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Disaster Management Knowledge Analysis Framework Validated

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Abstract

In Disaster Management (DM), reusing knowledge of best practices from past experiences is envisaged as the best approach for dealing with future disasters. But analysing and modelling processes involved in those experiences is a well-known challenge. But the efficient storage of those processes to allow reuse by others in future DM endeavours is even more challenging and less discussed. Without an efficient process in place, DM knowledge reuse becomes even more remote as the effort incurred gets construed as a hindrance to more pressing activities during the execution of disaster activities. Efficiency has to also be pursued without compromising the effectiveness of the knowledge analysis and reuse. It is important to ensure that knowledge remains meaningful and relevant after it is transformed. This paper presents and validates a DM knowledge analysis framework (DMKAF 2.0) that caters for efficient transformation of DM knowledge intended for reuse. The paper demonstrates that undertaking knowledge transformation and storage in the context of its use is crucial in DM for both, effectiveness and efficiency of the transformation process. Design Science Research methodology guides the research undertaken, by informing enhancements and how the framework is evaluated. A real case study of flood DM from the State Emergency Service of Victoria State Australia is successfully used to validate these enhancements.

Keywords Disaster Management · Knowledge Analysis · Knowledge Management · Agent-Oriented Modelling · Metamodeling

1 Introduction

A growing body of literature recognises that learning from the best practices of past experience has been envisaged as an effective way in DM resilience endeavours (Elia & Margherita, 2018; Li et al., 2019; Lin & Chang, 2020). In many cases, this is also an efficient value proposition as the knowledge is already available and is ready to be adopted and adapted to recurring disaster situations (Weichselgartner & Pigeon, 2015). The importance of knowledge reuse was tragically observed in the aftermath of the Indian ocean mega earthquake which was followed by the worst tsunami disaster in 2004 (McAdoo et al., 2006). People in Simeulue Island, Aceh Province Indonesia, harnessed DM knowledge passed to them from earlier generations (Syafwina, 2014) and this knowledge reuse saved almost the entire population of the island compared to the harrowing impact on the mainland of the province. Likewise, in the aftermath of the Japanese Tsunami in 2011 which caused more than 25,000 casualties in the most disaster-aware nation on Earth (Satake, 2014). Students in both elementary and junior high schools in the affected areas could manage to escape and save their lives, as they had been prepared with the similar prior knowledge (Parker, 2012). These instances demonstrate that reuse of best practices of past experiences can be hugely significant in DM. Knowledge reuse in this context requires facilitation of information flow to enable timely retrieval and speedier

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interaction with extant sources developed from past experience. Such efforts have been acknowledged and institutionalised by international communities, for instance, through Sendai Framework for Disaster Risk Reduction 2015–2030 (UNIDSR, 2015). This awareness essentially provides the space to pursue a process that hastens flow of information from past experiences and faster information flow within the current episode of a disaster management. This at the same time highlights the acute need to analyse and structure DM knowledge in a way it can be easily used to source information in the future. To allow this to happen, the essential and relevant knowledge elements need to be transformed into a reusable format to allow others to extract and apply effectively.

In documents describing DM knowledge, the essential and relevant knowledge elements are typically organised in a semi-structured format. Common examples of such documents are Disaster Management Plans (DISPLANs) and Situation Reports (SITREP). Although a DISPLAN usually includes best practices focused on scientific information and is seen as a timely reference for stakeholders (Inan et al., 2018b; Santiago et al., 2016), a SITREP contains real-time knowledge about how a crisis is occurring on the ground and is important for first responders (SES Victoria Australia, 2014). These two typical documents provide different type of DM stakeholders with first-hand and pivotal knowledge elements in a disaster event. These particular elements should be in a context-based representation that can be retrieved at the first place by those who are on the ground in need. However, as similar DM activities and concerns are common across different parts of the world with the different communities, geographic characteristics, etc., recognising the local characteristics where a disaster occurs is also critical to harness the power of reuse. This can ensure that the knowledge can be well adapted by DM stakeholders for effective use for all the hierarchy administration levels. Processes to delineating the reusable elements from those that need to be adapted to the local context have been formulated in Inan et al. (2018a). Those processes have been encapsulated within the Disaster Management Knowledge Analysis Framework version 1.0 (DMKAF 1.0) which is part of our larger project which is aims to contribute to the DM resilience endeavour. DMKAF1.0 facilitates the analysis and reuse of Disaster Management Plan (DISPLAN) by using Agent-Based Models (ABMs) to enable its subsequent transfer and unification into a unified repository. The repository can then be accessed at any point of the DM timeline determined by the roles requiring the access. The repository structure is developed following Meta Object Facility (MOF) (OMG, 2013) that is represented in three layers: *M0-M1-M2 describing* the real world components, model and the metamodel/modelling language, respectively. While *M0* is for those who are dealing with the technical activities on the ground, *M1* and *M2* is for the planning process and executive decision makers, respectively.

DMKAF1.0 was successfully tested with two real case studies of the State Emergency Services (SES) from the New South Wales (NSW) State of Australia. But those tests highlighted a number of shortcomings that limits its practical applicability. Firstly, the two Australian cases of Wagga-Wagga (Inan et al., 2016) and Wollongong (Inan & Beydoun, 2017b) municipalities, highlighted the complexity in conversion of DISPLANs to a unified language. In particular, they exposed the prohibitive cost of analysis and modelling activities within the framework. Secondly, the tests also highlighted that as similar DMs occur in different geographic areas and have context needs, incorporating such context-based characteristics tailored into the framework is very much needed. For this, reliance on external sources to support the analysis of the DISPLANs is needed. This is to allow the stakeholders, particular those who are on the ground, to respond the situations more effectively as they are equipped with more detail knowledge elements specifying the local context. Responding to these two shortcomings, reducing the conversion cost and incorporating localised external sources, are the key contributions to be illustrated in this paper. Clearly, pursuing a more efficient framework should be done without compromising its effectiveness. To evaluate our response to those two challenges in this paper, we use a new case study. This new case study will not only validate the enhancements. But more importantly, the evaluation will pave a way for the enhanced framework to be generalised for other similar case studies. Design Science Research of Information System (DSRIS) (Hevner et al., 2004) guides the research cycle. Thus, once the more efficient framework is developed (we call the new version of the framework as DMKAF v2.0) is developed, the validation will be conducted. Following DSR, the produced information system artefact is not only specified for a particular issue but should also be able for a class of problems (Gregor & Hevner, 2013; Rossi et al., 2012).

This is how the article is structured: The second section includes works from the existing literature. Section 3 describes the stages in the DSR methodology underpinning this research. Section 4 discusses the evaluation of the new framework with a real case study. Section 5 concludes and discusses the research and Sect. 6 outlines the future research direction.

2 Related Work

In DM, lessons learned are an integral part of the community, but the unique dangers and complex nature of scenarios also make effective documenting and sharing of previous experiences extremely difficult as best-practices knowledge is distributed among many stakeholders. In addition, global change exacerbates severity and likelihoods of hazardous events, calling for consistent monitoring of trends in data and models, and adaptive revision of DM planning procedures and their implementation to minimize losses and increase disaster resilience. For example, the Philippines in 2014 experienced zero casualties as the country put to use knowledge learnt from a previous typhoon disaster, a year earlier which in contrast had caused more than 6,300 casualties (Velasquez, 2014). In contrast, the response to the earthquake followed by the tsunami stroke Palu City in Indonesia in 2018 (BBC Indonesia, 2018), was not sufficiently informed by prior knowledge and this has proven to be the determining factor in the outcome (Widianto, 2018). The risk of that particular area was not sufficiently incorporated into subsequent plans (Fiantis & Minasny, 2018). Actually, post-mortems of catastrophe responses often illustrate the presence of sufficient knowledge but inadequate knowledge transfer (Bray, 2007). This is also recognised through large efforts that focus on dissemination of generic disaster preparedness and planning by international bodies such as evacuation manuals (CCCM Cluster, 2016). Authoritative agencies often act as custodians of DM knowledge in semi-structured text documents. For instance State Emergency Services (SES) is the authoritative agency to combat disasters in Australia. They are custodians of Disaster Management Plan (DISPLAN) documents (SES NSW Australia, 2016). However, the DISPLAN itself is mostly written in a business specification format which is subjectively perceived by the various DM stakeholders (Weichselgartner & Pigeon, 2015). Moreover, Providing representative knowledge in a timely manner is also another critical issue that needs to be addressed in the DM research agendas.

Whilst DM knowledge coding is intended for reuse, it is challenging to do so without a proper degree of contextualization and interaction of unique disaster characteristics. Furthermore, external sources that could easily assist in contextualising actions are often not sufficiently utilised as they may not be available for reuse and adaptation and do not easily integrate with recommendations expressed in textual DM plans. For instance, an appropriately calibrated flood simulation could easily highlight which parts of a flood management plan can be safely ignored, but these two existing knowledge sources are seldom integrated in real time. This leads to accelerating costs of DM calling for coherent digital knowledge services, which support decentralized decision making in the time- and resources-efficient manner and which evolve as new knowledge becomes available.

Scholarly concerns regarding the above include investigating techniques that can assist the DM authorities with sufficient and representative knowledge timely and improving the decisions making mechanism in disaster events (Elia & Margherita, 2018; Sword-Daniels et al., 2016). However, due to the unique existence of each catastrophe, it is impossible to create a standardised policy that would be successful in all Disaster Management situations. As the first and critical step towards these issues is by tackling the diffusion issues of the DM knowledge that permeate in all PPRR phases (Prevention/Mitigation/Planning; Preparedness; Response and Recovery). This is accomplished by comprehending (Thapa et al., 2017) and providing (Mejri & Pesaro, 2015; Rivera et al., 2015) DM implementation with as much applicable best practice knowledge as possible as a prerequisite for DM resilience endeavours. DM knowledge needs to also be decomposed and availed to promote a better decisions making mechanisms (Coppola, 2011).

This paper essentially extends our work in (Inan et al., 2018a). Previously, we developed a Disaster Management Knowledge Analysis Framework (DMKAF1.0) (Inan et al., 2018a) to analyse and model DM knowledge before storing it into a unified repository, Disaster Management Metamodel (DMM) (Othman & Beydoun, 2016). This repository key feature is that it abandons a timeline series in favour of unrestricted access to every step of the PPRR phases. DMM itself is a collection of complete concepts and their relations that lend themselves to represent the organisational know-how and the processes in DM activities. It was initially built conforming the structure that represents the DM domain thoroughly based on the three modelling layers of OMG (OMG, 2013): *M0-M1-M2* representing real world object, the model and the modelling language, respectively.

Agent-Based Models (ABMs) are utilised to disentangle the DM knowledge and complex characteristics of the domain (Lopez-Lorca et al., 2016). The ABMs is used from Agent-Oriented Software Engineering (AOSE) domain. ABMs are employed in a descriptive manner to disentangle the intertwined knowledge in DISPLANs using the elements in each representative model as a reference. The ABMs themselves are constructed using a metamodel, FAML (Framework for Agent Modelling Language) (Beydoun et al., 2009). Hence, the conversion process of ABMs to DMM is theoretically derived using FAML and DMM and it is construed as a model transformation, that is a model transferred to other models (Mens & Van Gorp, 2006; Sendall & Kozaczynski, 2003). This conversion process has been fully described by OMG (OMG, 2013) through the Meta Object facilities (MOF) framework. Thus, employing MOF has two missions: (1) guiding the conversion stages of ABMs to the unified repository; and (2) providing the clear-cut of the knowledge structured in ABMs as it is provided for the decision making process – planning and real-world object (Inan, 2017). Knowledge from the repository can be retrieved by various DM stakeholders. The knowledge elements in MOF's layers are interconnected based on their semantic knowledge as they fundamentally conform to the same meaning except in the different situations. Although previous evaluations have been successfully conducted to measure the efficacy and the effectivity of the developed framework, it also highlighted further scope for improvements. In particular, ensure that the analysis is more efficient and that it also applies to external sources beyond the DISPLANs. These are addressed in this paper.

3 Research Methodology

DSRIS methodology guides this research (Hevner et al., 2004; Inan & Beydoun, 2017a). In DSRIS, the essence is the "building" and "evaluating" activities, meaning once built, the next to proceed is the evaluation of the produced IS artefact. The output resulting from the building process could be a method, or model that might be turned into an instantiation. They will then be validated in the evaluation stage. This evaluation aims to discern the efficacy, that is, to what degree does the created artefact's functionalities operate in response to the formulated requirement; and the effectivity, that is to what extent the artefact contributes as a solution for the problems the artefact aims to address.

For this to happen, the evaluation therefore should be equipped with the appropriate metrics (Gregor & Hevner, 2013; Peffers et al., 2012; Venable et al., 2016). The aim is to guarantee that (1) the produced artefact can be measured its effectivity and efficacy (2) the feedbacks can be used for the later artefact enhancement; and (3) the produced artefact could contribute to the knowledge base. In other words, it is important to ensure that the produced artefact has experienced a suite of enhancement to meet the requirements. Moreover, it is also important to justify that the artefact produced from the research is not a routine design, but it should be either an *"invention, improvement or exaptation"* (Gregor & Hevner, 2013, p. 352). Therefore, understanding the interplay between technology, people and organisation to which the solution IS artefact aims to contribute to is critical. Understanding these interactions prior will not only contribute to the research but also define the evaluation criteria of the developed artefact(s) (Sein et al., 2011).

As previously described, this research is part of a larger project aimed to contribute to the DM resilience endeavours. Therefore, in this research, we do not showcase the construction of the artefact from scratch. Instead, we use our DMKAF1.0 as the basis for a further evaluation following the proposed enhancements outlined earlier. For this, we employ another real case study from the SES Victoria State. Although in one country, states in Australia have their own governments. Thus, even though there are obvious commonalities between the states of NSW (where another case study was executed) and Victoria (the current case study): the hierarchy of government structures, DM agencies, the stakeholders, and etc., their differences are unavoidable (e.g. the environments, geographical areas, etc.). This will inevitably pose the specific needs that might challenge the DM activities on the ground that differs between the municipalities under the state of Victoria. In addition, embracing a real case study setting from the SES Victoria State is aimed to discern the efficacy of the developed artefact in the real setting. In other words, in the naturalistic setting, the confounding variables can be recognised earlier representing the real environment (Pries-Heje et al., 2008).

The evaluation itself is an iterative process. The iterative process essentially is the DSR per (Iivari, 2015). The purpose is to guarantee that the produced artefact not only to address the problems formulated in particular, but it should also contribute to the domain knowledge. Moreover, the idea of iterative evaluations is also aimed to justify the generalisability of the developed artefact for other similar case studies. The idea is that this produced artefact also needs to address not just the particular problem at hand, but also a broader class of issues. This school of thought is closely linked to another general agreement in IS research: that it is not just tackling the emerging issue but also contributing to the domain knowledge (Gregor & Hevner, 2013). Aligning with improving the effectivity and efficiency the DMKAF1.0, indeed this is also our intention to discern on how this paper can clarify the generalisability of the enhanced framework in the DM cases through this evaluation.

In the evaluation stages, two DM experts from the State Emergency Services (SES) of the states of Victoria and New South Wales in Australia are engaged. Their expertise provides assurance that the content semantics of the original DM plans are preserved when they get converted by the framework and that the enhanced framework works as intended. Two experts (rather than one) mitigate against bias risk and increases the reliability of the evaluation. We managed to maintain the communication with the experts with an intimate DM knowledge in the whole cycle of the evaluation processes. Moreover, in the evaluation stage, we adopted the evaluation strategy as proposed by Venable et al. (2016) to account for why, when, how and what to evaluate. In other words, these empirical knowledge evaluation strategy guides its activity systematically. Particularly, this employed strategy is to ensure that the evaluation of the developed artefact is conducted rigorously and consistent with the problems formulated.

To ease these evaluation processes, we also instantiate the developed framework in a web-based tool. This tool is essentially a proof of concept constructed to demonstrate the principles of methods, modelling and constructing the framework. A master and two bachelor students of Management Information System (MIS) department were highly involved to rigorously test the framework during the initial stage along with the expert from the SES NSW agency. The evaluations of the developed artefacts encompass all their dimensions against the employed real case study. These aim to ascertain the functionality and usability, that fit with the organization, and other related quality attributes (Hevner et al., 2004).

4 Disaster Management Knowledge Analysis Framework Version 2.0 (DMKAF 2.0)

The enhanced framework, DMKAF v2.0, to be evaluated is shown in Fig. 1 (v2.0 as it is the improvement version of the previous one, DMKAF v1.0 (Inan et al., 2018a)). It generally includes three stages: (1) customising Agent Based Model (ABM) templates; (2) creating a unique DISPLAN; and (3) moving the DISPLAN into the repository. Nonetheless, previously indicated this comes with two enhancements as described as follows:

First, as earlier explained, instead of seven, the first enhancement of the improved artefact only employs six ABMs (Stage-1 of Fig. 1): *goal, role, organisation, interaction, environment and scenario models*. Essentially, *both agent* and *scenario models*, in this context, portray the same knowledge representation, i.e. capturing the activities performed by agents in reacting and pro-acting based on perceiving the environment changes. Both models pin down *the* activities to be performed, resources needed, pre-condition, post-condition prior to performing the activities, the trigger to react and so forth, by agent(s) based on a particular main goal, *e.g.* evacuation, providing flood information sources, maintain logistics. However, compared to the *scenario model*, *agent model* focuses on a lower-level aspects which can make the knowledge less reusable. Hence, removing it achieves two purposes: reduces the analysis burden and also makes the knowledge more reusable. It enables context specific knowledge from external sources to be integrated. This context dependent knowledge is generally of operational nature e.g. equipment manuals, usage logbooks etc.

The retained *scenario model* also integrates knowledge elements of all involved roles (played by agents). The *scenario model* aims to manage all the knowledge elements that are based on a specified goal(s) to be pursued. And by managing and visualising the knowledge elements for each main goal in a *scenario model*, the involved stakeholders (the agents) who play particular roles in the DM can comprehend the whole scenario they are in. For instance, what other agents an agent needs to be coordinated, negotiated and communicated with to achieve a particular goal; how to interact with each other as they all likely come from different organisations and hierarchy levels, what resources are needed in pursuing a particular goal and to share among the other agents, etc. Thus, between both agent and scenario models, employing the one that is more complete is preferred. The set of ABM's is examined to ensure only those relevant to the transfer are used. The lower level design model is deleted. Moreover, as noted here (YEO et al., 2010), these inquiries inform that further domain dependencies are better

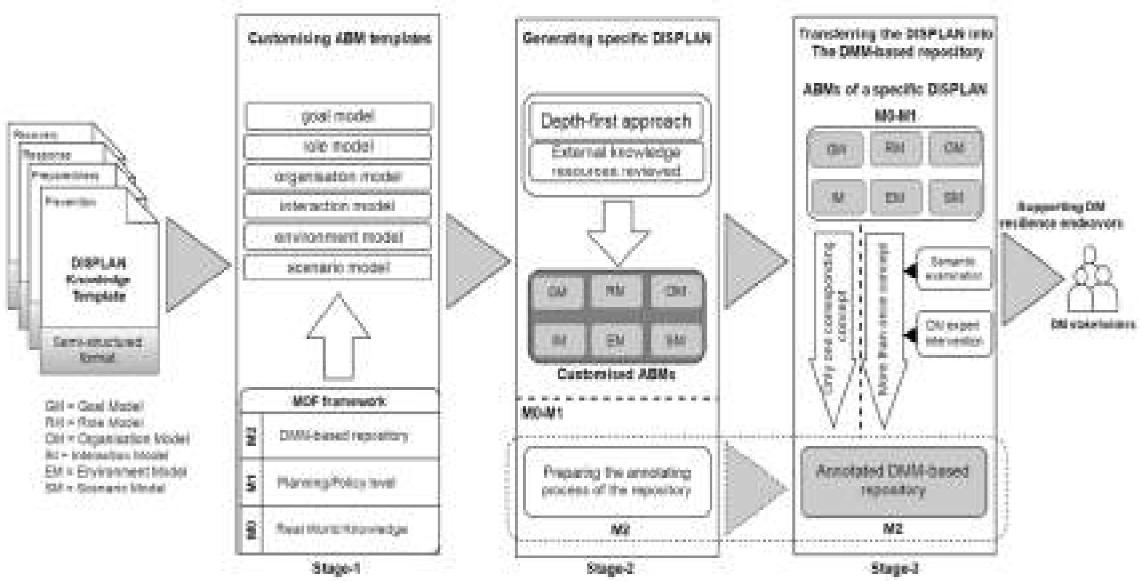

Fig. 1 The Disaster Management Knowledge Analysis Framework (DMKAF v2.0) to be evaluated

served by external sources which describe the specific context. This is further explained as the second enhancement of DMKAF in this paper.

Second, the second enhancement targets at providing more details for the activities involved in DM. To this end, a knowledge transfer pathway that reflects local characteristics has been introduced. Any additional information is needed beyond what is accessible in the DISPLANs. An example of such an activity is the use of Flood Intelligent Card (FIC) (Morgan et al., 2013). FIC is a product of flood intelligent activities intended to provide information related to flood behaviours and the likely impacts to a reference area from various sources (i.e. modelling and flood studies, reconnaissance, flood histories to the anecdotal evidences, insurance company claim record, etc.) (Morgan et al., 2013). The FIC is aimed to provide detail and related information for a better decision-making process in managing flood disaster for a specific environment. In FIC, all data relating to flood heights at a stream gauge and their implications within the gauge's reference region is available.

An example of this is the Stopper river Flood Intelligence Card (FIC) at Annex B of flood preparedness of Victoria SES (Commonwealth of Australia, 2009). As can be seen from this annex, that this typical record provides a detail of the consequences for each point of the water heights for that particular river. The typical information in the card does not only increase the preparedness level of the authorities but also inform the detail of know-how to respond to flood behaviour and its effect to the communities. For instance, all the consequences that might impact to the communities are presented since the river height is from 1.5 m (consequences: *"water starts to break out of the stopper river; flooding low-lying farmland to the south of Nevagazunda; livestock and equipment need to be relocated to higher ground"*) to 11.20 m (consequences: *"Probable maximum Flood (PmF) level: 500 residential properties and 120 businesses flooded over-floor in old Nevagazunda; 1000 residential properties flooded over-floor in swampy heights (3.5 to 3.7 m deep; 250 businesses flooded over-floor in Nevagazunda CBD"*) (Commonwealth of Australia, 2009). This typical information provides a tipping point for a more confidence decision-making process in managing flood disaster event.

Normally the FICs are not part of the main body of the DISPLAN. This is attributable to the fact that they provide confidential details regarding the impact of floods on privately owned land. Clearly, they are crucial for a better flood DM, so the challenges of further analysis to incorporate them in the employed ABMs are important. Analysis tasks are needed to analyse the knowledge elements in all FICs and place them into the corresponding each of the six ABMs that describe the local/specific context of a flood DM. These typical knowledge elements will equip frontline workers with detailed know-how of the activities. Thus, the following two enhancements are added in three stages of DMKAF v2.0 (they are enhanced from the DMKAF v1.0):

Stage 1: Customising ABM templates: A DISPLAN knowledge template and related external references are used as inputs to the system, the FICs. The FICs do not only provide the trigger mechanisms in the form of a threshold of the water height of a specific river, but also the consequences and the immediate actions required for a particular local context. As such, in the stage of analysis and model the DISPLAN template and the FICs, a DM specialist with agent-oriented paradigm understanding (or a knowledge engineer with comprehensive DM background) is involved, subsequently structures them into each of six (6) representative ABMs. These produce the six ABM templates describing the DISPLAN template. As described, the six ABMs that are analysed and modelled in this stage constitutes the first enhancement of the DMKAF v2.0, that needs to be thoroughly examined in this paper.

Stage 2: Generating the specific DISPLAN: the outcome of the Stage 1 is the customised ABMs. In this stage they become the ABMs to generate ones for a particular DISPLAN. A case in point, the customised ABMs are employed to generate a flood DISPLAN of the SES Moira Shire Municipality of Victoria State Australia.

Stage 3: Transferring the DISPLAN into the repository: In this stage, the six ABMs describing a particular DISPLAN (an example from the Stage 2 is the DISPLAN generated for the SES Moira Shire Municipality of Victoria State Australia are transferred into the unified repository. The transferred ABMs contain the analysed and modelling of the specification of external sources.

5 Evaluating the framework

The evaluation here is based on the enhanced framework, DMKAF v2.0, as shown in Fig. 1. In this paper, this is evaluated employing a case study from the flood DISPLAN template of the Moira Shire SES Victoria State of Australia. This typical template DISPLAN is chosen as it describes the similar flood DM knowledge as the one in the two previous evaluations, but it is formulated for a different setting. Thus, this evaluation of the framework with this particular real case study is not only about ascertaining its enhancements but also paving the way for it to be generalised.

5.1 Moira Shire Victoria Case Study

The State of Victoria is responsible for maintaining DISPLANs for its constituent regions and municipalities.

There are 80 Municipalities administered in 17 regions (Regional Development Victoria, 2016). The State of Victoria SES (VICSES) is the DM agency in the State level that is responsible to combat the flood disaster. As in the larger state in Australia, NSW, there is also a flood DISPLAN template for the State of Victoria developed to maintain the consistency for planners statewide at various municipalities. In the framework presented, this template is used as the starting input for the enhanced framework to produce the customised ABMs of the flood DISPLAN for the State of SES Victoria. In the evaluation, the ABMs of flood DISPLAN of the Moira Shire Municipality are generated out of the templates and subsequently transferred into the repository. Both template and the original DISPLAN of the municipality can be accessed freely from the SES Victoria website: https://www.ses.vic.gov.au/. However, FICs are not publicly and require permission from local planners.

The Moira Shire Municipality of the Victoria State that is chosen to demonstrate that every city at the same level of hierarchy (in this context is any Municipality of the State of Victoria) can efficiently generate its own DISPLAN conforming the template. In addition, we had good contact with one of the local planners in Melbourne (Mr Andrew Sheehan). In this context, the DISPLAN of SES Moira Shire inherits all the best lessons to learn from the template but for its specific context. Moreover, in the enhanced framework the knowledge specified the local context that characterises the Moira Shire setting is allowed to be incorporated into the generated DISPLAN. Eventually, this particular DISPLAN is deposited to the repository to be reused as the basis of decision-making mechanism for the flood DM of the Moira Shire Municipality. The detail evaluation employing the case study in this paper is elaborated in the following sections.

5.1.1 Stage 1: Customising the template of Six ABMs

In this stage, the flood DISPLAN SES Victoria is customized. As previously described, there are only six ABMs that will be used in these customising activities. A knowledge engineer analyses the flood DISPLAN template of the SES Victoria and models all the knowledge elements into each of the corresponding ABM templates. The result is the six customized ABM DISPLAN templates of the SES Victoria. These six customised ABMs of the SES Victoria flood DISPLAN will be the foundation to generate any local plan for Municipalities within the State of Victoria. In this paper, this will be the SES Moira Shire DISPLAN knowledge. The framework provides a depth-first mechanism to guide the knowledge engineer on how to do it in detail. The details are elaborated as follows:

Customising the goal model Customising the *goal model* is with the aim to produce a customised *goal model* of flood DISPLAN of the SES Victoria as drawn in Fig. 2.

The customised *goal model* produced in this evaluation is for the SES Vitoria and therefore it will be the basis to generate a *goal model* for any Municipality DISPLAN under the State of Victoria. A main goal "*evacuation*" is identified as an example for the *goal model* template. Following the main goal identification, the < *Municipality* > IC (Incident Controller) as its initiator is identified. All the sub-goals and the roles responsible for each of them are the following to be identified. For instance, a sub-goal "Managing the evaluation process" and the

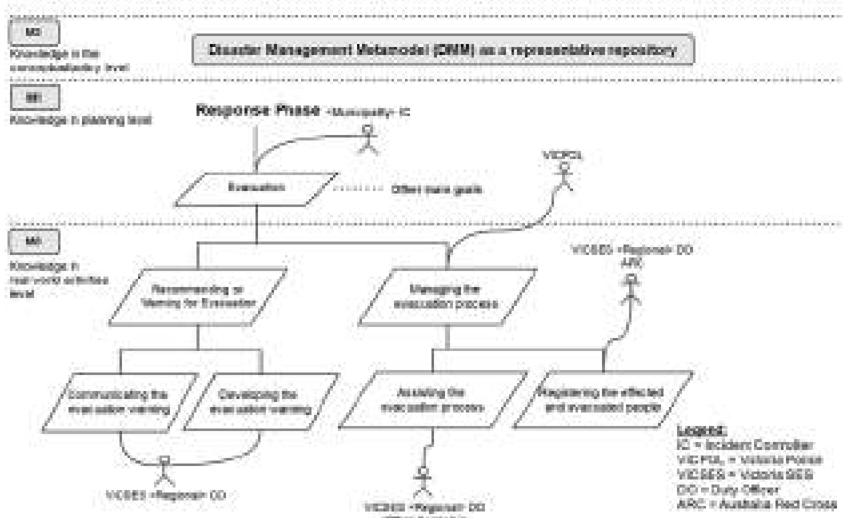

Fig. 2 A customized *goal model* of the DISPLAN of the SES Victoria for a main goal "*Evacuation*"

Table 1 Customized *role model* of the flood DISPLAN template of the SES Victoria State

DMM-based repository		M2
Role knowledge		MOF layer
Role ID	R2	M1
Role Name	VICSES <Regional> DO	
Description	If the knowledge analysed and modelled is from North East Region area, then the <Regional> becomes North East Region DO	
Responsibility	1. Communicating the evacuation warning 2. Developing the evacuation warning 3. Assisting the evacuation process 4. Registering the affected and evacuated people	M0
Constraint	-	

roles responsible for are VICPOL (Victoria Police) and the <*Municipality*> IC themselves. Once this model is completed, the knowledge engineer designates each of the knowledge elements in this model following the MOF framework as either M0 or M1.

Customising the role model Customising the *role model* is based on the previous customised *goal model*. Thus, in this instance, customising the *role model* drawn in Table 1 is based on the customised *goal model* sketched in Fig. 2. The aim is to produce the customised *role model* of the flood DISPLAN of the SES Victoria. Eventually, the knowledge

Table 2 Customised *scenario model* of flood DISPLAN template of the SES Victoria State

DMM-based repository					M2
Scenario knowledge					MOF layer
Scenario		S9			M1
Name		Evacuation scenario			
Goal		Evacuation			
Initiator		<Municipality> IC			
Trigger		1. Properties are expected to be flooded 2. Properties are apt to become segregated, and residents are not suited to those circumstances 3. Flooding poses a danger to public health 4. Critical facilities have been compromised and are no longer accessible to a population, and relocation is deemed the most appropriate risk management strategy			M0
Pre-condition		<Municipality> IC in consultation with <Municipality> ERC, <Municipality> ERO, DHS, DH, BoM, CMA, HC and VICPOL for the evacuation based on the triggers			
Post-condition		The evacuation decision is released by <Municipality> IC			
Description		The evacuation is aimed to protect people from the risks of an emergency. This is conducted by evacuating people from a specific locality such as an institution (educational or hospital), a town or an area of the state			
Condition	Step	Activity	Role	Environment Entity	
Interleave	1	Recommending or warning for evacuation	R1		
	2	Communicating the evacuation warning	R1, R2, R3, R4	E14	
	3	Developing the evacuation warning	R1, R2, R3	E1	
	4	Managing the evacuation process	R1, R7		
	5	Assisting the evacuation process	R1- R11		
	6	Registering the affected and evacuated people	R1, R2	E19	

engineer marks the knowledge elements in the *role model* as either M1 or M0. Table 1 shows the customised *role model* for only one role *R2*: VICSES < *Regional* > DO.

As this is the customised *role model* of the State of Victoria DISPLAN knowledge, any instance of this particular model for any Municipality under the State can then be generated efficiently and effectively from it as they conform to this customised model.

Customising the scenario model As the space limitation, the third model (out of six) customised in this paper is the *scenario model*. The knowledge elements in the customised *scenario model* are based on other customised models except for the elements of trigger, pre-condition and post-condition, as shown in Table 2.

For these three knowledge elements, the knowledge engineer has to revisit the original DISPLAN template of the SES Victoria State of Australia to identify and structure them in the customised model. Once this model is completed, all the subsequent knowledge elements in this model are marked as either *M1* or *M0* representing the knowledge in the policy/planning level or real-world activities, respectively.

5.1.2 Stage 2: Generating the customised six ABMs

All the generating processes in this stage are based on the customised ABMs of the previous stage of the SES Moira Shire Municipality for a flood DISPLAN. In this process, each of the ABMs from the customised stage produces the unique ones for the Moira Shire DISPLAN. However, as earlier discussed in Sect. 3.1 the DMKAF v2.0, the second enhancement in this evaluation is at targeting more detail describing the specific characteristics representing the Moira Shire Municipality. It takes place in this stage. The specific knowledge elements for specifying the detail are acquired from the external sources that initially are not part of the elements in the main body of the DISPLAN. The details of the generating processes are elaborated as follows:

Generating the goal model In this stage, all the knowledge element templates in each model are substituted to the ones representing the Moira Shire Municipality. The process then results in the *goal model* of flood DISPLAN of the Moira Shire Municipality, as seen in Fig. 3. The basis to generate this *goal model* is based on the customised *goal model* of the SES Victoria as shown in Fig. 2. All the knowledge elements in the customised *goal model* needs to be further scrutinised that are identified by the knowledge engineers (DM expert who has ABMs understanding or an engineer who has DM expertise background). Based on this evaluation, some element goals in the model are required to be more drilled down to be more comprehensively understood. The knowledge engineer then goes to identify the external resources that are useful to complement the existing goals in the model.

For instance, for the goal "*recommending or warning for evacuation*", there should be sufficient information required by the Moira Shire IC to make the decision. This will be

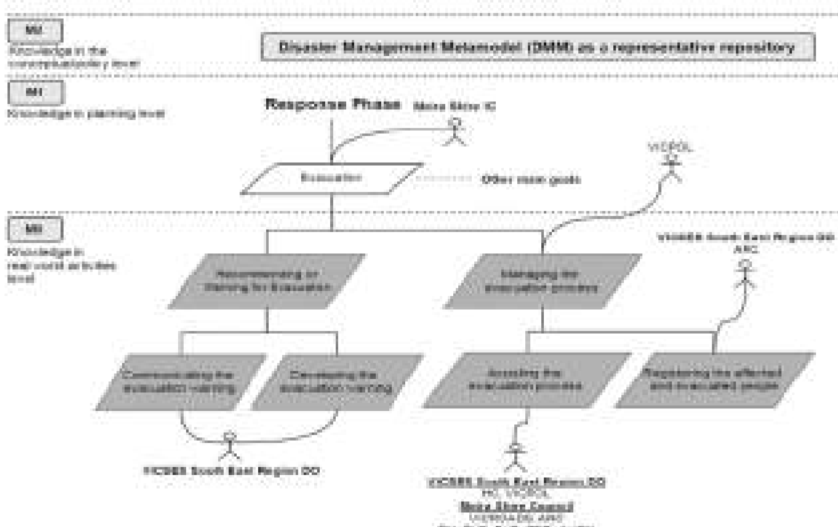

Fig. 3 The *goal model* of the flood DISPLAN of the SES Moira Shire Municipality

Table 3 The *role model* of the flood DISPLAN of the SES Moira Shire Municipality

DMM-based repository		M2
Role knowledge		MOF layer
Role ID	R2	M1
Role Name	VICSES South East Region DO	
Description	If the knowledge analysed and modelled is from North East Region area, then the <*Regional*> becomes North East Region DO	
Responsibility	1. Communicating the evacuation warning 2. Developing the evacuation warning 3. Assisting the evacuation process 4. Registering the affected and evacuated people	M0
Constraint	-	

based on the predicted gauge heights or likely occur of the flood and the times to evacuate. In addition, once the evaluation warning is issued, there should be a detail arrangement for the evacuation based on the characteristics of the Moira Shore Municipality, such as routes to be taken, the locations of the shelter for human and animals, the evacuation location for the caravans.

Specific local knowledge elements are identified from the external supplement documents other than the main elements of the DISPLAN. such as FICs. For instance exact locations of river gauges in the Moira Shire Municipality are not available in the DISPLANs but are evaluable in FICs. Their exact locations would be needed to execute decisions for "*Flood Evacuation Arrangement*". To be able to provide operational knowledge, related external knowledge elements should be thoroughly identified to be incorporated to each of generated model accordingly.

Generating the role model As in the *goal model*, generating a process of the *role model* means that all the substitutable knowledge elements in the *role model* template will be replaced with the ones representing the local wisdom of the Moira Shire Municipality. In Table 3 the *role model* of flood DISPLAN knowledge of the SES Moira Shire Municipality is shown. It describes all responsibilities of the role R2, VICSES South-East Region DO, being involved in pursuing the objective.

Table 4 The *scenario model* of the flood DISPLAN of the SES Moira Shire Municipality

DMM-based repository					M2
Scenario knowledge					MOF layer
Scenario		S9			M1
Name		Evacuation scenario			
Goal		Evacuation			
Initiator		Moira Shire IC			
Trigger		1. Properties are expected to be flooded 2. Properties are apt to become segregated, and residents are not suited to those circumstances 3. Flooding poses a danger to public health 4. Critical facilities have been compromised and are no longer accessible to a population, and relocation is deemed the most appropriate risk management strategy			M0
Pre-condition		Moira Shire IC in consultation with Moira Shire ERC, Moira Shire ERO, DHS, DH, BoM, CMA, HC and VICPOL for the evacuation based on the triggers			
Post-condition		The evacuation decision is released by Moira Shire IC			
Description		This school of thought is closely linked to another common consensus in IS research: that it is not just tackling the emerging issue but also contributing to the domain knowledge			
Condition	Step	Activity	Role	Environment Entity	
-	1	Recommending or warning for evacuation	R1	E14	
	2	Communicating the evacuation warning	R1, R2, R3, R4	E14	
	3	Developing the evacuation warning	R1, R2, R3	E1	
	4	Managing evacuation process	R1, R7		
	5	Assisting evacuation process	R1- R11		
	6	Registering the affected and evacuated people	R1, R2	E19	

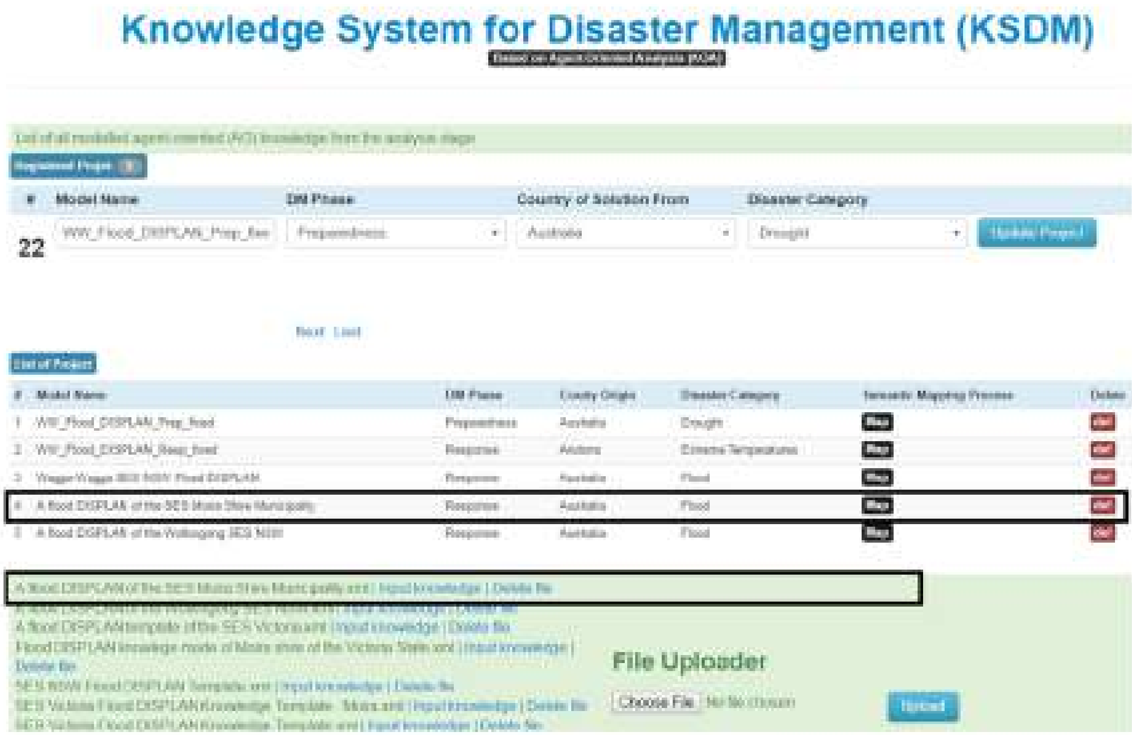

Fig. 4 The Agent-Based Models of the flood DISPLAN of the Moira Shire transferred into the repository

Generating the scenario model The last ABM that undergoes the generating process is the customised *scenario model*. In this third evaluation, it is the Moira Shire Municipality. Table 4 shows the generating process to produce the *scenario model* of the flood DISPLAN of the SES Moira Shire Municipality. A knowledge engineer examines all the elements in the model template to substitute with the ones representing a particular municipality.

5.1.3 Stage 3: Transferring the DISPLAN into the repository

There are 2 (two) activities in this stage: 1) Preparing the repository. The repository remains similar as the one from the previous evaluation as there is nothing to be changed; and; 2) Transferring the ABMs of the Moira Shire flood DISPLAN to the repository. Figure 4 shows the Moira Shire flood DISPLAN that is transferred to the repository. Figure 5 shows how the Moira Shire flood DISPLAN knowledge structured in the repository. A post-evaluation is also conducted in this evaluation as the enhancements of the framework. This post-evaluation is performed by a DM expert from the SES Victoria State where the case study came from. This is discussed in the following section.

5.2 Post-evaluation of the SES Victoria State case study

As indicated earlier, this post-evaluation is conducted with the aim to ascertain that the new knowledge representation in the DMM-based repository is unchanged after improving the framework. More importantly, this stage is aimed to validate that the knowledge representation is faithful to the content of the DISPLAN. It also validates that the content is reusable by the authoritative agency as a decision-making mechanism.

The evaluation is executed with two DM experts, one from State Emergency Expert (SES) of Victoria and another from SES of New South Wales in Australia. The involvement of the DM experts aims to ensure that the knowledge elements from the DISPLAN are fully extracted and deposited into the DMM-based repository without losing any meaning. Moreover, a post-evaluation is conducted to ascertain the efficacy of the new features of the framework. The disparate expert reviews represent a wider spectrum of stakeholders. The post-evaluation employs an observational approach based as advocated in DSR literature (Venable et al. (2016)). It essentially assesses the value of the framework to its target user groups.". In conducting this post-evaluation, the

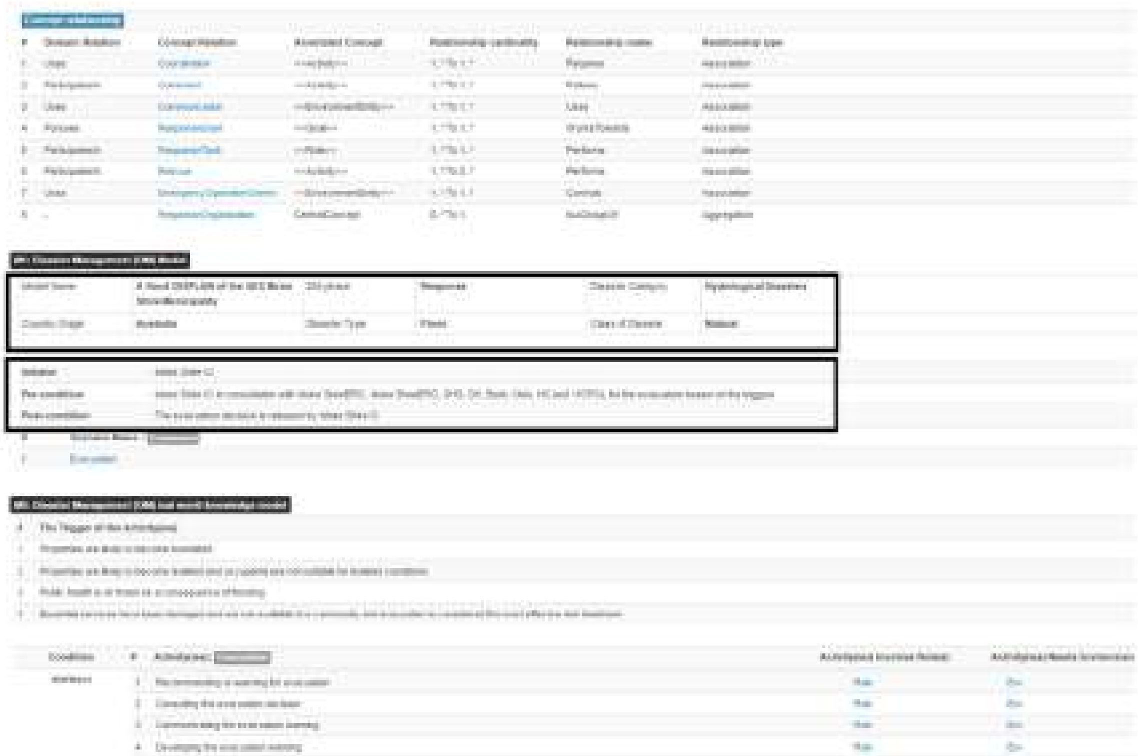

Fig. 5 The structure of Moira Shire flood DISPLAN knowledge in the repository

prototype GUI interface being developed for this research is utilised. The prototype allows the DM experts to easily access and browse the knowledge elements structured in the repository by 'clicking' them.

The post-evaluation begins by examining whether the resultant knowledge items and the way they relate to each other in the repository remain the same as in the original DISPLAN. This is critical to ensure the continuing usability and benefit of the resultant knowledge in the repository for the DM stakeholders. This is checked for each of the six ABMs employed in this research. The overall responses from both experts in this regard are positive. For instance, in the goal model evaluation, while a DM expert from SES Victoria State states that *"The knowledge meaning in the DISPLAN and in the AB models is still the same. It gets reworded in some part just to emphasize the meaning"*. The expert from SES NSW also informs that *"All key top-level goals have been elicited and instantiated for the goals pursuant to stakeholders"*. Similar judgements are given by both experts for all other five ABMs: *role model*, *organisation model*, *interaction model*, *environment model* and the *scenario model*. The only concern of the expert from SES NSW in this evaluation criteria is that if the plan is not well put together then this will continue to propagate to the analysis and modelling stage. As stated by the expert that "*The plan itself does not state all triggers similar to outlined in other items above. There are some activities that have very clear and quantitative trigger constraints and the work would benefit from exploring these in the future in detail, e.g. data inputs of river height and related warning issue triggers*". This feedback is related to the scenario model evaluation. However, this is in line with our expectations as our purpose is no to rectify issues with the orginal plans and it is well known that some knowledge elements can not be explicitly included in the plan as they, for instance, *"provide confidential details regarding the impact of floods on privately owned land"* (please see paragraphs 4–6 of the Subsection 3.1).

The next criterion to evaluate is to ascertain that the knowledge transferred into the repository is faithful to the content of the SES DISPLAN of the Moira Shire Municipality of the Victoria State. This process confirms that the enhanced framework, which now utilises the template as a starting point, is not only more efficient but also effective. Subsequently, the local characteristics can then be effectively synchronised to the template to produce a complete particular DISPLAN. The response from both experts are again positive. For instance, while the expert from SES Victoria states *"Moving to an approach such as is proposed here would enable the complexities of emergency planning for floods to better planned for. It would also support a model that provides flexibility to be adapted to different risk profiles across municipalities"*, the expert from SES NSW mentions that *"Yes this statement is generally agreed with. The plans themselves are written using templates at least within an agency for example which directly supports this statement"*. This post-evaluation then continues to look at other criteria: 1). Whether the knowledge structured in the repository can be easily comprehended; 2). Whether it is comprehensive; 3). Whether the repository structure allows incompleteness of knowledge to be identified easily, and finally whether the developed framework contributes to furthering the DM resilience agenda for Victoria State Government.

The last criterion aims to obtain the response from the expert whether the framework facilitates other stakeholders to reuse the best practice knowledge effectively and efficiently in other DM activities for a similar type of disaster. The expert from SES Victoria reemphasises and even goes beyond this comprehension by stating that *"The framework could also provide a mechanism or some tools to help DM experts to communicate with communities about their risks and understand levels of resilience in communities"*. This is consistent with the response from the SES NSW expert who confirms that *"The enablement of data-driven disaster management is a fundamental requirement for successful future resilience goals. The complexity of systems and participants requires a robust model for breaking down the problem into manageable components and the use of ABMs is a highly appropriate approach"*. The detail of the post-evaluation is presented in Table 5 in Appendix 1.

The responses from the experts of this post-evaluation are all positives. This illustrated that using only six ABMs instead of seven is sufficient in the analysis and modelling and had little effect in capturing the complex knowledge out of the DM domain. In addition, these evaluations not only asserted the sufficiency of the number of models being used but also demonstrated the improved efficiency in the knowledge analysis and modelling processes compared to the earlier version of the framework.

6 Discussion

This paper contributes to the enhancement of the DMKAF as drawn in Fig. 1. This new DMKAF v2.0 has two new and significant improvements. The first enhancement pursued is about reducing the number of ABMs employed in the analysis stages. We showed that the elements in the *agent model* can be well represented in other models. In other words, although that particular model is excluded in the analysis and modelling activities, the knowledge deposited in the representative repository still has the same meaning as the original, even as it gets reworded. In the analysis preparation phase, only six ABMs will be customised in the analysis and modelling activities (rather than the 7 ABMs in DMKAF v1.0). This efficiency then propagates to the knowledge conversion stages. Thus, DMKAF v2.0 is clearly more efficient as it reduces the stages of knowledge analysis activities without scarifying the semantics. This efficiency gain offers additional analysis bandwidth which gets used to enhance the efficacy of the knowledge extracted. External knowledge sources that are initially not part of the main DISPLAN are now recognised during the process. These often contain specific operational knowledge crucial to those who are on the front line to combat a disaster. This is evaluated in generating the DISPLAN knowledge of the SES Moira Shire Municipality from the customised ABMs (Stage 2 of the framework). The evaluation shows that external knowledge sources can be successfully adopted and incorporated within the customised ABMs. This particular enhancement aims to address the issues that the more complete the knowledge, the better the DM activities. Providing more complete knowledge with details of the local context of one particular area (e.g. the environment, the resources, etc.), better equips those who are on the ground and leads to an effective execution of DM activities.

As indicated earlier that these improvements are motivated by the feedback from the previous evaluation. Pursuing a more efficient framework should only be promoted only if the effectivity of the enhanced framework produced can be maintained. Therefore, guaranteeing that the semantic of the knowledge is not changed as in the original one is crucial. Moreover, as this activity is in the DM domain, how effectively the stakeholders in this particular domain comprehend and learn from the best practice knowledge is the primary goal of this research. In other words, a more efficient framework will be pursued only if it is still effective at addressing the main issue. The evaluation was conducted by engaging two flood DM experts of the SES Victoria and NSW States of Australia. The experts involved in the evaluation are from DM authoritative agencies in Australia (SES). The experts' involvement ensured that knowledge extracted is accurate and removed any inconsistency between the knowledge structured in the repository and the one in the DISPLAN template. To ease the evaluation processes, a web-based tool as a prototype of the framework is developed and used. The tool supports the whole process of the improved framework. It is operationalised by drop-down menus and hyperlinks (as exemplified in Figs. 4 and 5). The tool itself is described in detail as a post-evaluation in Sect. 5. This post-evaluation examines whether the DMKAF v2.0 can still be effective in the analysis and modelling the knowledge elements in the DISPLAN without losing any meaning.

In addition to the enhancements and the concomitant tool of DMKAF v2.0, another real case study can further confirm the generalisability of the whole approach. This is essentially the key objective of DSR methodology in information systems (Iivari, 2015). DSR has been an important guidance for this research, as advocated in (Gregor & Hevner, 2013; Hevner et al., 2004). With future generalisability confirmation, this research will pave a way for the framework to be used in, not only the flood DM cases. This has been started by evaluating the enhanced framework of DMKAF v2.0 in other types of DM such as the case of volcano eruption DM for Mt. Agung in Bali Indonesia, where we have demonstrated the efficacy of the framework (Inan et al., 2018b). In that case, Inan et al. (2018b) demonstrated that the enhanced framework not only successfully addressed the knowledge transfer mechanism, but also it supported towards a better decision making for the stakeholders at any point of the timeline during DM. Further generalisability efforts will also pave the way for using the approach in other countries with a similar hierarchy of government structures and in other DM cases. For example, it can be applied in Indonesia, where the government hierarchy level top downs from the central government to provincial to municipalities and districts (the smallest type of the government). Once the DISPLAN template is available in the central government to be managed by DM authority (BNPB/National Disaster Management Agency), instances for all the provincial levels can be generated out of it. This approach also applies to the relationship between the provincial and municipalities and district governments as well.

7 Conclusion

Representing the knowledge elements in a way they can be easily understood by the DM stakeholders in a timely manner is challenging. From the perspective of data-information-knowledge-wisdom pyramid, for instance as described in (Rowley, 2007), our research set out to extend the information into a knowledge/wisdom/insight. Information itself is embodied of the understanding of a relationship of some sort, possibly cause and effect which aimed to address "know-who", "know-what", " know-where", "know-what ", "know-with" and " know-when" questions (Bellinger et al., 2005; Chen, 2010). Our paper's contributions do not only provide answers to these questions but substantially it also enriches the information by addressing the "know-how" and "know-why" questions. These empirical knowledge elements that are holistically represented can improve the decision making process in DM activities during all phases and at various levels. Information that is not represented in a way it can be fully and easily understood, is particularly not useful. Information that is enriched to be the knowledge/wisdom/insight to the users is envisaged as critical for a better decision making system by the stakeholders in the DM activities. Completing the information to be more meaningful is undertaken by analysing and modelling the related data, information and/or knowledge elements using our enhanced framework, Disaster Management Knowledge Analysis Framework 2.0 (DMKAF v2.0) presented in this paper.

To facilitate comprehension, we embrace agent-based models from Agent-Oriented Software Engineering (AOSE) that lend themselves to representing the DM activities at any point of the timeline for various roles played by agents involved in the activities. The present paper is part of a larger research project aiming to contribute to the DM resilience endeavours. The first version of the DMKAF v1.0, published in this journal in 2018 (Inan et al., 2018a) did not incorporate information from external sources outside the official disaster management plans. With DMKAF v2.0 is this paper, we demonstrate how to incorporate the local wisdom/context which is crucial in the DM activities particularly in the real-world situation, into the formal knowledge structure. The new framework also reduces the analysis effort by omitting agent models that are not critical thus improving the overall efficiency of DMKAF by reducing the analysis and modelling activities.

This paper also operationalises the framework into a prototype which will enable deeper assessment. Our main focus in the previous version (DMKAF v1.0) was to ensure that the framework was successfully developed and that it can be materialised into a prototype, a web-based tool, to facilitate its ease of use by the stakeholders in the evaluation stages. Nevertheless, a case study with NSW State Emergency Services documents was executed (Inan et al., 2018a). The target of this paper is to measure the effectiveness of DMKAF v2.0 with actual DM stakeholders, e.g. whether the knowledge is still meaningful to its users, whether it can be understood easily by the DM stakeholders particularly for the decision making process, whether it can be navigated easily, etc. As a prelude to a field based trial, we prepare for this with both DM experts in which one of them from the agency that provided the case study (Victoria State Emergency Services). We approach the evaluation using the Design Science Research (DSR) methodology descriptively (Hevner et al., 2004) by assessing the artefact with the expert from the DM authoritative agency in Australia. Generally, the expert evaluation is accepted a preliminary evaluation method (Peffers et al., 2012). As the case study is about flood DM from the Victoria State Australia, the expert is selected from the same authoritative agency the case study is from, the Victoria State. However, to ensure the reliability's evaluation, another DM expert from the SES NSW wa also involved. Both experts have intimate knowledge of flood. In particular, the Victorian expert was also highly involved in developing the flood DM document of the Victoria State employed as the case study in this research. Indeed, we employ this qualitative evaluation based on DSR methodology over the others to ensure that the output of framework is faithful to the originally conceived plans. In other words, the choice of this evaluation method is driven by the artefact produced in this research. (as advocated in DSR literature please see for instance (Venable et al., 2016; Peffers et al., 2012)).

To shed more light for pursuing our improved framework's generalisability, we basically have also evaluated it using another case study other than flood DM, that is a volcano eruption DM of Mount Agung in Bali Indonesia that fluctuated since late 2017 to early 2018 (Inan et al., 2018b). In that evaluation, we directly communicated the evaluation activities of our improved framework with an expert from the Indonesia Disaster Management Agency (BNPB). The expert there was the deputy Head of Prevention and Preparedness BNPB who was also the National Chief of Mt. Agung DM. We successfully showed in that evaluation that not only can the knowledge of Mt. Agung DM be fully represented and better understood using the framework, but more importantly, it facilitates both bottom-up and top-down decision support system that can be used by the stakeholders at any level and any phase in DM activities (Please refer to (Inan et al., 2018b) for more detail evaluations).

8 Future Research Direction

As earlier described in the paper, the case for knowledge reuse from past DM experiences is compelling and strong. But DM knowledge reuse is extremely challenging. The best practice of past experience might be available, but whether it can be timely extracted requires a systematic and serious effort. In other words, although the best practices of past experiences of a DM are demonstrated to be useful in a particular DM case, this does not mean that they can be adopted directly and timely. Although this paper contributes to these issues by achieving a more efficient and effective framework, however, only the knowledge that has been codified in the DISPLAN, that is formalised in a semi-structured format and authorised by the DM agencies (e.g., SES in Australia, Indonesia Disaster Management Agency (BNPB), Federal Emergency Management Agency/FEMA in USA), will be the input to the framework.

Practically, there are many cases by which the unstructured knowledge still plays an important role to save lives and properties during a disaster. A case in point is in the deadly bushfire case that hit Australia just recently (Allam, 2020; Richardson & Goll, 2020). The knowledge reuse as primary source of wisdom is nonetheless worth seeking to complement authorities' expertise. However, harnessing them in a formal DISPLAN that can be easily comprehended by others is extremely challenging. We are aware that eliciting and analysing informal knowledge is difficult and costly, as illustrated in here (Audefroy & Sánchez, 2017; Lin & Chang, 2020). This will be also worthy avenue for our future research direction as it broadens the scope of our framework. ABMs as the analysis and modelling tools employed in this research proved effective for knowledge re-engineering in the DM domain. ABMs lend themselves to represent the complexities of the empirical knowledge elements in DM. A wider use of ABMs could render semi-structured DISPLAN obsolete. Our future effort will also use ABMs to elicit unstructured knowledge of best practices of past experiences.

Despite the promising results in this work, concerns remain and warrant further testing of the framework in real-world settings. This has been pointed out in the Post-evaluation Sect. 4.2 of the paper. Whilst Table 5 in Appendix 1 showed all criteria in the evaluation by experts are positive, there is a remaining concern about DMKAF v2.0 usability in a real DM environment. This is as mentioned by the expert "*A pilot approach would be a suitable approach to test and validate such a new process*".

Appendix 1

Table 5 Evaluation outcome of benefits and usability of the deposited knowledge from the DM experts of the SES State of Victoria and New South Wales of Australia

Addressing criteria	Outcome	Interrater reliability of expert comment	Knowledge Description
Knowledge related to goals to be pursued by stakeholders in the goal model and in the DM document is not changed	Y	E-VICSES: "The knowledge meaning in the DISPLAN and in the AB models is still the same. It gets reworded in some part just to emphasize the meaning" E-NSW: "All key top-level goals have been elicited and instantiated for the goals pursuant to stakeholders. Some low level or more opaque and nuanced goals have not been elicited but these are not required in the current stage in order to assess the research approach"	Knowledge related to goals is all the main objectives set to be accomplished by stakeholders in DM activities, for instance, evacuation, assisting the animal, maintaining logistics. The activities to pursue them are described as sub-goals. The main goals and the sub-goals are the responsibility of stakeholders assigned to them
Knowledge informing roles played by stakeholders involved in the activities is not changed	Y	E-VICSES: -idem- E-NSW: "As for goals, all top-level roles for stakeholders have been elicited. These roles provide very clear linkages of a stakeholder's role in a range of activities and with the associated agent linkages to other elements in order to confirm that the approach is successful"	Knowledge about roles is the description of all the DM stakeholders who are responsible for specific roles in DM to achieve the goals. For instance, Moira Shire Incident Controller plays a role to recommend (or warning) for evacuation and communicate the evacuation recommendation
Knowledge describing hierarchy organisation level for communication purposes between organisations and/or individuals is not changed	Y	E-VICSES: -idem- E-NSW: "The representation of organisations is likely almost as complete as is required for the immediate future iterations of this work. The organisational models required to govern and inform such information models and system processing, in the reviewer's experience, is best made relatively flat and simple"	Knowledge describing hierarchy organisation level is the description of the administration levels of organisations involved in DM activities. For instance, the Regional Duty Officer of Victoria State is the one who mediates the SES at the state and municipality levels. Thus, by the time Moira Shire Incident Controller aims to communicate with State Controller, this should be coordinated first through VIC SES Regional Duty Officer
Knowledge describing to what extent organisations and/or individuals are interacting is not changed	Y	E-VICSES: -idem- E-NSW: "As far as these interactions are defined in the original plans, the modelling process has elicited the key interactions required to demonstrate the approach. The plans themselves are not complete in this regard and there are other documents as well as un-documented interactions to reconcile and accommodate for"	Knowledge describing to what extent the stakeholders are interacting is about describing the communication / coordination/ collaboration between two or more stakeholders as they have activities to achieve the same main goal. For instance, in response phase activities of flood disaster, Moira Shire Incident Controller will interact with VIC Road agency in "liaising with VicRoads of erecting warning signs, closing roads and bridges"
Knowledge related to the resources required by roles for their DM activities is not changed	Y	E-VICSES: -idem- E-NSW: "As for interactions resources are a potential, and commonly poorly documented set of constraints. So as far as resource dependencies are documented the ABM quite sufficiently elicits these"	In DM activities, there are resources, e.g. tools, documents, and others, required by stakeholders to accomplish the tasks effectively. These resources need to be described in detail with the local-context concern. For instance, in an evacuation activity of flood disaster that requires a boat, providing the specific information regarding the boat weight, capacity, maximum speed and so on are important

Table 5 (continued)

Addressing criteria	Outcome	Interrater reliability of expert comment	Knowledge Description
Knowledge related to triggers, pre and post condition, activities to be undertaken, and initiating roles is not changed	Y	E-VICSES: -idem- E-NSW: "Triggers are another highly complex area that should be developed in future research phases. The plan itself does not state all triggers similar to outlined in other items above. There are some activities that have very clear and quantitative trigger constraints and the work would benefit from exploring these in the future in detail, e.g. data inputs of river height and related warning issue triggers. However, it's recognised that this is largely an outcome of the plan used and noting that past research that the reviewer has participated in addressed this issue"	In each DM scenario, all the details need to be specified for the affectivity. Thus, providing information not only the main goal (objective) to be accomplished, the activities to be undertaken and the roles that responsible for each of them, but also when they will be conducted, what trigger activating the scenario, who is the initiator, what is/are the pre-condition prior to the activities, what is/are the post-condition once the activities are concluded. Using our knowledge System for Disaster Management as drawn in Fig. 5, all the knowledge elements can be easily identified
The use of DISPLAN knowledge template instead of a unique plan increases the efficiency in developing specific plans under the same hierarchy administration	Y	E-VICSES: "Moving to an approach such as is proposed here would enable the complexities of emergency planning for floods to better planned for. It would also support a model that provides flexibility to be adapted to different risk profiles across municipalities. A pilot approach would be a suitable approach to test and validate such a new process" E-NSW: "Yes this statement is generally agreed with. The plans themselves are written using templates at least within an agency for example which directly supports this statement"	The use of DISPLAN knowledge template instead of a unique plan facilitates it to generate and instantiate to a specific plan under the same administration level as the template. This is because the knowledge structure within the same administration levels is similar. For instance, once ABMs of DISPLAN knowledge template of VICSES has been analysed and modelled, then it is easier to generate any plan for any municipality under the Victoria State (for instance Moira Shire Municipality) as it will follow knowledge structures and elements as in the state level. Put simply, the SES at the municipality level employs the DISPLAN template from the state level to generate the one for it effectively and efficiently
New knowledge representation enables goal formulation and planning for roles that need to be involved is easier to zoom in on than a standard plan document	Y	E-VICSES: "More than this however is that the interleaving and sequential nature of the elements of the models that enable the full picture to be built within the plan to enable DISPLANS to more effectively plan for the complexities of disasters and assign resources to respond to disasters. This includes contributing to role clarity of stakeholders" E-NSW: "Yes as above the ability to create new constraints and linkages between linked data objects is supported. This a fundamentally new paradigm for emergency management"	In the DM, the empirical knowledge elements representing why, what, where, who, when need to be easily identified. Thus, by using the developed framework, the way the empirical knowledge elements are structured facilitates the roles e.g. who involve, the role it plays and what are the responsibilities.

Table 5 (continued)

Addressing criteria	Outcome	Interrater reliability of expert comment	Knowledge Description
New knowledge representation enables identifying organisational levels to be engaged and resources needed is easier to zoom in on than a standard plan document	Y	E-VICSES: -idem- E-NSW: "While the organisation models may be relatively simple as discussed above, the persistence of this in a knowledge graph form with the addition of the ABM layers provides a greatly enhanced method to deriving new constructs of organisations"	Identifying organisational levels to be engaged and resources needed are crucial in any DM activity as they are heavily related to losses of properties and lives. The new knowledge representation, identifying these knowledge elements in a DM scenario can be undertaken easily as they are structured based on the main goal to be accomplished. For instance, as drawn in Fig. 5, the roles and the resources needed are structured based on each of the activities to be undertaken
Incomplete knowledge elements in the DM document can be identified systematically	Y	E-VICSES: "This might also provide a good lead in to provide material for exercises to be undertaken to test the DISPLAN" E-NSW: "The ABMs provide a representation of the constraints on a given chain of elements and therefore successfully shows that missing constraint elements can be calculated	The knowledge elements regarding the goal, role, interaction, organisation, resources and scenario are structured based on the corresponding ABMs. Thus, the incomplete knowledge elements can be identified easily by the authorities as they are those who formulate and develop the plan. They can easily identify the other resources needed for a particular activity, other roles that need to be involved in a specific task, etc
The new knowledge representation can help DM stakeholders to understand the scenario type they are in and other organisations they need to interact	Y	E-VICSES: "It is also important to understand timing for the onset of consequences, duration of inundation and the time for floodwaters to recede" E-NSW: "The graph representation of the ABMs will support a fundamentally improved knowledge discovery tool for organisations. As the research progresses to use more graph native models, this will allow the addition of machine learning to discover and recommend connections and important information which is an emerging trend"	The new knowledge representation can assist all the involved stakeholders to understand the DM scenario as all the empirical knowledge relating to why, when, what, who, where and how is presented in the scenario. This facilitates and equips the stakeholders with the relevant knowledge in their activities. For instance, in a scenario evacuation, who involve in its activities, what resources are required in it, to what extent the roles interact, etc., are outlined
The new knowledge representation assists DM stakeholders identifying activities to be undertaken for any trigger	Y	E-VICSES: -idem- E-NSW: "Specific data triggers are expressed in the ABMs and successfully support a stakeholder to trace the dependency between layers and in this process new representations of activities is sure to arise"	The trigger is related to empirical knowledge to address the "when" concern. Thus, for instance, to initiate the evacuation, the triggered knowledge needs to be presented in detail to assist the initiator in making the decision and all the involved stakeholders will be ready for all activities to accomplish the evacuation

Table 5 (continued)

Addressing criteria	Outcome	Interrater reliability of expert comment	Knowledge Description
New knowledge structure in the repository helps DM stakeholders in identifying appropriate response at any point of the disaster timeline	Y	E-VICSES: "There is also a significant hurdle of implementing an effective change management process to ensure that more than just having a good comprehension of English, practitioners would also be expected to adopt a new way of developing DISPLANS". E-NSW: "As discussed above the ABMs highlight the appropriateness of the approach to supporting a stakeholder to identify new and existing knowledge such as response actions".	New knowledge structure in the repository is structured conforming the DM unified repository in which the relevant concepts have been identified and are related in a way it enhances our DM understanding. For instance, command < <Activity> >concept is related to coordination < <Activity> >, communication < <EnvironmentEntity> >, goal < <goal> >, etc. This enlightens the stakeholders that for better DM activities, while the command activity is undertaken, the coordination activity also needs to be managed and the resources needed are described in communication for the goals that are listed in goal concept. This paradigm can facilitate DM stakeholders with more complete knowledge at any point during the DM activities without segregating it into the PPRR phase
Overall, the framework contributes in DM resilience agenda	Y	E-VICSES: "The framework could also provide a mechanism or some tools to help DM experts to communicate with communities about their risks and understand levels of resilience in communities." E-NSW: "The enablement of data-driven disaster management is a fundamental requirement for successful future resilience goals. The complexity of systems and participants requires a robust model for breaking down the problem into manageable components and the use of ABMs is a highly appropriate approach"	DM resilience is about the capability to adapt to the situation and/or bounding back from unforeseen stress. In other words, DM resilience endeavour needs to be equipped with the relevant knowledge for those who are in the decision-making and planning levels and also the frontline workers. The knowledge also needs to be easily shared and reused to allow others to learn from it. Our developed framework meets all these criteria based on the suite of evaluations with real and different case studies

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