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SOA4DM: Applying an SOA Paradigm to Coordination in Humanitarian Disaster Response

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***Abstract*—Despite efforts to achieve a sustainable state of control over the management of global crises, disasters are occurring with greater frequency, intensity, and affecting many more people than ever before while the resources to deal with them do not grow apace. As we enter 2015, with continued concerns that mega-crises may become the new normal, we need to develop novel methods to improve the efficiency and effectiveness of our management of disasters. Software engineering as a discipline has long had an impact on society beyond its role in the development of software systems. In fact, software engineers have been described as the developers of prototypes for future knowledge workers; tools such as Github and Stack Overflow have demonstrated applications beyond the domain of software engineering. In this paper, we take the potential influence of software engineering one-step further and propose using the software service engineering paradigm as a new approach to managing disasters. Specifically, we show how the underlying principles of service-oriented architectures (SOA) can be applied to the coordination of disaster response operations. We describe key challenges in coordinating disaster response and discuss how an SOA approach can address those challenges.**

***Index Terms*—SOA, Disaster Response**

I. Introduction and Background

Recent disasters such as earthquakes, hurricanes, tsunamis, and disease outbreaks have put a spotlight on the effectiveness of disaster response efforts. In order to develop and maintain a sustainable way to protect societies from death and destruction as a result of disasters, it is necessary to develop an ability to mitigate, prepare for, respond to, and recover from disasters. The increase in both frequency and intensity of disasters is unmatched by the increase in availability of resources needed to respond to them [29]; therefore, it is critical to discover ways to improve disaster response.

Innovations originating in software engineering have been applied in a number of areas of importance to society. Service orientation and componentization have helped businesses transform from silos of internally-focused competencies to agile customer-focused enterprises [6]. The open source philosophy originating in software development has been adopted in a variety of domains [14], [19]. Software tools such as Github and Stack Overflow have been adopted in domains as diverse as law, natural languages, arts and crafts, and cooking [20]. Software developers have been referred to as prototype developers for knowledge workers of the future [25]. It is both interesting and important to consider how paradigms of software engineering might bring novel solutions to issues of sustainability and disaster management.

In this paper, we present the paradigm of service-oriented architectures (SOA) [9] [28] as an innovation opportunity in the design and implementation of disaster management approaches. In the realm of software engineering, SOA is an approach to building systems in which independent software services can be discovered and then invoked to implement business processes [9]. Key to its effectiveness is standardization, which makes publishing, discovering, and invoking services possible across organizational boundaries [28]. The benefits of SOA design principles include: flexibility and adaptability in selecting service(s) to invoke for specific processes; matching of published service requirements with available service capabilities; standards for communicating capabilities and requirements; and, availability of agreements. The intention of SOA is the design and implementation of technological solutions but we propose that the concepts of SOA be applied to disaster management in order to provide an alternative approach to disaster response coordination.

Past work has investigated SOA for managing information systems and software tools in humanitarian efforts and disaster management. SOA design has been identified as an approach for providing data and software services in geographic information systems (GIS) for emergency response [31] and integrating GIS and Enterprise Resource Planning in the context of emergency management [27]. SOA has also been used to design a simulation environment for emergency response systems [4]. A service-oriented architecture model to facilitate information exchange among loosely coupled systems in humanitarian organizations and development projects is proposed in [11]. SOA methods are used to design and prototype an information-exchange framework as an information system for disaster management (ISDM) that can collect, combine, and share information [23]. Relevant and

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TABLE I. RELATIONSHIP OF SOFTWARE SERVICE ENGINEERING PRINCIPLES [28] TO DISASTER RESPONSE COORDINATION CHARACTERISTICS

SSE Tenet [28]	*Underlying SSE principle*	*Disaster Response Coordination Characteristic*
Technical Federation	Logically and physically distributed	Provider organizations physically distributed
Virtualization	Aggregated into service compositions at runtime	Services must be integrated on the fly
Organizational federation	Developed and maintained in different organizations, institutions, and even countries	Services provided by global, foreign, and local organizations
Explicit boundaries (contracts)	Governed by behavioral, structural, and policy contracts through service-level agreements	Organizations and activities governed by local and national laws and customs as well as global policies
Heterogeneity	Heterogeneity	Significant heterogeneity in organizations, offerings, structure, requirements
Business-IT alignment	Aligned with business processes or workflows	Aligned with disaster response processes or workflows
Holistic engineering approach	Characterized by the fact that services play a part in a broader, holistic environment.	Responding to disasters is part of a broader economic, social, political, ecological, humanitarian situation

interesting research has also looked at flexible business processes and workflow management systems to enable implementation of on-the-fly processes in disaster management information systems [16], [22]. While SOA is typically used to design and implement IT-enabled business processes [6], to the best of our knowledge, we are the first to suggest applying SOA to the coordination of organizational and human activities in emergency responses.

II. DISASTER MANAGEMENT AND RESPONSE

A disaster is defined as: *a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses that exceed the ability of the affected community or society to cope using its own resources.* [34]

The Comprehensive Emergency Management (CEM) Model divides disaster management into four phases: mitigation, preparedness, response and recovery. In this paper, we focus on disaster response through which assistance is provided during or immediately after a disaster to save lives and provide necessities to those affected [9] in an operational environment that is often volatile and constantly changing.

We use the case of the 2010 Haiti earthquake to highlight issues and underline challenges in disaster response coordination. A 7.1 magnitude earthquake struck Port-au-Prince, Haiti, and caused a major urban disaster with approximately 200,000 deaths, 300,000 injured, millions displaced and billions of dollars in damages [2]. This earthquake was particularly devastating because, prior to the earthquake, Haiti was the poorest country in the Western Hemisphere, compounded by the loss of their leadership, and the destruction of the local and national systems of response along with a portion of their infrastructure [29]. After the earthquake, the ground shook for 11 days with up to 59 aftershocks registering greater than 4.5 on the Richter scale [7] adding chaos to an operational environment characterized by turbulence and uncertainty. An international disaster response was mounted to provide relief to those impacted. The sheer number of organizations and agencies pouring into the affected areas provided a practical demonstration of why coordination is crucial to the efficacy of disaster response operations [8]. Without adequate coordination, organizations and agencies duplicated their efforts, wasting precious time and resources [18]. The efficient allocation of resources to optimal effect is crucial for sustainability [29].

Another issue is the struggle to adequately manage a large influx of relief workers on site during international disaster operations like the one in Haiti in 2010. The number of nongovernmental organizations (NGOs) present to deal with health issues would normally be between 15 and 20; however, in Haiti (2010) there were 300 NGOs [15] comprised of both established and emergent groups [31].

Several types of disaster management systems are used at disaster sites but a common one is the Incident Command System (ICS) [8]. This flexible, modular, and scalable system was designed so that the person in charge of coordination does not lose sight of the broader context and is able to manage personnel and resources, allowing labor to be divided based on functional responsibilities and responders to collaborate working towards a common goal [8]. While ICS is one of the better disaster management systems, research shows several challenges remain, especially in the context of large disasters. Critics claim that the ICS is better suited to simpler, small-scale disasters, where responders have trained together and are familiar with one another [1]. ICS has also been known to have difficulty absorbing groups of responders who are independent or poorly organized. One can argue that the ICS alone would not have been effective in the aftermath of the Haiti earthquake, three weeks after which 2,000 organizations and agencies reported to the operational theatre [2].

The cluster approach is another disaster management system developed by the Inter-Agency Standing Committee (IASC) in 2005 to strengthen coordination globally and in the field [3]. The nine global clusters are: nutrition, health, water - sanitation, emergency shelter, camp coordination - management, protection, early recovery, logistics and emergency telecommunications [12]. In Haiti, UNOCHA employed the cluster approach, which is used in conjunction with other disaster management systems, including ICS [2] [15]; however, coordination issues continued to arise. One cause that was identified and further explored, was the importance of the cluster lead's role in managing and sharing information [2]. Without effective information management, coordination becomes difficult, especially in a complex and dynamic environment such as a site of a major disaster.

III. THE SOA PARADIGM AND DISASTER RESPONSE EFFORTS

We propose an SOA-inspired solution to the disaster response coordination problem meant to function at the

TABLE II. SOA4DM SOLUTIONS TO KEY CHALLENGES OF DISASTER RESPONSE COORDINATION

Challenge	*SOA4DM Solution*	*Relevant SOA Principle*	*SOA4DM Applied to the 2010 Haiti Earthquake Response [13]*
Identifying appropriate provider organizations and agencies	Standard way of publishing and registering service provider information	Service discoverability; service abstraction	In Haiti, the SOA4DM approach could have resulted in fewer responding organizations, but ones that were better suited to the environment and to the operation.
Coordinating large numbers of organizations and agencies	Standard way of publishing requirements; mechanisms for orchestrating providers (through registry) to satisfy requirements	Service composability; service loose coupling	The SOA4DM approach could have enabled the significantly larger number of organizations (2000 operating in Haiti) to be better coordinated according to their size and capability at the time of the disaster. It would also have ensured finding alternative organizations for those committed to other disasters at the time of the request.
Enabling flexibility and on-the-fly identification of service providers	Clearly articulated processes and coordination through the registry and feature interaction detection	Service composability; service discoverability; service loose coupling;	The SOA4DM approach could have enabled new agencies to be summoned to changing conditions in Haiti complicated by: 11 days of aftershocks (59 above 4.5 on the Richter scale), a cholera epidemic discovered in Oct., 2010 and still ongoing, and Hurricane Tomas that made landfall on Nov. 5, 2010.
Ensuring efforts are not duplicated	Clearly articulated processes; coordination through the registry; mechanisms for orchestration	Service composability; Service loose coupling;	By orchestrating resources through clearly articulated processes coordinated in a central location, an SOA4DM approach would have helped reduce the duplication of effort in the complex operational environments of the Haiti disaster.
Ensuring inclusion of and coordination with key partners	Registry incorporates requirements for participation of specific partners	Standardized service contract; service discoverability	Incorporating requirements for the systematic participation of Haitian civil society and local authorities could have improved understanding of the operating context, enabled a more sustainable provision of relief, and contributed to local and national capacity-building.

executive rather than ground or mid levels of a response operation [30]. This approach becomes operationally relevant after communication has been established, either immediately or following efforts to solve or work around the partial or complete collapse of telecommunications infrastructure commonly encountered in the aftermath of a disaster [20]. It also presupposes that those operating at the ground level recognize that coordination is necessary to optimize operational performance. We compare several characteristics of disaster response coordination to the seven tenets of software service engineering [28] in TABLE I. The similarities highlight an opportunity to apply the SOA paradigm (an approach we call SOA for disaster management: SOA4DM) to the coordination of non-IT services in disaster response.

A key challenge is the difficulty in identifying organizations (especially smaller, local, so called "freelancers" [12]), their capabilities, and their ability to satisfy the requirements of a given response process. The SOA4DM model can make use of a service provider registry, published requirements, and standard specifications such that service providers can be more systematically matched with requirements. Coordinating large numbers of organizations and agencies is a challenge that can be met by SOA4DM through standard ways of publishing requirements and mechanisms for orchestration. Another challenge is the need to have flexible processes and engage appropriate service providers on the fly at the time of action. This challenge can be met using SOA4DM through clearly defined processes and coordination via a registry of providers and needs. Duplication of effort is an issue in coordination of disaster responses. Clearly defined processes, the service registry, and service orchestration capabilities made available through an SOA4DM model can help prevent duplication of work. The dynamic and volatile nature of disaster response can result in positive and negative interactions similar to feature interactions in web services, thus, methods for resolving feature interactions in SOA4DM are necessary [33]. Finally, SOA4DM can help ensure that key partners are included by incorporating requirements for service providers in the standard information and registry. TABLE II. summarizes the SOA4DM solution and identifies specific opportunities where SOA4DM might have applied in the context of the Haiti earthquake.

IV. CONCLUSIONS AND FUTURE WORK

We propose that the principles of service-oriented systems be applied to coordination of disaster management response. We identified key challenges of disaster response coordination and showed how an SOA4DM approach can address those challenges. We note that there are considerable complexities in the management of disasters that are not solved by adopting our proposal alone. Matters of leadership and coordination still remain and issues of conflict, disease, and access further complicate the implementation of a humanitarian response. However, we believe there is sufficient promise in adopting the paradigm of SOA for human and organizational aspects of disaster management and response. The next steps are to conduct a case study analysis to further our understanding of circumstances under which software principles can best be applied in a disaster context. As our understanding of SOA4DM grows, it will be necessary to look at existing SOA research challenges and roadmaps [5], [17] and alternative methods for managing dynamic workflows [24], [26] in the context of SOA for disaster management.

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