous access. To ensure coordinated workflow, the traffic must be controlled too (e.g., road blockages, instructions for incoming relief units). Then, a systematic search can be conducted which leads to the rescue process. Subsequently, patients have to be quickly triaged to guarantee adequate physical and mental treatment. The incident commander is responsible for the coordination of the entire search and rescue process. Fire brigade, military, police, and veterinarians are needed for securing the dangerous area. Veterinarians are necessary in case of (dangerous) animals run free and even animals that are not normally dangerous might become hazardous in the case of panic. Only authorized responders are allowed to control the traffic (fire brigade, military, and police). Most emergency responders including dog teams are involved in systematic search, while volunteers can support ground-based surveys. For rescue, authorized emergency responders are needed because special equipment is used (e.g., vehicles, machines, tools). The emergency management services triage victims and treat patients physically, while crisis intervention teams and psychologists focus on the mental treatment of patients. The identification commission for identifying deceased and the police are exclusively authorized to identify deceased victims.

Regarding the EU Civil Protection Modules (European Commission 2014a), there are three modules specialized in search and rescue: (1) "Heavy Urban Search and Rescue", (2) "Medium Urban Search and Rescue", and (3) "Search and Rescue in Chemical, Biological, Radiological, and Nuclear Conditions". Furthermore, the module titled "Flood Rescue Using Boats" is crucial for search and rescue related to an emergency policy flooding scenario. The modules titled "Advanced Medical Post (With Surgery)" and "Field Hospital" conduct pre-hospital treatment which is essential for nearly all emergency scenarios. The general module titled "Technical Assistance and Support Team" is responsible for coordination.

Table 4 Search and rescue: interaction between key emergency interventions/tasks and main emergency responders (including EU Civil Protection Modules) (University of Vienna 2015a, 2016)

Search and Rescue *Interaction between Emergency Interventions/Tasks and Emergency Responders/Skills (including EU-CP Modules)*			Emergency Interventions/Tasks *j*								
			Response								
			1	2	3	4	5	6	7	8	9
			Coordinating Search and Rescue	Securing the Danger Zone	Traffic Control	Systematic Search	Rescue	Triaging Patients	Physical Prehospital Treatment	Mental Prehospital Treatment	Identifying Deceased
Emergency Responders/Skills *j*	1	Government	x								
	2	International Organizations	x								
	3	European Union	x								
	4	Incident Commander	x								
	5	Head of Communications	x								
	6	Head of Liaison	x								
	7	Head of Logistics	x	x	x	x	x	x	x	x	x
	8	Head of Media and Press									x
	9	Head of Operations	x	x	x	x	x	x	x	x	x
	10	Head of Personnel, Administration, and Finance	x								
	11	Head of Public Information									x
	12	Head of Situational Awareness and Forecast		x	x	x	x	x			
	13	Head of Safety		x	x	x	x	x	x	x	x
	14	*Crisis Intervention Teams*								x	
	15	*Dog Teams*				x					
	16	Emergency Medical Services				x	x	x	x	x	
	17	Fire Brigade		x	x	x	x				
	18	*Identification Commission for Identifying Deceased*									x
	19	Military		x	x	x	x	x	x	x	
	20	Police		x	x	x					x
	21	*Psychologists*								x	
	22	Search and Rescue Teams				x	x	x			
	23	*Veterinarians*		x			x				
	24	Volunteers				x					
EU CP-Modules		Advanced Medical Post						x	x	x	
		Advanced Medical Post With Surgery						x	x	x	
		Field Hospital						x	x	x	
		Flood Rescue Using Boats				x	x				
		Heavy Urban Search and Rescue				x	x				
		Medium Urban Search and Rescue				x	x				
		Search and Rescue in Chemical, Biological, Radiological, and Nuclear Conditions				x	x				

5.3 Overview map on emergency responders and emergency interventions

Tables 5 and 6 (University of Vienna 2015a, 2016) summarize the interaction between key emergency interventions and main national emergency responders (alphabetically listed), who are supported by international organizations and the EU. These overview maps are implemented in the S-HELP DSS. For example, government, international organizations, and EU mainly perform strategic tasks such as emergency interventions related to general management, while national emergency responders, who are directly engaged at the impact site, are responsible for operational tasks (e.g., emergency medical services and volunteers). The incident commanding team

Table 5 Overview map (part 1): interaction between key emergency interventions and main emergency responders (University of Vienna 2015a, 2016)

Interaction between Emergency Interventions and Key Emergency Responders/Skills PART I	Emergency Interventions					
	Preparedness / Response / Recovery				Response	
	General Emergency Management	Emergency Communication	Forewarning	Evacuation Management	Impact Response	Search and Rescue
Additional Transportation Personnel						
Civil Engineers						
Cleaners				x		
Communities	x			x		
Construction Workers						
Crisis Intervention Teams				x		x
Dog Teams						x
Donors				x		
Electrical Engineers						
Emergency Medical Services	x			x		x
Energy Providers	x					
Environmental Agencies	x		x	x	x	
European Union	x	x	x	x	x	x
Field Team Leaders On-Site						
Fire Brigade	x			x	x	x
Food/Water Inspector				x		
Food and Beverage Providers	x			x		
Geotechnical Engineers						
Government	x	x	x	x	x	x
Head of Communications	x	x	x	x	x	x
Head of Liaison	x	x	x	x	x	x
Head of Logistics	x	x	x	x	x	x
Head of Media and Press	x		x	x	x	x
Head of Operations	x	x		x	x	x
Head of Personnel, Administration, and Finance	x	x	x	x	x	x
Head of Public Information	x		x	x	x	x
Head of Safety	x	x	x	x	x	x
Head of Situational Awareness and Forecast	x	x	x	x	x	x
Health Care Organizations	x			x		
Heavy Plant Operators						
Humanitarian Organizations	x			x		
Hydraulic Engineers						
Identification Commission for Identifying Deceased						x
Incident Commander	x	x	x	x	x	x
Information and Communication Services	x	x				
International Organizations	x	x	x	x	x	x
Interpreters						
Kitchen Personnel				x		
Media	x		x	x		
Military	x	x	x	x	x	x
Other Emergency Services	x				x	
Police	x		x	x	x	x
Psychologists						x
Sanitary Engineers						
Search and Rescue Teams	x					x
*Standard Development Organizations**		x				
Storekeepers				x		
Strategic Health Authorities	x			x		
Structural Engineers						
Surveyors						
Traffic Controllers						
Transportation Services	x					
Veterinarians						x
Volunteers				x		x
Waste Disposal Services	x			x		
Water and Sewerage Undertakers	x			x		

Key Emergency Responders/Skills

Table 6 Overview map (part 2): interaction between key emergency interventions and main emergency responders (University of Vienna 2015a, 2016)

Interaction between Emergency Interventions and Key Emergency Responders/Skills PART II		Emergency Interventions				
		Response				
		Recovery				
		Emergency Transportation	Emergency Engineering	Emergency Shelter	Emergency Food Program	Care of Vulnerable and Secure Groups
Key Emergency Responders/Skills	*Additional Transportation Personnel*	x				
	Civil Engineers		x			
	Cleaners				x	
	Communities			x	x	x
	Construction Workers		x			
	Crisis Intervention Teams			x		
	Dog Teams					
	Donors				x	
	Electrical Engineers		x			
	Emergency Medical Services	x		x		x
	Energy Providers					
	Environmental Agencies					
	European Union	x	x	x	x	x
	Field Team Leaders On-Site	x				
	Fire Brigade	x		x		
	Food/Water Inspector				x	
	Food and Beverage Providers				x	
	Geotechnical Engineers		x			
	Government	x	x	x	x	x
	Head of Communications	x	x	x	x	x
	Head of Liaison	x	x	x	x	x
	Head of Logistics	x	x	x	x	x
	Head of Media and Press		x		x	x
	Head of Operations		x			
	Head of Personnel, Administration, and Finance	x	x	x	x	x
	Head of Public Information		x		x	x
	Head of Safety	x	x	x	x	x
	Head of Situational Awareness and Forecast	x	x	x	x	x
	Health Care Organizations			x		x
	Heavy Plant Operators		x			
	Humanitarian Organizations			x	x	x
	Hydraulic Engineers		x			
	Identification Commission for Identifying Deceased					
	Incident Commander	x	x	x	x	x
	Information and Communication Services					
	International Organizations	x	x	x	x	x
	Interpreters					x
	Kitchen Personnel				x	
	Media					
	Military	x	x	x	x	x
	Other Emergency Services		x	x		
	Police	x				x
	Psychologists					
	Sanitary Engineers		x			
	Search and Rescue Teams					
	*Standard Development Organizations**					
	Storekeepers				x	
	Strategic Health Authorities			x		x
	Structural Engineers		x			
	Surveyors		x			
	Traffic Controllers	x				
	Transportation Services	x				
	Veterinarians					
	Volunteers	x		x	x	x
	Waste Disposal Services	x		x	x	
	Water and Sewerage Undertakers			x	x	

needs strategic, tactical, and operational skills. The emergency intervention regarding care of vulnerable and secure groups is a most critical issue because if an evacuation is necessary, temporary accommodations for hospital patients or prisoners will be challenging due to the high number of people which will have to be displaced to other institutions with limited space.

5.4 Overview map on emergency interventions and EU Civil Protection Modules

EU Civil Protection Modules (cf. Sect. 4.3) play an important role in supporting emergency responders cope with a major disaster (European Commission 2014a). Table 7 (University of Vienna 2015a, c) displays which key emergency interventions are supported by EU Civil Protection Modules. For strategic planning it is important to know for which key emergency interventions EU Civil Protection Modules are available for assistance. For example, the general EU Civil Protection Module titled "Advanced Medical Post (AMP)" is needed for all disaster types in case that people are affected. This module can be requested for the emergency interventions titled "Evacuation Management", "Search and Rescue", "Emergency Shelter", and "Care of Vulnerable and Secure Groups". This overview map is provided by the S-HELP DSS to improve policy making.

For the flooding emergency scenario of S-HELP, the EU Civil Protection Modules "Flood Containment (FC)", "Flood Rescue Using Boats (FRB)", and "High Capacity Pumping (HCP)" support the following emergency interventions: (1) impact response, (2) search and rescue, as well as (3) emergency engineering (European Commission 2014a). In the case of a chemical spill emergency policy scenario, "Chemical, Biological, Radiological, and Nuclear Detection and Sampling (CBRN)" and "Search and Rescue in Chemical, Biological, Radiological, and Nuclear Conditions (CBR-NUSAR)" offer their help for the following emergency interventions: (1) forewarning, (2) impact response, as well as (3) search and rescue.

Table 7 Overview map: interaction between key emergency interventions/tasks and EU Civil Protection Modules (University of Vienna 2015a, 2016)

Interaction between Emergency Interventions and European Civil Protection Modules			Emergency Interventions										
			Preparedness / Response / Recovery				Response		Response / Recovery				
			General Emergency Management	Emergency Communication	Forewarning	Evacuation Management	Impact Response	Search and Rescue	Emergency Transportation	Emergency Engineering	Emergency Shelter	Emergency Food Program	Care of Vulnerable and Secure Groups
European Civil Protection Modules	Advanced Medical Post	AMP				x		x			x		x
	Advanced Medical Post with Surgery	AMPS				x		x			x		x
	Aerial Forest Firefighting Module using Airplanes	FFFP					x						
	Aerial Forest Firefighting Module using Helicopters	FFFH					x						
	Chemical, Biological, Radiological, and Nuclear Detection and Sampling	CBRNDET					x						
	Emergency Temporary Shelter/Camp	ETS									x		x
	Field Hospital	FHOS						x			x		x
	Flood Containment	FC					x			x			
	Flood Rescue using Boats	FRB						x					
	Ground Forest Firefighting	GFFF					x						
	Ground Forest Firefighting using Vehicles	GFFF-V					x						
	Heavy Urban Search and Rescue	HUSAR						x					
	High Capacity Pumping	HCP					x			x			
	Medical Aerial Evacuation of Disaster Victims	MEVAC				x			x				
	Medium Urban Search and Rescue	MUSAR						x					
	Search and Rescue in Chemical, Biological, Radiological, and Nuclear Conditions	CBRNUSAR						x					
	Technical Assistance and Support Teams	TAST	x	x					x				
	Water Purification	WP								x		x	

5.5 Digitalization and transformation of the emergency management taxonomies for incorporation into the S-HELP DSS Toolset

The skills taxonomy together with the resources taxonomy and the skills/disaster taxonomy (cf. Sect. 3) are incorporated in the Decision Support Module of the S-HELP DSS Toolset. The skills taxonomy is, as can be seen in the previous sections, designed and detailed using spreadsheets (MS Excel) for interlinking main national emergency responders needed for key emergency interventions. It contains all the relevant and valid data for the purpose of the S-HELP DSS Toolset. However, it does not lend itself easily to data re-combination, querying, or data mining needed for a DSS. In addition, spreadsheets provide a poor support for more than two dimensional relationships among data which complicates the intersection among more than two variables/categories.

Therefore, this limited matrix-based structure of the taxonomy was digitized and transformed from category cells and "X" cells into a data structure more suitable for the S-HELP DSS Toolset. As an example in Table 7, the EU Civil Protection Modules titled "Advanced Medical Post" and "Evacuation Management" are two categories or labels that intersect with an "X" providing content to a data structure.

The data structures found suitable for the S-HELP DSS Toolset were class models (for software code using the data structure) in Unified Modeling Language (UML), a conceptual data model (for a relational persistent data structure) also in UML, and a relational data model (University of Lund 2016). The relational data model was transformed into a physical data model which was implemented in an RDBMS (relational database management system) providing automation and querying facilities.

The data models and the data base for the S-HELP DSS digitize and support all the taxonomies in Fig. 2. Since the skills taxonomy is just one of the taxonomies incorporated, Figs. 8 and 9 show the complete data model digitizing all the taxonomies and red markings highlighting the data models that comprise the skills taxonomy discussed in this paper. We understand that the models in Figs. 8 and 9 are too small to see details, but they serve only to show that the digitized skills taxonomy is part of the complete database and not an independent component.

In a first step, the taxonomies were transformed into a data structure that was capable of holding the content of the taxonomies. This step could not be automated but relied on skill, design thinking, and imagination to capture everything important in a new form. As a simplified notion of the concept of imagination discussed by Scruton (1979) and Asplund (1970) this meant to *see* the spread sheets *as a* conceptual data model which highlights certain important aspects and neglects other non-important in the context.

This is not a linear engineering process in which a method or a set of design rules will "guarantee" a certain and wanted outcome. Instead, it is a design process where the designer learns about the design "problem" when solving it (e.g., Lawson 2006; Schön 1983) in a circular or spiral fashion. In addition, the taxonomies themselves were also design work products that were changed and updated through the development of the S–HELP DSS. This fact required rethinking and redesign of the data structure and content several times (University of Lund 2016).

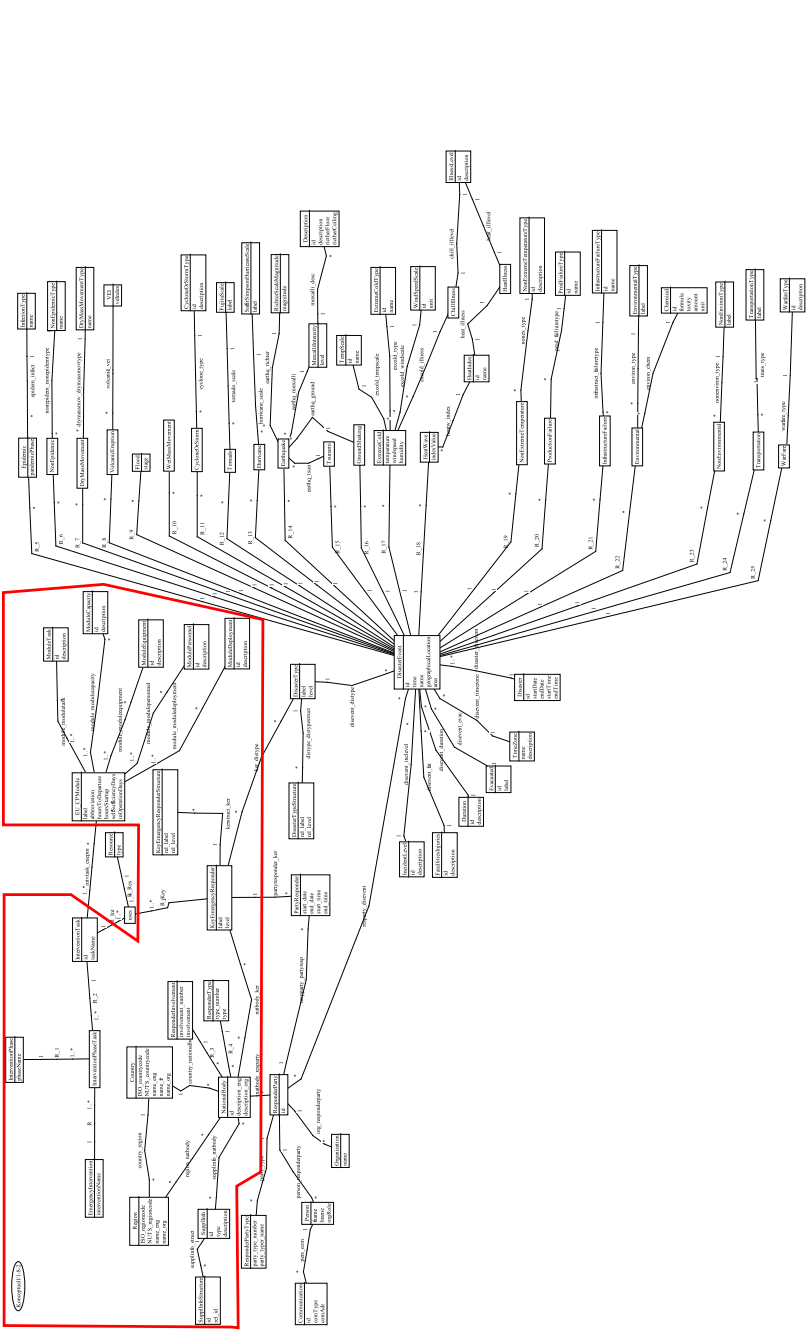

Fig. 8 The skills taxonomy (inside the red marking) as part of the complete conceptual model for the S-HELP DSS (CIM level, ZEFA row 2, column 1), version 14 (University of Lund 2016) (color figure online)

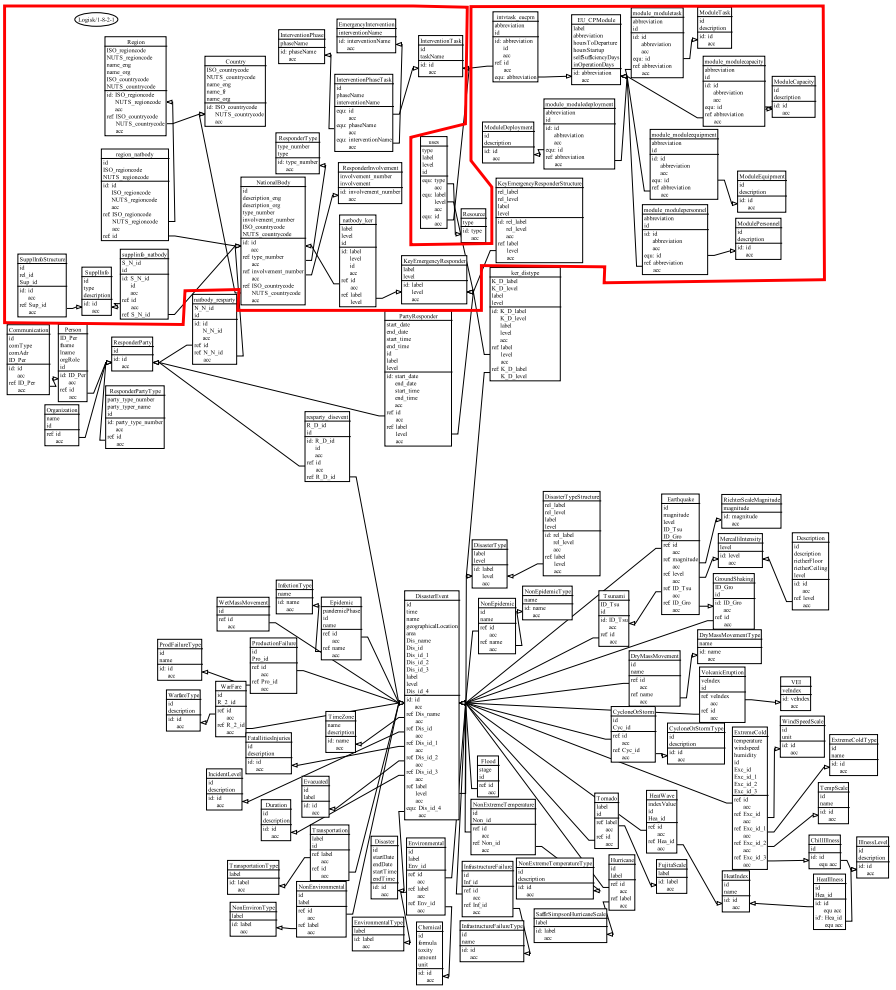

Fig. 9 The skills taxonomy (inside the red marking) as part of the complete logical data model for the S-HELP DSS (PIM level, ZEFA row 3, column 1), version 20 (University of Lund 2016) (color figure online)

The data structure consists of a conceptual, a logical, and a physical model from an OMG (Object Management Group) MDA (Model Driven Architecture)[1] perspective using a Computation Independent Model (CIM), a Platform Independent Model (PIM), and a Platform-Specific Model (PSM), respectively. In the Zachman Framework for Enterprise Architecture (ZEFA) (cf. Finkelstein 2015; Zachman 1999), these models for data reside in the inventory column. Due to the underlying relational model, transformation between CIM and PIM as well as between PIM and PSM are possible by using rule-based algorithms (i.e. to a large extent automatic).

[1] http://www.omg.org/mda/.

The list of inventory types in ZEFA row 1, column 1 found in the spreadsheets of the skills taxonomy was manually transformed into a conceptual enterprise data model (CIM as illustrated in Fig. 10) by University of Lund (2016) using imagination, skill, and a design tool called DB Main.[2]

In Fig. 10 the skills taxonomy part of Fig. 8 (inside the marking in Fig. 8 – irrelevant entities have been omitted from Fig. 10) is detailed. The generic key emergency responders are connected to national, country-specific key emergency responders that could be linked to certain regions of the national responder country. As can be seen in the figure country and region are uniquely identified through the official ISO 3166-1 country code list, the ISO 3166-2 region code list, and the Eurostat NUTS (Nomenclature of territorial units for statistics) 2013 classification. These code lists cover together all the countries and regions relevant in the S-HELP DSS and skills taxonomy. In Fig. 10, the EU Civil Protection (CP) modules (EU_CPModule) are also implemented and detailed with their respective Task, Capacity, Equipment, Personnel, and Deployment characteristics as associated types.

Next, the design tool DB Main 10.0.3 was used by University of Lund (2016) to transform the CIM level, ZEFA row 2, column 1 model into a relational data model PIM level, ZEFA row 3, column 1 (see Fig. 11 which details the model part inside the red marking in Fig. 9 with irrelevant relations omitted). Figure 11 illustrates the relational model of the conceptual model in Fig. 10 of key emergency responders which might be country-specific and EU CP modules. Even though the transformation is rule-based, some tweaking of details was needed to correctly capture inherent hierarchical relationships in the taxonomy spreadsheets in an effective way. Thus, University of Lund (2016) de-normalized a few relationships in the logical data model (cf. e.g. Elmasri and Navathe (2011) or Finkelstein (2015) on data normalization).

Finally, the design tool DB Main was used to transform the logical model (PIM level) into a physical model of the database in the form of an SQL script. This script was then used to implement the physical model in the MySql RDBMS and create the database with its tables, columns, indices, etc. (PSM level, ZEFA row 4 and 5, column 1). Hence, the structure of the database for the S-HELP DSS Toolset based on the taxonomies was created. In total, 14 versions of the conceptual model and 20 versions of the logical model were designed (University of Lund 2016).

The second step was to compile all the "X" in the spreadsheets and turn them into data to populate the data structure and to digitize the taxonomies. This transformation work could be only partly automated and mostly required manual work and a number of intermediary steps using spreadsheets. For further information, we refer the reader to University of Lund (2016).

After finishing all the above conversion steps, all spreadsheets were compiled and stored individually as.csv files (Comma–Separated Value files). In total, 33,513 rows of data were produced from the taxonomies. Using several bespoke java programs built using NetBeans 8.1, these rows were transformed into SQL scripts with insert statements. These SQL scripts were run in MySql Workbench 6.3 to populate the tables. For additional information, we refer the reader to University of Lund (2016).

[2] http://www.rever.eu/en/db-main.

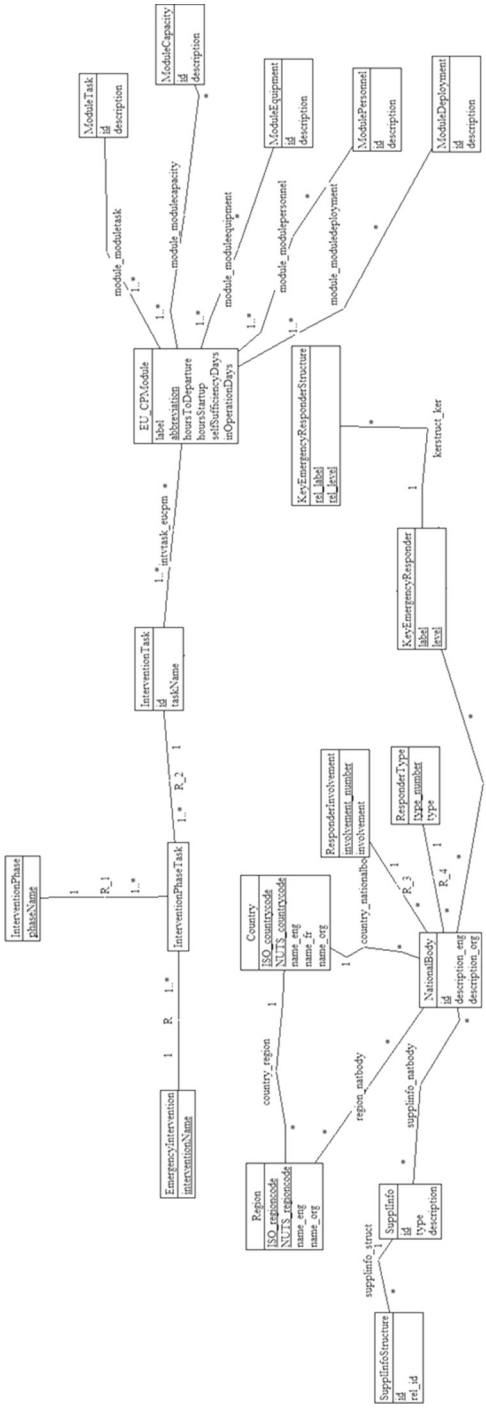

Fig. 10 Enlargement of the content in the red marking in Fig. 8—the skills taxonomy part of the conceptual data model (CIM level, ZEFA row 2, column 1), version 14 (University of Lund 2016). Irrelevant entities have been omitted from the figure

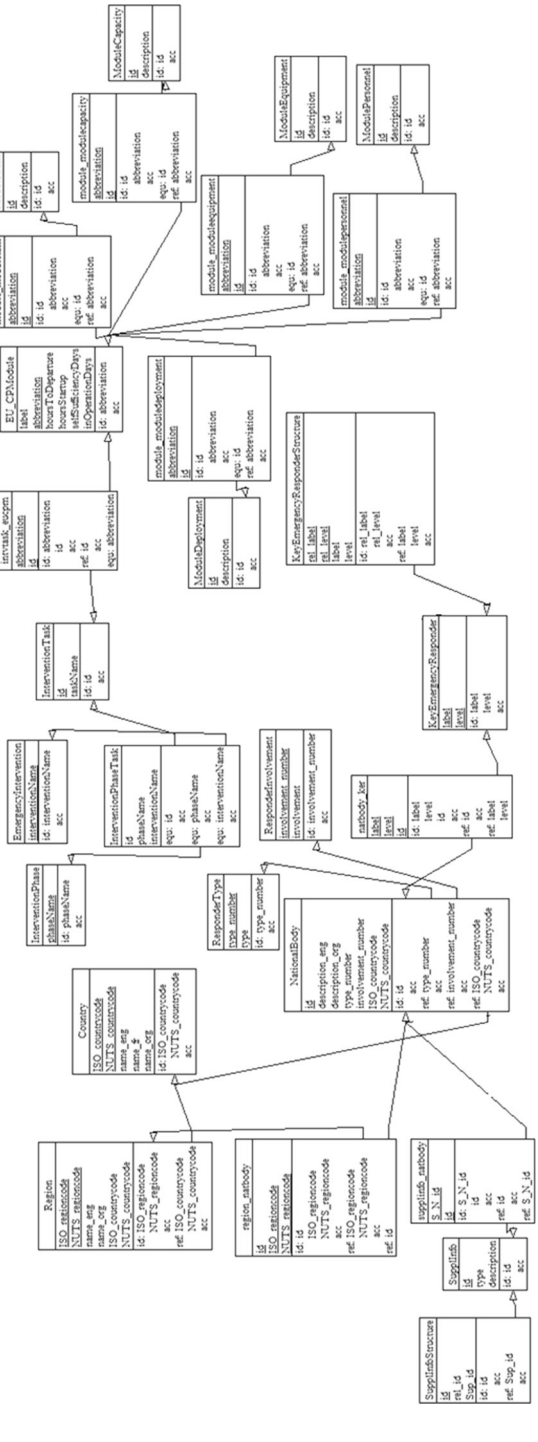

Fig. 11 Enlargement of the content in the red marking in Fig. 9—the skills taxonomy part of the relational data model (PIM level, ZEFA row 3, column 1), version 20 (University of Lund 2016). Irrelevant relations have been omitted from the figure

```
SELECT
    `ker_data`.`KER Label`,
    `ker_data`.`National Body Eng.`,
    `ker_data`.`National Body Org.`,
    `ker_data`.`Region Eng.`,
    `ker_data`.`Region Org.`,
    `ker_data`.`NUTS Region Code` AS 'NUTS r. code',
    `ker_data`.`ISO Region Code` AS 'ISO r. code'
FROM
    `shelp_v8`.`ker_data`
WHERE
    `ker_data`.`NUTS Country Code` LIKE 'AT'
        AND `ker_data`.`D2.8 Responder Label` LIKE 'Civilian Airports'
ORDER BY `ker_data`.`D2.8 Responder Label`;
```

Fig. 12 Database query for national emergency responders

The resulting database consists of 94 tables and 270 columns representing the 33,513 data rows taking up 30.2 megabyte. The skills taxonomy's part of this database is 23 tables and 70 columns. The taxonomies have thus been transformed from static spreadsheets very difficult to query into a stable and dynamic relational database (ZEFA row 6, column 1) that can be queried using SQL.

The fully implemented database can be queried as in Fig. 12 where 'ker_data' is a table created from joining data from seven other skills taxonomy tables in the database. The query retrieves:

- the label of this emergency responder in the hierarchy of emergency responders ('ker_data'.'KER Label'),
- the national emergency responders ('ker_data'.'National Body Eng.' and 'ker_data'.'National Body Org.'),
- the possible regions ('ker_data'.'Region Eng.' and 'ker_data'.'Region Org.'), and
- the ISO and NUTS region codes ('ker_data'.'Region Eng.' and 'ker_data'.'Region Org.'),

given that the generic emergency responder ('ker_data'.'D2.8 Responder Label') is 'Civilian Airports' and the country is 'AT' for Austria ('ker_data'.'NUTS Country Code' LIKE 'AT').

The results in Table 8 show that under the generic emergency responder 'Civilian Airports' in Austria there are 'Airport Operators' emergency responders that are associated with certain regions.

Another example of a query made possible by the digitization of the skills taxonomy (cf. Fig. 2) is the one displayed in Fig. 13. This query fetches which of the EU CP modules, including capacity and equipment, that could be useful to which generic emergency responder ('incident_eucpmodule'.'D2.8 Responder Label') when performing the 'Caring of Victims' intervention task ('incident_eucpmodule'.'Intervention Task' LIKE 'Caring of Victims') from a table created by joining several other tables. The result (Table 9) shows that the generic emergency responder 'Communities' could have use for the EU Civil Protection Module titled 'Advanced Medical Post' which has availability of supplies for the treatment of 100 patients with minor injuries per 24 h and provides tents for the personnel.

Table 8 The result retrieved by the query in Fig. 12

KER label	National body eng.	National body org.	Region eng.	Region org.	NUTS r. code	ISO r. code
Airport Operators	Airport Vienna	Flughafen Wien AG	Vienna	Wien	AT130	AT-9
Airport Operators	Airport Carinthia Operating Company	Kärntner Flughafen Betriebsgesellschaft mbH	Carinthia	Kärnten	AT21	AT-2
Airport Operators	Airport Salzburg Operating Company	Salzburger Flughafen Ges.m.b.H.	Salzburg	Salzburg	AT32	AT-5
Airport Operators	Airport Linz Operating Company	Flughafen Linz Ges.m.b.H.	Upper Austria	Oberösterreich	AT31	AT-4
Airport Operators	Airport Vienna	Flughafen Wien AG	Vienna	Wien	AT13	AT-9
Airport Operators	Airport Tyrol Airport Operating Company	Tiroler Flughafenbe-triebsgesellschaft mbH	Tyrol	Tirol	AT33	AT-7
Airport Operators	Airport Graz Operating Company	Grazer Flughafen Betriebsgesellschaft	Styria	Steiermark	AT22	AT-6

```
SELECT
    `incident_eucpmodule`.`D2.8 Responder Label`,
    `incident_eucpmodule`.`Module Label`,
    `incident_eucpmodule`.`Module Capacity`,
    `incident_eucpmodule`.`Module Equipment`
FROM
    `shelp_v8`.`incident_eucpmodule`
WHERE
    `incident_eucpmodule`.`Intervention Task` LIKE 'Caring of Victims';
```

Fig. 13 Database query for EU CP modules associated with an intervention task and a generic emergency responder

Table 9 Excerpt of the results from the query Fig. 13

D2.8 responder label	Module label	Module capacity	Module equipment
Communities	Advanced Medical Post	Availability of supplies for the treatment of 100 patients with minor injuries per 24 h	Command post
Communities	Advanced Medical Post	Availability of supplies for the treatment of 100 patients with minor injuries per 24 h	Logistic and medical supply deposit
Communities	Advanced Medical Post	Availability of supplies for the treatment of 100 patients with minor injuries per 24 h	Tent(s) for the personnel
Communities	Advanced Medical Post	Availability of supplies for the treatment of 100 patients with minor injuries per 24 h	Tent(s) with interconnected areas for triage, medical care, and evacuation

The Data Model created by University of Lund (2016) is used in the Decision Support Module. It provides a frontend for querying the S-HELP taxonomies created by University of Vienna (2014, 2015a, b, c, 2016). It enables users to select an emergency management phase (e.g. response, recovery) and displays resulting interventions that can be taken. A drill down function allows the user to select tasks that are relevant to the selected emergency management intervention. Moreover, the user can identify the resources, materials, and responders that are needed to perform this task. Figure 14 illustrates the related user interface.

First, a decision maker selects an emergency management phase interested in (#1 in Fig. 14) such as “Recovery”. Next, an intervention (#2 in Fig. 14) such as “Evacuation Management” of the related emergency phase can be chosen. Then, all essential tasks of this intervention are listed such as “Returning to Homes” (#3 in Fig. 14) and it is shown that the emergency responder, “Head of Safety” is leading that issue and all resource types needed such as “Communication Systems”.

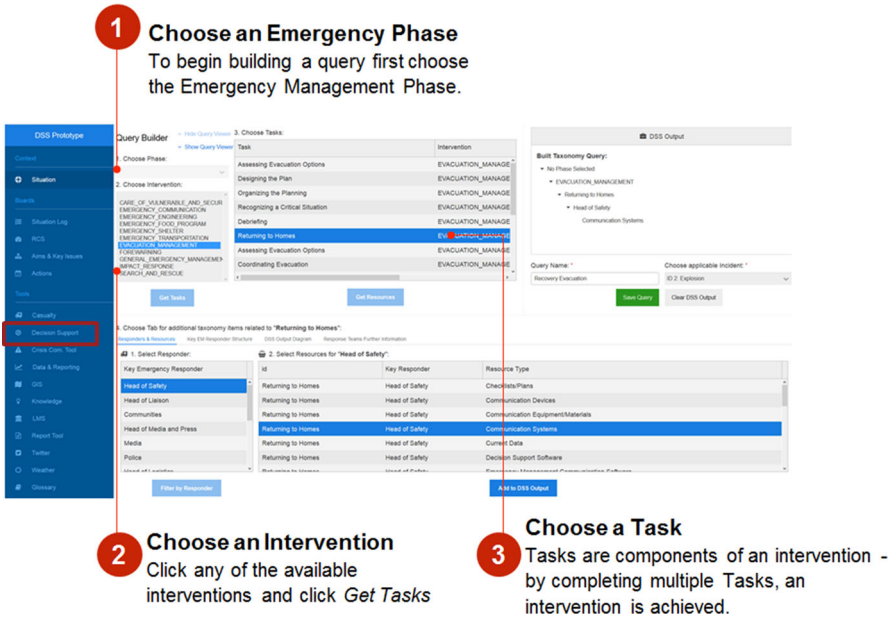

Fig. 14 User interface of the decision support module of the S-HELP DSS Toolset Adapted from (Neville 2017, p. 24)

6 Conclusion and policy implications

The skills taxonomy interlinks key emergency interventions by identifying the related tasks of emergency responders and incorporating them with the EU Civil Protection Modules. By incorporating these, the decision-making undertaken during specific emergency interventions are facilitated and ensures that rapid response is supported for the appropriate emergency responders when required. This unique skills taxonomy is implemented in the S-HELP DSS to support disaster policy making and training by enhancing the semantic, operational, and technical interoperability. This new approach also closes a gap in the literature.

We identified eleven main emergency interventions for preparedness, response, and recovery in the emergency management lifecycle. These interventions are distributed across the various lifecycle phases as follows:

- *The preparedness, response, and recovery phases*: general emergency management, emergency communication, forewarning, and evacuation management
- *The response phase*: impact response as well as search and rescue.
- *The response and recovery phase*: emergency transportation, emergency engineering, emergency shelter, emergency food program, and care of vulnerable and secure groups.

To illustrate the scope of the taxonomy, we presented two selected emergency interventions: (1) "general emergency management" for the preparedness, response, and recovery phases and (2) "search and rescue" for the response phase. The key tasks for

these interventions are provided by different national emergency responders across a number of countries with their own education and legislation, as well as their own domain-specific skills and capabilities. A new comprehensive classification for main national emergency responders is provided using the following categories: (1) core responders, (2) non-core responders, and (3) co-operating bodies. In addition, the paper incorporates incident command-related national emergency responders in the skills taxonomy. These national emergency responders are supported by international organizations and the EU. Furthermore, the skills taxonomy shows for each of the eleven main emergency interventions which EU Civil Protection Modules are useful for emergency management policy makers to cope with major disasters. The skills taxonomy informs emergency management policy makers on the general availability, start of operation possibility, self-sufficiency, and operation time of the EU Civil Protection Modules. For future research, the role of different international organizations could be elaborated in more detail. It is worth noting that a resources taxonomy was also developed to interlink key emergency responders and main emergency interventions with key emergency resources (cf. University of Vienna 2015b, 2016).

The paper contributes a skills taxonomy from a general non-country-specific level from a strategic long-term perspective. The findings from this study help inform more country-specific information being gathered for the three policy scenarios (i.e., mass flooding, chemical explosion, and a biological-hazard). These scenarios are being designed in terms of real-world disaster situations with a cross-border element, requiring emergency responders from different countries and regions to work together during response and recovery activities (cf. Bharosa et al. 2010; Mendonça et al. 2007). This represents a preparatory activity that tests the S-HELP DSS and highlights the need for a taxonomy of shared terms to support multi-agency interoperability (cf. Waugh and Streib 2006). It is necessary for relevant agencies to assign suitable emergency responders to undertake the strategic, tactical, and operational emergency interventions in accordance with their authority and skill-set. The skills taxonomy provided in this paper provides a basis for such activities.

In conclusion, this paper contributes to research and industry practitioners by providing a skills taxonomy that identifies and categorizes emergency responders and aligns the EU Civil Protection Modules with the relevant skills to undertake main emergency interventions and related tasks. As a result, this work addresses some of the challenges identified in the literature associated with multi-agency coordination and collaboration during a cross-border emergency incident—such as complexity, lack of shared structures, vocabulary, and a working history (cf. Lee et al. 2011; Manoj and Baker 2007; Carver and Turoff 2007)—and thus identifies appropriate interventions in the work towards solving such issues. Through the creation of essential taxonomies this research is a critical step towards creating much needed interoperability standards to serve independent emergency service agencies and help them to work together more effectively and efficiently. This approach is both useful and essential in addressing the challenges of cross-border emergencies but also provides a foundation for future work to build upon.

The limitations of the study include the time constraints involved in creating such taxonomies, and thus the choices made in the selection of taxonomies to develop, which were based on specific countries and scenario situations relevant to the S-

HELP DSS. For example, international emergency responders are only considered on the strategic level and not further detailed in the skills taxonomy as we focused on general national emergency responders in detail. We limited the country-specific main national responders to the examples of Austria, England, Ireland, Israel, and Northern Ireland due to time and language limitations. Data gathering for one country takes about 0.5 man-years as well as related language skills and background knowledge about the country. These limitations can be addressed by future work into other relevant scenarios in different contexts/countries and by applying additional policies.

This paper addresses the gaps in research with regards to emergency management solutions that account for the entire lifecycle in a holistic and integrated way, as opposed to solutions that overlook certain emergency management activities and thus extends the knowledge base for research on activities across the emergency management lifecycle (cf. Altay and Green 2006).

Unfortunately, our societies' susceptibility to hazards and other threats is increasing due to urbanization and increasing populations (Coppola 2011; Faulkner 2001; Neville et al. 2013), thus it is becoming more and more critical to enable better coordination and communication among the agencies that respond during a crisis. By providing a skills taxonomy, operational inefficiencies and delays can be reduced and the decision-makers are provided with time-critical and essential information to perform the assignment of resources. This work can be used to extend our current understanding of emergency management interoperability and provide a basis for further work in this area. Such an approach may prove useful for EM practitioners and system designers and contributes to both EM and software design practice. In the future, operation research models related to fields such as humanitarian logistics or disease control could be incorporated into or benefit from the S-HELP DSS.

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