Dedi-6

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Developing a Decision Support System for Disaster Management: Case study of an Indonesia volcano eruption

Abstract

Disaster Management activities often focus on specific tasks (e.g. evacuation, logistic or coordination) and are confined to one specific DM phase (e.g. Preparedness or Response). New awareness about an external change, be it environmental or organisational, typically act as a trigger for such focussed activities. A variety of views or stakeholders are also involved in those activities, and their various concerns get often intertwined. This work advocates the use of a Decision Support System (DSS) that can be deployed as a single access point. Such a system requires a sufficient amount of representative knowledge, and facilities to avail the knowledge to the appropriate stakeholders in an appropriate form. With the multitude of stakeholders and their varying knowledge requirements, the system will need to present the knowledge differently according to the stakeholders needs in their decision making process. Such processes can vary, e.g. whether for policy making or for operational real time responses. This paper presents a hybrid of knowledge elicitation and retrieval mechanisms, some are top down and others are bottom up. The mechanisms make use of the Meta Object Facility (MOF) to structure and present the knowledge appropriately according to different interests and roles. A case study of the recent Mt. Agung volcano eruption in Bali Indonesia is successfully used to demonstrate the efficacy of the mechanisms proposed and the resultant DSS.

Keywords: Disaster Management, Decision Support System, Knowledge Management, DSS Development Process

1 Introduction

Disasters and their resultant economic losses are on the increase (Tatham *et al.*, 2017). Disaster Management (DM) is the systematic attempt to reduce their impact (Coppola, 2011). A key DM objective is to achieve resiliency (Blackman *et al.*, 2017), that is: (1) a capability of bouncing back from unforeseen stress; and/or (2) capability to adapt to the situation. Resiliency is essentially determined by the level to which the affected communities have the necessary resources and ability to manage them during the disaster situations (UNISDR, 2012). Decision Support Systems have a key role to play, but mechanisms to create them in a way to account for the holistic nature of DM decisions remain challenging (Leskens *et al.*, 2014; Rosenzweig & Solecki, 2014).

DM decision making processes are typically initiated by governmental authorities (e.g.: National Disaster Management Agency (BNPB) in Indonesia or State Emergency Services (SES) in Australia). The processes can be either reactive (bottom up) or proactive (top down). Reactive processes aim to pursue particular objectives in response to a dynamic environment. In such event driven processes, the objective is to bounce back as soon as possible from the impact caused by a disaster event. For instance, whenever it is perceived that a volcano is going to erupt, this becomes a trigger for authorities to undertake all the necessary activities to ensure that all the available resources are in place to protect lives in affected areas e.g. evacuate inhabitants to a safer place. Evacuation activities need to be typically guided by knowledge from Disaster Management Plans (DISPLAN) or Situation Reports (SITREP). A DISPLAN typically contains best practice based on empirical knowledge and is used a guide for stakeholders in a timely fashion (Santiago *et al.*, 2016). A SITREP contains real time knowledge of how a situation is unfolding on the ground and is critical for first responders. Both types of documents equip various stakeholders with empirical and crucial knowledge elements in a disaster event. These elements in such communications should also be in a context-aware format. They need to be accessed directly by the roles that require them. Example of empirical knowledge elements include: where to evacuate? who will assist in the evacuation of properties and animals? which routes should be taken in the evacuation? who will assist those with disabilities? what is the pre- and post-condition before and after an evacuation? and etc.

Proactive improvements can also be initiated by some DM stakeholders (Fogli *et al.*, 2017). These are top-down decision making process where stakeholders aim to develop DM resilience. For instance, as described in (Opper *et al.*, 2010), to be able to be effective and efficient in achieving evacuation tasks in a flood disaster event, all related activities should also be known and thoroughly understood by those who are actually living within the prone communities. The stakeholders need not only to recognise the need for evacuation when needed but also other prior community related activities. For instance, they may well need to be aware of the following: public education and/or risk assessment, assistance for stranded travellers and animals, managing aircraft, maintaining logistics, etc. Therefore, ensuring that the DISPLAN covers as much useful knowledge as possible, not only pertaining to the response (e.g. physical evacuation), but also those all other preluding or ensuing concepts (those related to preparation or mitigation).

This paper presents an approach to create a DM DSS that accounts for both types of decision making processes, bottom up or top down. The paper also demonstrates how these decision making processes can be supported in DM. A number of challenges are addressed: first is delineation of DM knowledge across phases (Leskens *et al.*, 2014; Rosenzweig & Solecki, 2014). Second is removing any implicit or fuzzy conditions. This requires dealing with the unspoken constraints associated with actions described but often left implicit such as organisation constraints, time and uncertainty. The paper is organised as follows: Section 2 provides related works from the extant literature focussing on DSS in DM. Section 3 describes the representation of the decision making mechanisms as deployed in this research. Section 4 describes the evaluation with a real case study of a recent volcanic eruption event. Section 5 and 6 discusses and concludes this research respectively. Finally, in Section 7, the limitations and future research directions are presented.

2 Related works

The pursuit of Decision Support Systems (DSS) for Disaster Management (DM) is driven with the fact that disasters cannot be prevented, but they can be better managed to reduce loss of properties and lives. This section describes prior work related to DSS development for DM. It is organised according to the emphasis and the problems tackled in the research.

2.1 The urgency for addressing the diffusion of DM knowledge across phases

Investigating DSS has been a continuing concern in DM research (Briceño, 2015; Fogli *et al.*, 2017; Weichselgartner & Pigeon, 2015). The research pursues ways for providing sufficient and representative knowledge for DM authorities to assist in timely and improved decisions. Given that there are no identical disasters, it is impossible to develop a generic formulation that can be applied to all DM cases (Coppola, 2011). However, the combined understanding (Thapa *et al.*, 2017) and equipping (Mejri & Pesaro, 2015; Rivera *et al.*, 2015) of DM stakeholders with best practice knowledge continue to be the best path for DM resilience endeavours. The appropriate presentation knowledge is also critical (Weichselgartner & Pigeon, 2015).

DM stakeholders are numerous and have different backgrounds and interests. They might adopt different description of resources, activities, responsibilities, roles, etc. Ontologies have been proposed to mediate representation discrepancies (Haghighi *et al.*, 2013; Mescherin *et al.*, 2013; Xing-Ling & Xue-Lian, 2012). Whilst this idea of harnessing ontologies is well accepted (Reddy *et al.*, 2009), various researchers highlighted (Haghighi *et al.*, 2013; Mescherin *et al.*, 2013; Xing-Ling & Xue-Lian, 2012) that the proposed ontologies not present how decision making mechanism can be constructed. They are typically used in the elicitation without due attention to appropriate formatting for those who are on the ground.

Other scholars (Grolinger *et al.*, 2015; Horita *et al.*, 2017; Poslad *et al.*, 2015) emphasize that there are many potential reusable knowledge sources if sufficient monitoring and reconnaissance of likely disasters is done. Their view is to leverage these various knowledge sources to enhance the DM decision making processes. They emphasize the need to demonstrate how this knowledge can be operationalised into decision making. In a cloud computing environment, Grolinger *et al.* (2015), a knowledge as a service (KaaS) framework is developed to support knowledge acquisition and delivery from various knowledge sources to end users. Similarly, Poslad *et al.* (2015) and Horita *et al.* (2017) developed frameworks for Internet of Things (IoTs) and big data environments that aim to enhance DM activities. Nevertheless, how the knowledge acquired is able to be retrieved by stakeholders remains unclear. While in other approach (Dorasamy *et al.*, 2017), an integrated knowledge management system for DSS in DM is presented but how knowledge is sourced and presented into an understandable format remains unspecified.

2.2 The need for formal structures for DSS development in DM

DSS supported decision making in DM has received considerable attention recently. Most relevant to this work, are those concerned with model driven DSS mechanisms as in (Benaben *et al.*, 2016; Chen, N. *et al.*, 2015; Lauras *et al.*, 2015; Othman & Beydoun, 2016). These scholars employ a metamodel based structure as a knowledge repository underpinning the DSS knowledge base. A metamodel is advocated as a basis for the representation, as the ensuing structure enables ease or tracing the decision making process and at the same time storage and retrieval are directly based on elements constituting the structure. A metamodel consists of concepts and relations that directly describe the domain. As such, for a particular disaster event, the stakeholders can have a broader understanding how to achieve a DM resiliency by identifying the concepts required for that. For facilitating the decision making processes in this work, Meta Object Facility (MOF) is also employed (OMG, 2013). MOF is a framework defining how the knowledge can be exchanged from the conceptual to the real world layers and the reverse (as illustrated in Figure 1). The use of MOF to support DM metamodels has been illustrated by Othman and Beydoun (2016). Othman and Beydoun (2016) developed a metamodel using 89 existing DM models. The metamodel is called, DM Metamodel (DMM) (Othman & Beydoun, 2011). DMM has been validated rigorously through actual DM case studies (Othman *et al.*, 2014).

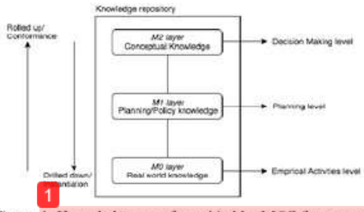

Figure 1. Knowledge transfer guided by MOF framework.

The model driven DSS approach is also used in other works (Benaben *et al.*, 2016; Chen, N. *et al.*, 2015; Lauras *et al.*, 2015). Nonetheless, unlike the work in Othman & Beydoun (2016), these scholars shortfall in two ways: (1) they do not inform how their metamodels are developed and validated. This is important to guarantee that the decisions constructed based on the metamodel are able to inform the knowledge required to each of particular context; (2) their metamodels do not cover all disaster management phases. For instance, (Lauras *et al.*, 2015) cover only the response phase, (Benaben *et al.*, 2016) cover two phases of preparedness and response. Others only focus on a particular type of disasters, e.g. (Chen, N. *et al.*, 2015) focus only on floods. Notwithstanding these, taking into account of the complexities of the knowledge in the DM activities as the basis of DSS in DM, the model driven approach is clearly offering a more understandable format representing the DM timeline (Benaben *et al.*, 2016; Chen, N. *et al.*, 2015; Lauras *et al.*, 2015; Othman & Beydoun, 2016)

As mentioned earlier, this paper based extends our initial works (Inan *et al.*, 2015). The work presented in this paper is part of a larger aim to contribute in the DM resilience endeavours. In fact, one of the authors of this paper was also highly involved in developing DMM (Othman & Beydoun, 2013). The DMM is resulted from synthesising various DM models ranging from natural disaster: bushfire, flood, earthquake, etc., to manmade: nuclear disaster, etc. Those synthesised concepts in DMM will provide a structure of typical knowledge needed in the decision making processes. Secondly, in the previous works (Inan *et al.*, 2017), we have addressed one of the key challenges on how to disentangle the complex knowledge elements described earlier. In particular, we developed a Knowledge Analysis Framework (KAF) to analyse and model DM knowledge and subsequently depositing it into DMM based repository. KAS provides a systematic analysis and modelling activities that employs Agent-Based Models (ABMs) from Agent-Oriented Software Engineering (AOSE). The use of ABMs for disentangling the knowledge out of the DM domain because of their focus on human activities and organisational structures has been previously used to identify characteristics out of complex domains (Lopez-Lorca *et al.*, 2016). In DM knowledge analysis, ABMs are used to decompose the intertwined knowledge in the DISPLANs guided by modelling elements in each representative model.

The conversion process of the knowledge ABMs to DMM based repository is a model to model transformation (Syriani *et al.*, 2013). This has been defined by OMG (OMG, 2013) through the Meta Object facilities (MOF) framework. Adopting MOF in this work is twofold: (1) to guide the transformation of ABMs to the repository; and (2) to provide the clear boundaries of the knowledge structured in ABMs which can be aimed planning/policy or for real world activities. This is as illustrated in Figure 1.

Once knowledge is placed in the repository, it can then be retrieved by stakeholders as needed. The way the knowledge is structured in the repository allows decision making as briefly described earlier. The storage of the knowledge allows distinguishing the knowledge from a conceptual, planning and or operational perspective. The knowledge in these three layers are linked by their semantic relationships as they essentially refer to the same activities but for different context. This work adds to the previous efforts by identifying the need for two streams for knowledge transfer to the knowledge base of the DSSs proposed. Indeed, while KAF is an existing contribution, KAF is deployed as a tool to develop the bottom up and top down approaches for constructing and retrieving DM knowledge (from or to a DSS knowledge base). Further details of KAF will be presented in the next section as it is used in this paper.

The work responds to the challenges in decision making processes for the complex disaster domain (Elia & Margherita, 2018), not only in providing a conceptual framework but a concrete solution.

2.3 The knowledge analysis framework underlying the decision support development

As earlier described, the various knowledge access and elicitation mechanisms sought in this work are underpinned by our existing Disaster Management KAF (Inan & Beydoun, 2017a). Thus, an overview of how the framework works is first provided. KAF is shown in Figure 2. It consists of three stages: (1) customising Agent Based Models (ABM) templates; (2) generating the specific DISPLAN; and (3) transferring the DISPLAN into the repository. KAF was earlier validated with three different case studies from Australia: Two are from SES of the state of NSW (Inan &

Beydoun, 2017b; Inan *et al.*, 2016) and a third is from SES of the Victoria State (Inan & Beydoun, 2017a). The evaluation adopted Design Science Research (ADR) (Sein *et al.*, 2011) and showed the efficiency and the semantic effectiveness of KAF. The evaluation process followed the strategy prescribed in (Venable *et al.*, 2016). The results ensured KAF generalisability as defined in (Sein *et al.*, 2011) and that it can be used in other DM cases. For the purpose of this paper, each of the three stages of KAF will be briefly discussed to present a general picture how this framework works.

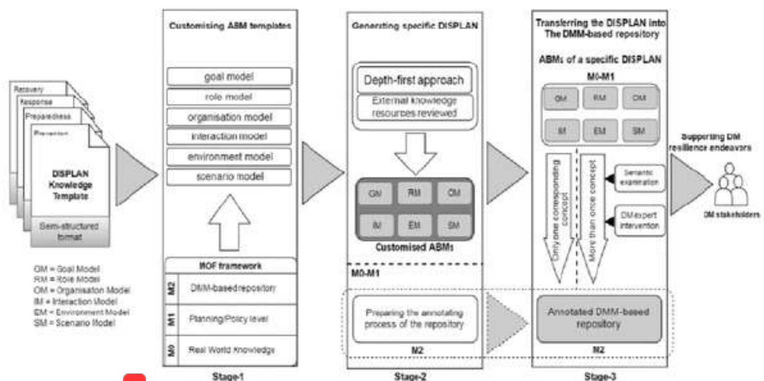

Figure 2. The validated Disaster Management Knowledge Analysis Framework (DM KAF).

2.3.1 Customising ABM templates

The input to the framework is a template document of the DISPLAN knowledge. The template is used to ensure that the analysis process accounts for elements in the template. The template is typically structured in a business specification format and constitutes the primary foundation for the authoritative use in describing DM activities.

A knowledge engineer with extensive DM background (or DM expert with agent-based paradigm understanding) is involved in the analyses and models the DISPLAN template and structures it into the each of six (6) representative Agent Based Models: *goal model, role model, organisation model, interaction model environment model and scenario model*. The aim here is to parse the intertwined and fuzzy knowledge elements to be used in the later phase. The MOF in this stage is used to distinguish knowledge of actual real world DM activities (or based on MOF it is also known as *M0*) from knowledge used in the planning level (M1). The analysis is at the same time guided by the knowledge elements of the ABMs and conducted iteratively. The final outcome is six ABMs templates describing the DISPLAN template.

2.3.2 Generating the specific DISPLAN

Once the ABMs representing the DISPLAN template is in place, the next step is to generate the Agent Based Models a particular DISPLAN. For instance, the ABM DISPLAN templates are used to generate a description of Wollongong SES Municipality DISPLAN. The process is depth-first to guarantee not only the efficiency but also the effectiveness of this process (Inan *et al.*, 2017). Preparing the repository to which the knowledge will be deposited is also done in this stage. The concepts are structured and related utilising a metamodel called DM Metamodel (DMM) (Othman *et al.*, 2014). Based on MOF, the repository structure is at the *M2* layer. The process is by annotating the concepts in a DM Metamodel with the representative constructs of the Agent Based metamodel FAML (Beydoun *et al.*, 2009). This allows a mapping between the two metamodels, the agent based metamodel and the DM metamodel based on MOF (OMG, 2013).

2.3.3 Transferring the DISPLAN into the repository

The ABMs representing a paticular DISPLAN is then transferred into the repository. Most knowledge elements in this stage are sufficient to represent activities to be executed. For some elements, however they need to be further specified with local characteristics to become sufficiently prescriptive towards enacting real world activities. The transfer process is carried out semi automatically by engaging a DM expert with the intimate DM knowledge for a particular disaster. The knowledge structured in the repository underlies the decision making processes. In the repository, the knowledge is organised based as a 3D structure representing the various DM phases. For responding a particular disaster event, the knowledge will inform what DM phase the concern should be taken into account, the representative DM activity, and the urgency level.

2.3.4 The framework prototyping

A prototype operationalising the framework is built. The architecture is as described in (Inan & Beydoun, 2017b). It essentially comprises of two tools. The first one is the Agent-Oriented Analysis tool. This tool is used to analyse and model the knowledge elements from DISPLAN template and structure them based on the corresponding ABMs. The output of the tool is the ABMs of the DISPLAN template that is compiled in an XML file. Subsequently, the knowledge in the XML format is then transferred to the second tool representing the repository. The repository is built using MySQL, an open source Data Base Management System (DBMS). The knowledge stored in the DBMS is easily accessible and modifiable during decision making processes.

3 Decision making support based on the framework

As earlier described, knowledge elicitation and/or retrieval mechanisms follow two processes: either bottom up or top down. As can be seen in Figure 3, in the top down process concepts in the repository are first identified before drilling down to enable instantiation of actual DM activities. In the bottom up process, the decision can be formulated based on particular activities which are rolled up conforming to the structure of the constructs in the repository. The constructions steps (downwards instantiation or upwards conformance) are in accordance with MOF as elaborated (see Figure 1). All decision making processes are operationalised in the prototype demonstrated in this paper. In this section, the prototype showing both types of knowledge mechanisms is presented.

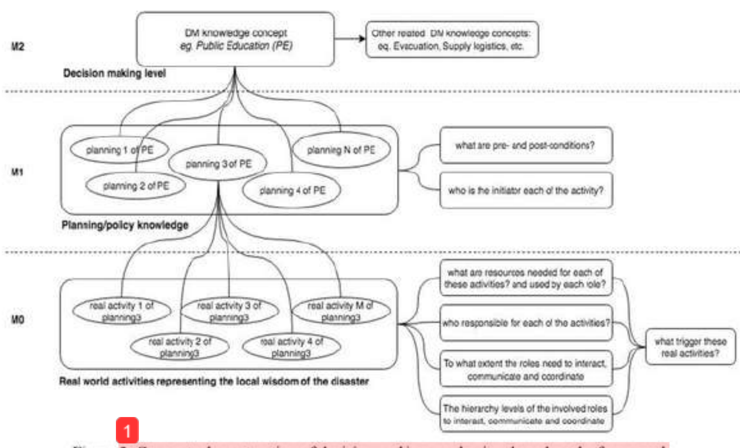

Figure 3. Conceptual construction of decision making mechanism based on the framework.

3.1 Bottom up approach

In the bottom up approach, the decision making begins by identifying the knowledge guiding the DM activities, carried as a response to environmental changes. This knowledge guides stakeholders undertaking real world activities, e.g. stakeholders evacuating inhabitants threatened by the disaster. They interact, collaborate and negotiate with each other, and also educate people living in affected areas, distribute aids, etc. The knowledge identified should be sufficient to guide such roles in these particular activities. The authorities who use elements of this knowledge need to be able to use it directly. Based on the conceptual construction of the DSS as shown in Figure 3, this typical knowledge is structured as *M0*. This then rolls up to identify the representative knowledge elements of the empirical knowledge. Both empirical knowledge and its abstracting elements are different MOF layers.

The representation of the knowledge at *M0* is described more abstractly at *M1* layer. At M1, the knowledge is aimed at the authorities who develop plan or policy of the DM activities. As can be seen from Figure 3, each of the DM knowledge plans in *M1* contains various and empirical activities of *M0*. While the *M0* layer contains know-how, -what, -with, -who, -why and -when, these empirical elements may be represented as one plan/policy only as they fundamentally are in one concept at M1. Moreover, there might be various plans/policies that aim to pursue that particular concept at M1. This concept can be easily retrieved from the DM knowledge repository structured according to a DM metamodel as presented in (Othman & Beydoun, 2016). Recognising the plans/policies and their concept representation uses the semantic mapping described in KAF (Inan *et al.*, 2017). For instance, in a case of a volcano eruption, the trigger knowledge from the response authority inform that "*volcano is going to erupt*". This knowledge element will be the trigger for other authorities to perform the necessary activities to respond to. The related activities for instance "*Search and Rescue (SAR) Team standby in each designated post*", "*SAR and authorised DM agency keep monitoring visually and technologically the volcano activities*", etc. The operationalisation of these knowledge elements needs to be further specified, i.e.: whether it could be done using a telescope or a drone with appropriate technical specifications. In other words, the knowledge should inform not only: "what are the activities", but also "who activates them", "to what extent the involved roles negotiate, coordinate and interact with each other", "what are the resources needed by the roles to perform the activities", and other empirical knowledge elements. Since these elements have been previously stored in the repository, they can then be easily retrieved and reused as needed.

All above knowledge elements might represent one DM plan only, for instance "*initiating response phase activities*". In reality, there might be multiple alternative plans. All alternative plans may in turn represent one concept, for instance, "*command*" in the repository (*M2*). In other words, under the "*command*" concept of this particular case, multiple plans can be provided and each plan may have different activities.

3.2 Top down approach

In the top down approach (instantiation), the decision making process is constructed by instantiating identified concepts into the corresponding activities. In this paper, an initial set of the relevant and essential DM concepts have been appropriately deposited the knowledge repository. A relevant concept is first identified as relevant by authorities with the aim to develop resiliency. For instance, in order to develop resilience to a volcano eruption disaster event in the Response phase activities, there is a need of "*A system to manage incident prioritization, critical resource allocation, communications systems integration, and information coordination which includes facilities, equipment, personnel, procedures and communications during a disaster*". Among the populated and synthesized concepts in the repository, this semantic meaning essentially is represented by a concept, *Coordination* from DMM (Othman *et al.*, 2014, p. 258). To operationalise this concept, more DM concepts are required to achieve various goals, identify roles and resources needed, and activities to be performed. The repository itself consists of a number of high level concepts that get refined to achieve goals. The repository has 21 concepts in Prevention, 25 in Preparedness, 25 in Response and 21 in Recovery phases. All these concepts are refined into knowledge elements describing the activities, roles, resources and goals of DM as shown in Figure 3.

The high level layer, M2, is designed for the high level decision makers and this where they begin their decision making process. The *M1* layer is intended for those who are in the planning/policy level, and *M0* layer contains the operationalisations of elements described in the *M1* layer. Using the same example from the previous section, but in reverse, instances of the concept *Coordination* are "*Search and Rescue (SAR) Team standby in each designated post*" and "*SAR and authorised DM agency keep monitoring visually and technologically the volcano activities*". These are essentially examples of plans/policies instantiated from *Coordination* concept. Lower level operational activities are accessible via drilling down from them. All these elements are stored and structured in the repository using KAF (described in Section 2.3). Once the *Coordination* concept is fully processed, other related concepts can be extracted in a similar fashion.

In the next section, we illustrate both decision making approaches within the context of Mt. Agung recent volcano eruption (still active at the time of writing).

4 Evaluations with a case study of Mt. Agung volcano eruption in Bali Indonesia

A case study of Mt. Agung volcano eruption is used to evaluate the developed knowledge pathways. The event is a recent volcanic eruption in Bali Indonesia. The eruption ebbed and flowed since November 2017 up to the time of writing[1]. Using this current and an ongoing event also enables the framework evaluation using fresh reports that are constantly changing as monitoring and response activities are undertaken by authorities. The reports are obtained through constant monitoring of the website of The Centre of Vulcanology, Hazard Mitigation and Geology (PVMBG)[2]. This is the authorised agency in Indonesia that is responsible for assessing the status level of the eruption and enacting associated DM activities. There are four different levels: (1) *normal*: no volcano activity is detected; (2) *vigilant*: there are indications of volcano activities appearing; (3) *alert*: the volcano activities are increasing and, (4) *warning*: the volcano activities are at the highest status and an eruption is probable or under way.

Enacting a particular status level by PVMBG leads to enacting corresponding DM activities by BNPB, the authoritative agency for managing the disaster of this type. In Figure 4, the timeline of the recent fluctuations of the Mt. Agung status levels is shown.

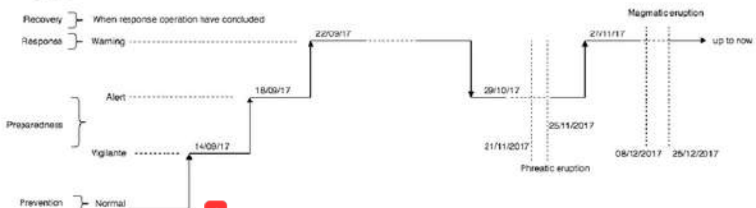

Figure 4. The timeline of Mt. Agung volcano eruption fluctuations.

PVMBG experts observe visually or through sensors data the volcano to appraise any status fluctuations. Once a particular fluctuation is observed, PVMBG issues a recommendation for all the stakeholders (agencies/communities/individuals). For instance, Figure 5 shows a photograph of the condition of Mt. Agung taken by PVMBG on 27 November 2017. After a thorough evaluation by the agency, the status was raised to level IV (*warning*). In addition, as part of the evaluation, recommendations are also issued, which also inform BNPB DM activities and other stakeholders.

As previously mentioned, the objective of the research is to construct the decision making process of this disaster event based on the developed KAF described in Section 2.3. In addition to monitoring the PVMBG website, we sourced knowledge through direct communication with the Deputy Head of Prevention and Preparedness BNPB who is also the National Chief of Mt. Agung DM. He provided us reports containing day to day activities of the agencies involved and the roles they play[3]. These reports contained the knowledge to guide the activities of the involved agencies, for instances: the coordinating and communicating the evacuation activities by Indonesia Search and Rescue agency (BASARNAS) and BNPB, distributing tents and coordinating their constructions by Social Ministry, providing temporary education in the evacuation areas by Education Ministry, and etc. We use these to illustrate how KAF can be used to construct the decision-making mechanisms.

The illustrations of the conversion of the reports from both sources, and how these conversions took place (bottom up and top down) constitute a compelling case study based on real time reports in an actual DM scenario. The evaluation strategy follows the Design Science Research (DSR) (Hevner *et al.*, 2004) in Information System (IS) approach adapted from Venable *et al.* (2016). The evaluation uses the process underlined in KAF. The components of this have been validated statically previously in (Inan & Beydoun, 2017b; Inan *et al.*, 2017). This current case study provides a complementary real time assessment.

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[1] https://bnpb.go.id/berita

[2] http://www.vsi.esdm.go.id/

[3] https://sites.google.com/view/updategunungagung/laporan-harian

Figure 5. Mt. Agung condition that raised the status to level IV (*warning*), taken on 27 November 2017 by PVMBG (PVMBG, 2017).

4.1 Bottom up approach of the case study

To demonstrate the DSS knowledge construction in the bottom up approach, we populate and analyse the reports until one day before the magmatic eruption took place (7 December 2017). We then model and deposit the knowledge in those reports utilising KAF (As described in Section 2.3). We subsequently visualise the deposited knowledge using the developed tool. This paper only discusses DSS construction in Response phase. As can be seen in Figure 4, in the Mt. Agung case study, PVMBG issued a *vigilant* status on September 14th. In only subsequent four days, it issued *alert* status, on September 18th. A *warning* status, the highest one, was enacted since September 22nd 2017 (BNPB, 2017). This *warning* level status triggers DM authorities to undertake the necessary Response phase activities under their jurisdiction. The maximum *warning* status means (a) *volcano is going to erupt*; (b) *eruption will happen in 24 hours*; and (c) *first eruption will be started with gases and ashes*. In the repository, these elements are structured in the trigger section, *M0* (Figure 7b (1)). As indicated previously, once the external conditions are perceived by PVMBG, it then issues recommendations for BNPB, as drawn in Figure 6. To summarise, the process begins with evaluating and presenting the disaster risk potentials, and concludes with issuing the recommendations for that particular condition. The recommendations are operationalised by BNPB which guide the activities for all the involved stakeholders.

Figure 6. The evaluations (1) – disaster potentials (2) – conclusions (3) – recommendations (4) issued by PVMBG for BNPB (PVMBG, 2017).

Figure 7b (2) shows all the corresponding knowledge activities that have been triggered. The activities knowledge was previously stored in the repository. The output of the system guides the responsible roles [(3) in Figure 6]. As for The resources needed in each of the activities or used by each of the roles can also be traced [(4) in Figure 6]. The appropriate sequencing of the activities is also part of the output [(5) in Figure 6]. For instance, for the activity: *maintaining and socialising CHECK YOUR POSISTION application*, the responsible roles are: BASARNAS and

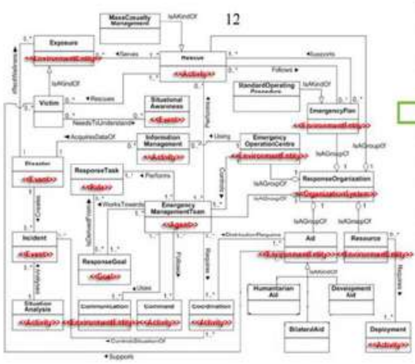
BNPB. The resources needed for this particular activity are *Radio FM* and the website URL needed to download the application. All these knowledge elements are constructed based on the daily activities described in the report provided. In the actual system, these elements are organised in *M0* layer to indicate that they specified for active roles responsible for real world activities. In other words, they are the operational roles that do not interpret the knowledge any further but utilise it on the ground. Activities of such roles are also typically time sensitive.

Knowledge System for Disaster Management (KSDM)

Based on Agent-Oriented Analysis (AOA)

Home | mGoal | mRole | mOrganisation | mInteraction | mEnvironment | mAgent | mScenario | **Response** | Project | How To | About |

M2: Disaster Management (DM) Metamodel - Concepts and Relations



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Annotated DMM concepts of Response Phase 11

#	DMN Concept	Annotated Concept	#	DMM Concept	Annotated Concept
1	Aid	<<Activity>>	14	Incident	<<Event>>
2	BilateralAid	<<EnvironmentEntity>>	15	InformationManagement	<<Activity>>
3	Command	<<Activity>>	16	MassCasualtyManagement	<<Activity>>
4	Communication	<<EnvironmentEntity>>	17	Rescue	<<Activity>>
5	Coordination	<<Activity>>	18	Resource	<<EnvironmentEntity>>
6	Deployment	<<Activity>>	19	ResponseGoal	<<Goal>>
7	DevelopmentAid	<<EnvironmentEntity>>	20	ResponseOrganization	CentralConcept
8	Disaster	<<Event>>	21	ResponseTask	<<Role>>
9	EmergencyManagementTeam	<<Agent>>	22	SituationalAwareness	<<Event>>
10	EmergencyOperationCentre	<<EnvironmentEntity>>	23	SituationAnalysis	<<Activity>>
11	EmergencyPlan	<<EnvironmentEntity>>	24	StandardOperatingProcedure	<<EnvironmentEntity>>
12	Exposure	<<EnvironmentEntity>>	25	Victim	<<EnvironmentEntity>>
13	HumanitarianAid	<<EnvironmentEntity>>			

Concept and the annotation

DM Phase	**Response**
Concept	**EmergencyManagementTeam** 9
Annotated Concept	**<<Agent>>**
Concept Terminology	**An organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps.**

Concept relationship

#	Domain Relation	Concept Relation	Annotated Concept	Relationship cardinality	Relationship name	Relationship type
1	ParticipatesIn	Coordination	<<Activity>>	1..* To 1..*	Requires	Association
2	ParticipatesIn	Command	<<Activity>>	1..* To 1..*	Follows	Association
3	Uses	Communication	<<EnvironmentEntity>>	1..* To 1..*	Uses	Association
4	Pursues	ResponseGoal	<<Goal>>	1..* To 1..*	WorksTowards	Association
5	Plays	ResponseTask	<<Role>>	1..* To 1..*	Performs	Association
6	ParticipatesIn	Rescue	<<Activity>>	1..* To 0..*	Performs	Association
7	Uses	EmergencyOperationCentre	<<EnvironmentEntity>>	1..* To 1..*	Controls	Association
8	-	ResponseOrganization	CentralConcept	0..* To 1	IsAGroupOf	Aggregation

10

1

Figure 7a. *M2* Knowledge structure for decision making system based on MOF framework.

1

All knowledge elements detailed in *M0* are also abstracted at the planning/policy level, M1. For instance, elements describing *activities* represent only one planning/policy, "*keep activating national assistance post (POSPENAS)*" (see Figure 7b). To fully perform an activity, knowledge of related planning/policies may also be needed. Utilising the KAF, those can be easily examined as shown in (Figure 7b (6)). For instance, for the activity "*maintaining a health cluster call centre: 085 337 106 319*", clicking the corresponding element shows in addition to the M0 knowledge the following: the pre- and post-condition of the activity, the initiation sequence from a planning perspective and the initiators of the activities [(7) in Figure 7b]. Those are "*POSPENAS has been established since Preparedness phase*", "*POSPENAS is kept activated*" and "*BNPB*" respectively. The information regarding the origin of the knowledge, the type of the disaster, as well as the context (e.g. country) are also presented in this layer. This allows other stakeholders to get insight and scope of reuse for similar DM types [(8) in Figure 7b].

As can be seen from Figure 7a, the planning/policy knowledge is represented only as a *coordination* concept in the DM knowledge repository (*M2*). There are other various concepts shown in Figure 7a (9) that are directly related to the *coordination* concept. These other concepts can further enrich the insight for those who are highly involved in the Response phase activities in any level real world activities – planning/policy – decision making.

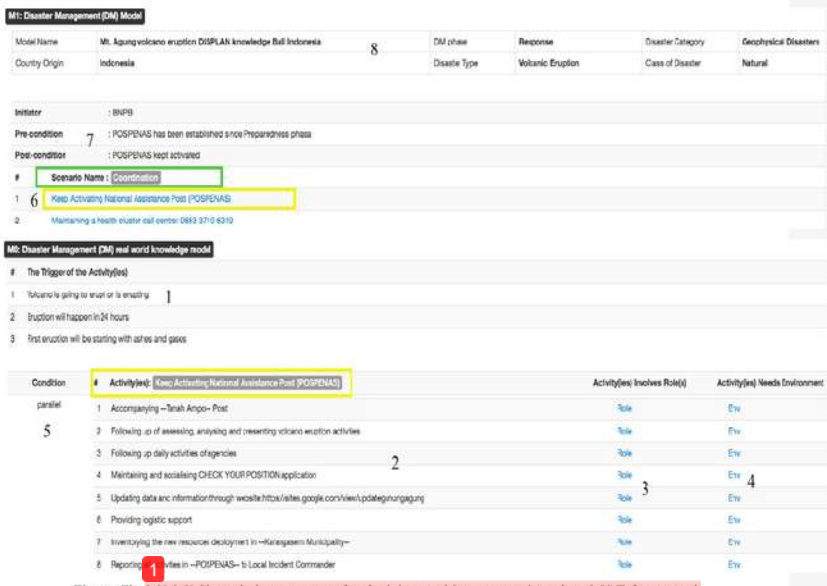

Figure 7b. *M1-M0* Knowledge structure for decision making system based on MOF framework.

4.2 Top down approach of the case study

The construction of the decision-making process can also be undertaken in a top down fashion. In this approach, the essential and relevant concepts are first identified. This aims to broaden an understanding how the DM activities would be performed. The concepts first identified are made available in the DM knowledge repository. The DM repository has facilities using an the inbuilt existing metamodel (at M2 level). As can be seen in Figure 7a, for example all the essential and relevant knowledge concepts in the Response phase are listed in (Figure 7a (11)) and their relations in (Figure 7a (12)). In this case, once a concept is recognised from the metamodel, others that are directly related can also be identified easily. The way these concepts are related further facilitates knowledge perusal. The complete set of concepts, once identified from the metamodel, allows performing the DM activities in a more comprehensive way.

In this approach, BNPB identifies fluctuations in the circumstances by proactively accessing the related and essential concepts in the *M2* level (DMM) of the repository. These are then used to identify *coordination* activities for those who are on the planning and real world activity levels. For instance, once there is a need to "*manage incident prioritization, critical resource allocation, communications systems integration, and information coordination which includes facilities, equipment, personnel, procedures and communications during a disaster*" (Othman *et al.*, 2014, p. 258) then these activities are identified. However, instead of getting insight of the activities within the *Coordination* concept alone, recognizing other related concepts is crucial to understand the full DM activities required in the Response phase. This leads to a better understanding in developing DM resilience overall endeavours and better identification of all essential concepts. As can be seen from Figure 7a, other concepts directly related to concept *Coordination* are: *Command, Communication, ResponseGoal, ResponseTask, Rescue, EmergencyOperationCentre*. The recognised concepts inform that not only be the *Coordination* should be performed in the decision-making mechanism, but also due attention is needed to those other concepts. The concept *Command* informs other activities, *Communication* defines the resources needed by the activities and/or used the involved roles, *ResponseGoal* describes the goals to be achieved in each activity scenario and etc. (see Figure 7a (10) and (11)).

In our DSS, the knowledge access begins at the *M2* layer for the benefits of the stakeholders involved in the decision-making processes. Once a decision is made then those who are on the planning/policy layer (*M1*) need to describe the knowledge fit for those operating at this particular layer. This process continues to the lower layer, *M0*, that is aimed to identify guidance for responders who will be active on the ground. This knowledge structure allows the decision-making process to be transparently and holistically executed, with a clear visibility from high level decision making, to the policy/planning and to real world M0 responders.

5 Discussion

The contribution of this paper has an important implication for successful deployment of Decision Support Systems in DM. The paper has highlighted the need for two modes of knowledge transfer to support to two decision making styles in DM. The two styles are valid and appropriate but under different settings. Specifically, this paper has demonstrated as to how the decision is mechanised in a disaster event when the knowledge trigger either comes from external factors that is environmental changes (reactive) or based on the initiative of the authorities for managing the disaster (proactive). This issue essentially has been a continuing concern in DM research stream for instance as recognised by these scholars (Dorasamy *et al.*, 2017; Doyle *et al.*, 2014; Fogli *et al.*, 2017). A functioning prototype is also developed to operationalise the two approaches for decision making.

The work here assumes that the knowledge is tied to specific disaster plans, management of a volcanic eruption. In principle, knowledge applicable to different types of disasters can be stored and managed at the same time. Some scholars, e.g. (Fogli *et al.*, 2017; Othman & Beydoun, 2016) illustrated how generic DM decision processes can be developed, for managing various disaster scenarios. This work sought operationalisation of the knowledge in the context of the event described. That is, the aim was that the knowledge conversion process reflects operational knowledge (know-how, -what, -with, -who, -why and -when) for those who are on the ground. The KAF adopted allows this. The knowledge elements stored and reused allowed the decision making process to be laid out in practical and operational timeline, across each layer of MOF. This timeline arrangement of elements is crucial to prevent a hazard turning to catastrophic loss of life (Santiago *et al.*, 2016).

By adopting KAF as a tool for knowledge conversion process, to some extents, the work provided guidance to address the challenging issues of eliciting the complex knowledge elements from the DM domain. This issue for instance has been the focus of various works e.g. (Hiwasaki *et al.*, 2015; Kniveton *et al.*, 2015). KAF allows the authorities to deal with uncertainties in DM domain by understanding and analysing subsequently structuring them into a format by which common stakeholders are able to understand them. The work enables eliciting of knowledge during a disaster management response and/or disaster preparation. The knowledge elicited supports subsequent decision making processes in disaster events. Particularly, we have demonstrated our elicitation process in a conceptual framework shown in a case study accommodating knowledge construction and reuse using either bottom up or top down approach. Which of these two approaches is more suitable to guide the decision development process depends on the context and the knowledge reuse/storage trigger, be it external (e.g. response phase) or internal (e.g. preparation). If the trigger is due to environmental changes, then the bottom up process is chosen (reactive). On the other hand, if the trigger is based on the internal initiative (proactive), the top down approach will be automatically followed to escort the development of decision making process. Once the approach is chosen the knowledge elements in the conceptual – planning/policy – real world activity levels can be generated accordingly.

The two approaches are validated in line with the Design Science Research (DSR) methodology. As KAF is the foundation of the approaches, its validation has already been conducted (ex-ante naturalistic) (Venable *et al.*, 2016) using three case studies of the SES Australia (two from New South Wales and one from Victoria States) (Inan & Beydoun, 2017a, 2017b; Inan *et al.*, 2016). The paper provides an additional ex post naturalistic evaluation (Venable *et al.*, 2016). Thus, both approaches are verified using the recent event from Indonesia, Mt. Agung volcano eruption. The scenarios of verification are developed based on the eruption fluctuation times. Once the warning status was enacted (the highest one), the bottom up approach then guided the decision making process from formulating the empirical knowledge elements to the conceptual ones for the authorities. In the top down approach, the initiative for the DM is taken by the authorities and the relevant concepts were first populated from the repository (DMM). The concepts were subsequently used to generate empirical knowledge elements. In addition, a web-based tool was built for the purpose of this verification and its impact and usage were discussed.

6 Conclusion

This paper presents knowledge construction and retrieval mechanisms for decision making system in the DM domain. The mechanisms are based on two approaches: bottom up and top down approaches. The ongoing (at the time of writing) volcanic eruption event of Mt. Agung in Bali Indonesia is used to evaluate both approaches. This event is chosen as its currency enables the evaluation to go in parallel with the volcanic activity fluctuations from *normal* level to the *warning* level. Our evaluation successfully shows that the decision making mechanism in DM can be constructed using either bottom up and/or top down. Each approach has its own merit in supporting reuse of knowledge. The knowledge from the dynamic situations perceived by the authorities act as a trigger for them to select appropriate operational activities. Extant DM knowledge elements deposited previously in the repository facilitates the authorities to assess triggers and select corresponding activities. To ensure completeness of operational activities and that none are overlooked, a higher level view is needed. The top down approach knowledge retrieval enables this and lays out knowledge elements in the upper layer (planning/policy layers) to support this. These higher level elements provide broader view to uncover the need for any further and related operational activities, in addition to those identified due to the triggers.

In some cases, it is possible to initially identify all essential and relevant knowledge concepts from the higher level view to identify all operational activities. That is, a top down approach would be sufficient. In practice, this approach relies on recognising few starting high level corresponding concept appropriate for developing resiliency or response. These starting concepts broaden the scope of understanding of the authorities whose ultimate goals are to produce actions on the ground. Those concepts are thus refined into lower level concepts using the underlying metamodel in the DM knowledge repository. The Disaster Management Metamodel (DMM) adopted in this research allows this to happen (See Figure 7a (11) and (12)). The concepts and their refinements are subsequently used to generate descriptions of operational activities.

Both approaches described in this paper are enabled by the use of Knowledge Analysis Framework (KAF). This is chosen as it has been successfully evaluated (Inan *et al.*, 2017) in transforming semi-structured DM plans into a MOF based repository. The KAF facilitates the knowledge elements deposited in the repository to be structured in a way that they can be used at any point of the timeline in a DM case. This paper complements existing work towards sharing and reusing prior DM knowledge and illustrates the decision making process in an unfolding disaster. The decision making approaches presented accommodate the four DM phases (Prevention, Preparedness, Response and Recovery). Whether the knowledge elements are rolled up or drilled down, will depend on the time sensitivity of events and this is typically phase dependent. In other words, it is clear that activities across various phases have different time requirements and both approaches are needed. Our communication with the Deputy of Prevention and Preparedness of BNPB revealed that in the Mt. Agung volcano eruption, both approaches take place. The decision making process has top down features. The initial communication between the Deputy and BNPB underlying the high level decision making process is modelled at *M2*. The knowledge communicated by the provincial DM agency is modelled at M1. At the municipality/regency level, knowledge provided is at the *M0* level (In Indonesia, BNPB is in the national level and its form in the provincial/municipality/regency is called BPBD). Although this delineation illustrates the effectiveness of the knowledge representation based on MOF vis-à-vis the Indonesian DM activities, further scrutiny is required. Further validation is required to confirm whether the M0 knowledge (in regency/municipality level) conforms to its *M1* source (provincial level), and to confirm that *M1* conforms to *M2* (national level). Indeed, the current practices modelled are not fully documented in DISPLANs for provincial/municipality/regency that can be accessed as the evidence. In this regard, our approach can also supplant the DISPLANs but broader consultation would be needed with the DM agencies concerned.

7 Limitation and future research direction

The recent eruption of Mt. Agung volcano in Bali Indonesia is used as a case study to demonstrate usage of a DSS for DM. This successfully evaluates the proposed system architecture. Notwithstanding the promising results, the following limitations are worth noting: Firstly, the evaluation relied on a re-enactment of the disaster situation, rather than the actual disaster as it unfolded. A stronger evaluation would require a real time deployment of the system. In other words, stakeholders directly engaging with the system during the disaster event is required to ascertain the performance of the system in an operational environment. This will provide feedback and evaluation of the real world activities that would ensue as a result of the system. That would certainly shed more light of the efficacy and effectivity of the DSS approach in interacting with the stakeholders under a stressful situation. Without an appropriate regulatory approval, this real time embedding of the system is clearly not yet feasible at this stage. Towards that, a deeper understanding the impact of the developed approach on end users is first needed. An intermediate study is required to prepare for an evaluation in a real disaster event. Such study could use IS theories such as activity theory (Engeström, 1999) which has been broadly proposed for the DM domain, e.g. (Allen *et al.*, 2014; Bharosa *et al.*, 2012; Chen, R. *et al.*, 2013; Hasan *et al.*, 2017). The use of this IS theory will be part of our future research direction.

Ideally, the approach would be more effective using a pre-existing level of planning as encoded by the disaster management plans. This is not always feasible. For instance, BNPB does not yet have fully documented DM plans that can be accessed publicly. Such plans would inform the DM activities in Provincial and/or Regency/Municipalities as they can utilise it in conjunction with their own local wisdom. This has been previously demonstrated in the development of DISPLANs in Australia, for the Municipalities of Wagga-Wagga and Wollongong in NSW SES context and for Moira Shire Municipality in Victoria State (Inan & Beydoun, 2017a, 2017b; Inan *et al.*, 2016). It is our hope that our presented approach will be a further impetus for such plans to be developed where they currently do not exist. Indeed, in our view is that it is urgent for BNPB (and perhaps other DM agencies in other countries) to develop a fully prescriptive and comprehensive DISPLANs that can be used as foundational knowledge in a system such as the one presented in this paper.

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