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# Agent-Based Knowledge Analysis Framework in Disaster Management

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**Abstract** Disaster Management (DM) is a complex set of interrelated activities. The activities are often knowledge-intensive and time sensitive. Timely sharing of the required knowledge is critical for DM. For recurring disasters (e.g. floods), developed countries tend to have dedicated document repositories of Disaster Management Plans (DISPLANs) that can be accessed as needs arise. However, accessing the appropriate plan in a timely manner, and sharing activities between plans, often requires significant domain knowledge and intimate understanding of the plans in the first place. This paper introduces an Agent-Based (AB) knowledge analysis method to convert DISPLANs into a collection of knowledge units that can be stored into a unified repository. The repository of DM actions then enables the mixing and matching of knowledge between different plans. The repository is structured as a layered abstraction according to Meta Object Facility (MOF). We use the flood DISPLANs plans used by SES (State Emergency Service), an authoritative DM agency in New South Wales (NSW) State of Australia (hereinafter referred to as SES NSW) to illustrate and give a preliminary validation of the approach. It is illustrated by using displans along the flood-prone Murrumbidgee river in central NSW.

**Keywords** Agent-oriented analysis · Metamodeling · Disaster management · Knowledge analysis · Knowledge management

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## 1 Introduction

Timeliness of response and action is critical in DM scenarios (Sword-Daniels et al. 2016). With various stakeholders bringing their own structures and background, and without appropriate communication channels being in place ahead of time, the timely knowledge exchange between the various stakeholders is severely compromised (Heard et al. 2014). The communication and knowledge-sharing support is critical to enabling negotiation and cooperation. Currently, the agency leading the program to combat the disaster assumes the role of organising and eliciting the knowledge, and ultimately structuring it in a shareable and reusable format. The knowledge is produced as DM plans that are made available via the web. However, accessing the knowledge specified in a semi-structured natural language format is very challenging. The written knowledge tends to be structured in a business specification format which, in fact, is seen as subjective by the stakeholders.

Much analysis may be required to enable development of useful and actionable insights. In this paper, we view the challenge of DM as one of harnessing and sharing knowledge between stakeholders who are involved in the timely and effective reduction of the impact of a disaster. The first step towards this is to revisit the codification of DM knowledge document sources to facilitate the reuse and sharing of the knowledge they contain. But analysing the written knowledge in a complex domain, such as DM, is not only difficult but also time-consuming (Tran et al.

2007; Brown et al. 2016). This paper presents a framework to facilitate this first step of harnessing the knowledge. The paper recognises that the PPRR DM process model, consisting of the four phases of DM—Preparedness, Prevention, Response, Recovery—is typically used to organise DM knowledge (Weichselgartner and Pigeon 2015).

Indeed, various DM activities and knowledge units required throughout the DM processes are organised according to the sequence of these four phases. However, with all the efforts that go into developing them, substantial knowledge about various phases can be scattered throughout the documents and therefore they may not fully adhere to the PPRR process. At the heart of the PPRR itself lies a problem more difficult to correct: with all its prominence in DM activity, PPRR does not actually conceptualise the process of DM holistically, rather it does it sequentially (Becken et al. 2014). This feature of PPRR is completely inconsistent with the modern view of aiming to have risk management permeate all DM activities (Crawford et al. 2013). Linear and sequential descriptions of events are inherently limited. Participants are hindered from engaging beyond the limit of the event timeline. In order to mitigate the risk of introducing errors, sequential modelling was abandoned in the software development many years ago (Lopez-Lorca et al. 2016). It is well accepted that software practitioners typically engage in iterative thinking and problem-solving, moving up and down multiple abstraction layers. Applying this same paradigm and insights to representing DM processes, a multi-layered metamodeling approach which follows the MOF approach (OMG 2013) is proposed. As a first knowledge analysis step to enable this, the paper proposes an approach based on Agent-Oriented Analysis (AOA) to appropriately codify DM knowledge.

DISPLANs do not articulate a single goal. Entities involved in a DM activity need to not only react or adapt to the environment, but to also exhibit their local goal formulation (Doyle et al. 2014). The ability of each entity to recognise the relevant DM knowledge (Dominey-Howes et al. 2014; Hiwasaki et al. 2014) needs to be encouraged. Critical environment characteristics cannot be controlled and predicted, but awareness of them is essential to facilitate cooperation. Entities/organisations/individuals involved have their own goals, resources and structures. At the same time, the need to communicate and negotiate to pursue common goals is paramount. Identifying the goals of the DM activities of other entities is crucial (Hawe et al. 2012). This will require those others to be involved. To enable all this, there is an imperative for timely sharing and reusing of knowledge.

The paper addresses the challenge of how to convert existing DM knowledge into layers of abstraction to enable a unified point of access. This paper advocates the use of a knowledge repository based on a common MOF modelling framework, the Object Management Group (OMG) (OMG 2013), and a Disaster Management Metamodel (DMM) (Othman et al. 2014). DMM was originally developed following the use of a MOF rigorous methodology to represent the DM domain according to the three modelling layers advocated in the work of (Daniel and Matera 2014): *M0* (real world objects), *M1* (model) and *M2* (modelling language/metamodel). This enables abandoning a timeline sequence in favour of free flow access to any point. The proposed approach converts end user models to concepts and notation from the DMM, and relies on AOA to achieve this. Agent-Oriented (AO) models lend themselves to representing organisational know-how and DM processes. They emphasise the constructs of roles, agents and organisations to represent systems' behaviours. With appropriate supporting tools, this knowledge can be deposited and shared using a DMM-based system.

The rest of this paper is organised as follows: the next section reviews the background and related work; the third section presents the knowledge analysis requirement; the fourth section draws the intermediate framework of AOA and shows how to convert extant DISPLAN domain knowledge to DMM constructs; the fifth section illustrates the approach using an actual case study of a DM flood plan of SES NSW; the paper concludes with a discussion of future work in the sixth section.

## 2 Related Work

Metamodels are often utilised as a high level knowledge structure that enables the creation of knowledge repositories with an intelligible interface (Kaptan 2014; Othman et al. 2014; Ramete et al. 2012). A metamodel is a collection of classes to describe domain concepts to represent domain entities, actions or states (Othman and Beydoun 2013). A metamodel thus contains the specification of a modelling environment and defines the syntax and the semantics of the domain (Syriani et al. 2013). Classes and relations in a metamodel represent the set of constructs and rules of how these constructs interact (activities, interactions, conditions, actors, roles, triggers and so on). The development process of a metamodel typically complies with a rigorous and systematic methodology (Whittle et al. 2014). For DM, a specific metamodel, Disaster Management Metamodel (DMM), was developed (Othman and Beydoun 2013). DMM represents prescient concepts and relations in DM.

The DMM metamodel was developed using 98 extant DM models prescribed by various government, private, and academic efforts as detailed in the work of Othman et al. (2014). The development process of the metamodel aims at completeness and consistency of outcome, and extends a metamodeling process that was used in software engineering of complex systems (Beydoun et al. 2009; Beydoun et al. 2006). The process iteratively reconciles and validates individual concepts and their relations. The DMM therefore represents a complete picture of disaster management, but the level of rigour and detail is left for the users of DMM to apply. For instance, *PublicEducation,* a DMM concept in the preparedness phase of the DMM is defined as follows: "*A process of making the public aware of its risks and preparing citizens for hazards in advance of a disaster and as a long-term strategic effort*" (Othman et al. 2014, p. 257). The detailed knowledge of *public education* DM activity in the preparedness phase will be stored in a knowledge repository location that can be accessed by this concept. This enables partitioning of DM problems into sub-problems easier to manage. It can also provide an easily accessible layered representation of knowledge.

For practitioners engaged in responding to a disaster, their actions are generally event-driven; however, their reflections and motivation may be policy-driven or even constrained within the structure of their organisation. In other words, knowledge generated during the events pertains not only to the events, but also to the policy development, and even perhaps to reflections on scope for restructuring. Enabling the representation of this abstract knowledge is key to enabling continuous process improvement (Inan et al. 2015; Xu et al. 2011). Using DMM instead of PPRR can enable stakeholders to engage at all levels of abstraction as required (events, policies and organisational structures). Several recent works use metamodeling to represent diffused DM knowledge (Chen et al. 2015; Lauras et al. 2015; Ramete et al. 2012). However, most focus on specific DM phases (e.g. either Prevention/Mitigation, Preparedness, Response or Recovery). Unlike this paper, none yet provides any support for converting the DM knowledge into the metamodel constructs themselves. The paper deploys DMM that is disaster and phase independent.

DM modelling aims to capture the complex characteristic of DM and present it in a way people who have no expertise in it can easily understand (Sackmann et al. 2013). The DM knowledge has four characteristics in common with Agent-Based Models (ABMs): a) *Situatedness* in an environment (Cavallo and Ireland 2014). As disasters are dynamic, unpredictable and uncertain, the environment changes rapidly which leads to the second characteristic. b) *Time sensitivity* (Janssen et al. 2010); in a disaster, every activity has to deal with deadlines, otherwise the consequences might lead to casualties, or even fatalities. c) *Non-deterministic* (Wex et al. 2014). Disasters often throw up unexpected eventualities. This factor means the level of unpredictability is very high. d) *Presence of autonomous entities* (Ernstsen and Villanger 2014). This means that in a DM activity, individuals/agencies/organisations are coming from different backgrounds, knowledge, abilities, structure, mandate, with no common perception and so on. The AB modelling approach enables analysis of complex systems, in particular socio-technical systems (Sterling and Taveter 2009).

The AOA is also quite intuitive for humans, and thus can be easy to learn for non-technical professionals. It uses constructs from familiar organisational settings (e.g. roles, activities, interactions etc.) (Miller et al. 2014). It is at the high-level of abstraction that enables analysts to apply, from their daily deductive processes, concepts with which they are familiar (Winikoff and Padgham 2013). Furthermore, in both AOA and the context of DM, there are agents driven by local goals that need to interact towards a system goal. Such agents have specified roles and in many instances are situated so they can respond in real time (Lopez-Lorca et al. 2016). Not surprisingly, there have been various attempts recently to use AOA to support DM (García-Magariño and Gutiérrez 2013; Padgham et al. 2014; Scerri et al. 2012). However, much of these works focus on developing simulations of disaster events to gauge the effectiveness of existing practices. This paper introduces a knowledge analysis framework based on the AOA to facilitate modelling and sharing of DM knowledge. AOA templates are used to convert DISPLAN to an intermediate form which can then be mapped to DMM-based constructs. This in turn enables the conversion of DISPLANs to the shareable form that enables DM stakeholders to engage in cooperative decision-making processes. The process exploits the abstraction layering of the Meta Object Facility (MOF) framework.

As shown in Fig. 1, MOF abstracts the knowledge in layers. The first layer, *M0*, describes how knowledge related to tactical activities are structured. In the next layer, *M1*, knowledge from the *M0* is abstracted and generalised to describe policy and planning contexts. In the *M2* layer, the knowledge is then abstracted in the conceptual level. The relationship between the model's layers is described as an instance, and its classifier (or class and object) (OMG 2013). The lower layer of MOF is an instance of, and therefore should conform to, its higher layer; otherwise a higher layer would be able to instantiate a model as its lower layer. The lowest level of MOF is the domain being modelled, named *M0*. Therefore, the model in the higher layer (*M1*) is the model itself, as the resultant of modelling the *M0*. A model in a higher abstraction layer basically represents language to be expressed for the model in the lower level. Thus, with respect to the analogy, the model at *M2*, called the metamodel, is a classifier that represents language for the model of *M1* (instance of). Analysing DM knowledge sources requires a

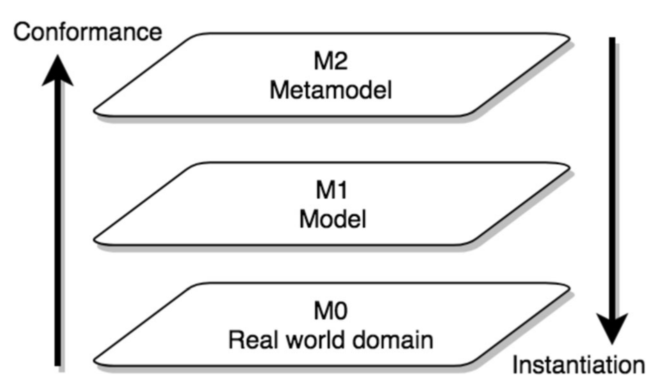


**Fig. 1** The Meta Object Facility (MOF) framework

conceptual tool, which includes not only adequate analysis processes, but also structures to guide analysts in identifying those complex characteristics. In the next section, an analysis framework is presented that utilises AB constructs as a mediating representation between the DM knowledge sources and the structured DM metamodel. The DMM is based on the MOF metamodeling framework.

It is worth nothing that the analysing and modelling these intertwined and fuzzy characteristics out the DM domain are the knowledge engineering type activities (Beydoun et al. 2011; Jakus et al. 2013; Markman 2013). That is a knowledge engineer carries out the analysis and codifications processes to ensure that the knowledge elements are completely extracted and subsequently understood by others (Beydoun and Hoffmann 2001). As the knowledge needs to be shared and reused by other stakeholders then there is a need of a representative repository for the knowledge to be preserved for the basis of decision-making mechanisms in the typical disaster. However, in our context, the issue is not only representing the knowledge out of a domain but the most important part of the task is that the domain itself is a complex one. This means that the fuzzy and intertwined elements are interrelated each other in a way that they are aimed to achieve a common goal but difficult to be later disentangled.

The efforts in representing the knowledge themselves have been the issue since many years ago (Beydoun et al. 2017; Hotz et al. 2014). There are various techniques in attempts to formulize an effective way in representing knowledge out of the domain (Baral and Giacomo 2015; Chandrasegaran et al. 2013; Oramas et al. 2016). However, in our context, the knowledge from the problem domain, the DM, has been in place in DISPLAN semi-structure formats. In addition, given that the complexities of the problem domain itself, the representation of the knowledge elements in that particular plan is fuzzy. Often, it is incomplete and intertwined across the DM phases (Briceño 2015). In the context of DM activities, these factors become the hindrances of effectivity and efficiency developing DM resilience endeavours, as they are difficult to perceive, particularly by the people who have no domain expertise. Therefore, a representative method under which it will be the most suitable approach to represent those complex knowledge characteristics is extremely required.

## 3 DM Knowledge Analysis Requirements

Emergency services covering a wide range of hazards develop DISPLANs of various structure and intent. In general, the plans are created as instances of centrally developed templates, for example those, which are developed by the NSW and Victorian SES's State planning policies. The structured DISPLAN knowledge of the cities/municipalities in each State show commonality as they are developed using the same typical template, however there is also local expert knowledge added to each instance. As a template, all the relevant and observable knowledge elements will be included and identified. The template serves as a general guideline to be embraced by agencies to develop their own DISPLANs by adjusting them to their local resources and environments. Eventually, each of the cities themselves will decide which knowledge will be appropriate. In other words, each of the cities will inherit the knowledge from the template and customise it with respect their conditions and situations.

Knowledge of the relation between various tasks and how the specific area of control overlaps with adjacent organisations, but particularly between Incident Management Teams at Local, Regional and State levels, is an essential component of success in implementing the DISPLAN. Accessing this knowledge leads to a cascade of further context awareness. It typically leads to further identification of other related knowledge, along with those tasks that might be performed in parallel, sequentially or even interleaved. In terms of performing those tasks, an agent (a person, a group of people or an agency) may play various roles and interact with many other agents. Furthermore, agents typically have different scope of control, and belong to different layers in various administrational or command and control hierarchies. Notwithstanding this, the agents still need to be able to communicate with each other to pursue a particular goal(s). As they collaborate, agents are often required to maintain their own situation awareness and need to react to changes in their environment as events unfold. In the midst of all of this, agents need to be knowledgeable of not only their goals but also of their resources and supporting systems. The breadth and complexity of this knowledge presents a number of significant challenges for disaster managers and participating organisations, as well as the community. The NSW SES prepares and maintains some 123 individual Local Flood Plans across NSW Local Government Areas, and this involves extensive processing of flood risk data, and consultation with all organisations and participants involved, to develop the strategies in the plan. Other hazard managers, such as bushfire managers, maintain similarly large numbers of Local and Regional-level disaster plans.

Due to the significant size of the DM knowledge involved, efficiency of analysis is a key requirement. Thus, analysis begins with the DISPLAN knowledge template, rather than a unique localised plan. The use of templates as the input instead of a unique plan increases the effectiveness and efficiency of the analysis by first tuning the ABM templates to suit the core structure of all DISPLANs. In this context, effectiveness relates to the adoption of the process in which the modellers producing customised ABMs are able to more quickly generate many instances of DISPLAN that are strongly based on the core template but are specific to localised parameters. This mirrors the approach taken by emergency management agencies. Further, templates are a benefit if any ratification of changes or updates occur as these can be promulgated and adapted in any instance of localised plans.

Finally, templating is a key approach to effective interoperability as it helps stakeholders to quickly identify the urgent and relevant knowledge to respond to a particular activity by developing a familiar construct of actions, which can easily be navigated. The application of the metamodel and customised ABMs extend all of these efficiencies even further. The customised ABMs generated from this process can be further adjusted according to context and resources where they will be implemented and facilitate the ability to promulgate template changes across a digital repository of DISPLAN in real time. This is illustrated in Fig. 2. In the case of a State level DISPLAN, the template can be employed to generate the plans for all municipalities/cities across the State, as they are all under the same hierarchy level. Therefore, all instances automatically conform to their template. For instance, in NSW, Australia, all the cities and regions across the State adopt the same DISPLAN template for flood disaster developed by the SES NSW. The template is developed as a classifier which is used by the SES NSW in each region and its cities to instantiate their specific DISPLANs. These particular DISPLANs adapt and adjust the customised template based on their resources and environments. This can also be observed in the State of Victoria, Australia, for similar disasters.

The work outlined in this paper addresses inefficient maintenance of such a large connected but disparate knowledge representation currently maintained as individual text documents. But the critical outcome of the paper is facilitating shared understanding and access to DM knowledge, roles and actions. For example, how is a participating organisation or officer, or an individual in the community, best enabled to explore and understand their role and actions in the context of a large and complex DISPLAN? This shared understanding is important to support the goal of creating disaster resilient communities. That is resilient communities who have awareness of risk, and of strategies to mitigate it, before disasters strike. They have gained understanding before the disaster and are proactive and pre-emptive in their actions. This is opposed to attempting to acquire knowledge during the disaster phase when there will be little time to try and develop this understanding for the first time. The analysis requires answering complex questions such as: how a goal can be identified and evaluated; how agents negotiate their priorities as they collaborate in common goal(s); what specific activities agents perform as they pursue their goal(s); what resources are needed for given goals or agents; what time and resource constraints should be imposed on particular agents; and so on. The proposed framework of knowledge analysis of a DM domain within a DISPLAN, transforms the knowledge involved into a representative repository to enable reuse and sharing.

## 4 Knowledge Analysis Framework

The transformation process into DMM follows the MOF framework to ensure the acquired knowledge is correctly represented and positioned (in a knowledge repository) at the appropriate abstraction layer in MOF. For example, a DM preparedness activity in a flood DISPLAN is described as follows: "*...responsibilities to ensure the residents in the council area are aware of the flood threat in their vicinity and how to protect themselves from it*" (SES NSW Australia 2006, p. 14). This activity is intertwined with many other activities. To properly analyse these interconnections between activities, it is important to identify who are the people involved, when should they be active, what resources they require, what are the pre- and post-conditions of their activities, and so on. Without appropriate answers to such questions, it is not possible to map the knowledge involved to the appropriate concepts and relations in the DMM. The transformation process is underpinned by intermediate analysis and modelling tasks. It aims to extract and identify information showing how any given activity relates to the rest of the DM body of knowledge represented within the DISPLAN.

As expected from the discussion in Section 3, in the first stage of our knowledge analysis framework, the knowledge engineer customises ABMs with respect the DISPLAN template. The modeller is then able to synthesise and adjust them with respect to the environment and local resources of that city/municipality. The synthesised templates are then transformed into the repository following a specified semantic mapping. The knowledge structured in the repository can then be adopted by the particular city as its DISPLAN and shared and reused by other users for

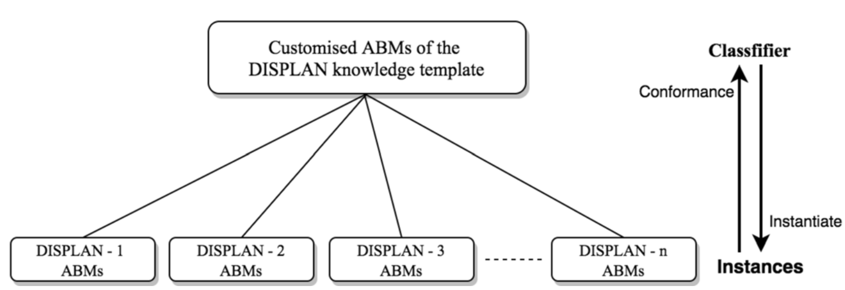


**Fig. 2** Template and the DISPLANs relationship

their DM activities. The knowledge analysis framework is shown in Fig. 3. It consists of three stages, as follows:

Stage 1: The input is customised by seven ABMs that are tightly coupled with the MOF. The input is the DISPLAN knowledge template across all PPRR phases in a semi-structured format. This process results in the customised ABMs of DISPLAN knowledge templates.

Stage 2: The customised ABMs from Stage 1 are used to analyse the DISPLAN template based on the specific local resources and circumstances. This process results in the ABMs of DISPLAN. In this stage, the repository is also prepared by annotating it. This produces an annotated DMM-based repository that is ready to be used for transformation processes.

Stage 3: This is the knowledge transformation process. It requires that the repository is in place and ready for the depositing processes. In this stage, the ABMs of DISPLAN produced in the second stage are transferred to the annotated DMM-based repository. A DM expert intervention is normally required to guarantee that the models resulting from the previous stage are mapped and positioned correctly to the appropriate concepts based on the semantic meaning.

These three stages are essentially knowledge engineering tasks conducted by a DM expert who has knowledge in AO paradigm (or the other way around, a knowledge engineer who understands DM). These tasks are manual and laborious works, particular in Stage 1, as the knowledge engineer needs to assure that all the knowledge elements are completely codified into the corresponding ABMs prior to transferring them into the representative repository. As previously stated, our aim is, however, not to build a piece of software based on an agent-oriented paradigm; instead we develop a mechanism to facilitate a knowledge transfer analysis of DM domain in a way that stakeholders who have no DM expertise are able to comprehend the domain and its characteristics relatively easier. As such, they can have a capability to develop their DM resilience endeavours by understanding the DM natures comprehensively at the first place. The remainder of this section details the stages of our knowledge analysis framework.

### 4.1 Stage 1: Customising Agent-Based Models

A DISPLAN template describes the structure of every DISPLAN. It also has knowledge that is common to all plans, for example contact details within the state or the names of roles. The template is in a semi-structured format and covers all four PPRR phases. ABMs can represent organisational processes and activities as described in a typical DISPLAN. In this step, the commonalities captured and expressed in the template are transferred to the AB templates. That is, each AB template undergoes four steps in this customisation:

1. Common knowledge elements are transferred to the ABMs.
2. Each ABM template is reduced in size to delete elements that are not required. That is, only the required elements are used in the ABMs.
3. Each element in the model is marked as either *M0* or *M1* (this later acts as a pointer in the transfer in Stage 3).
4. Each element in the model is marked with potential target DMM concepts (this acts as another point in the transfer in stage 3).

Essentially, this process is to use the template of the DM knowledge (the DISPLANS) to extract any meta characteristics to simplify the modelling (in Stage 2) and to simplify the transfer process (in Stage 3). The output of this stage is a set of customised AB models of DISPLAN knowledge templates. We identify the following seven AO templates to customise to facilitate the capture of the DM knowledge. The details of

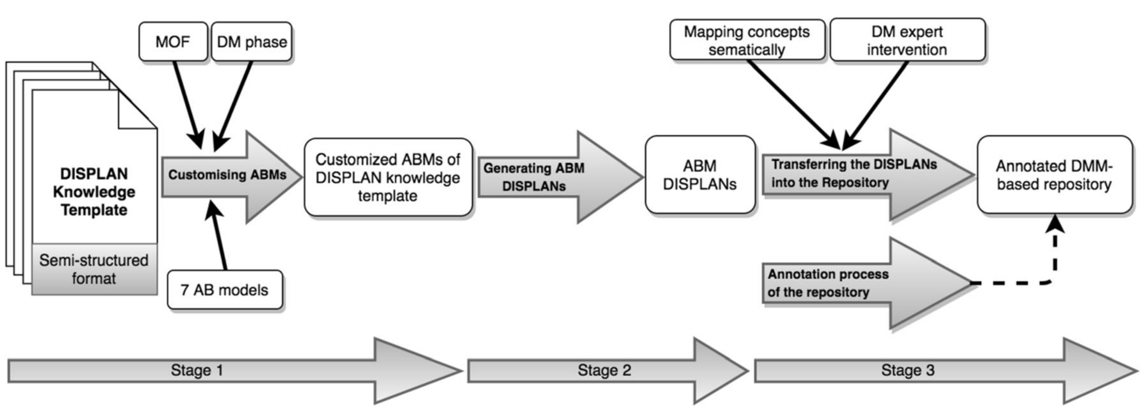


**Fig. 3** Three main stages of knowledge analysis framework

these models are based on (Lopez-Lorca et al. 2016) and are as follows (Note, only figures for *goal model* and *role model* are shown due to space limitations).:

***Goal models**:* The *goal model* represents a particular condition that an agent persistently strives to accomplish. It contains goals/sub-goals and roles responsible for each of them. It describes goals/sub-goals that describe conditions that need to be achieved and the roles (played by agents) for which they are responsible. A *goal model* is introduced to capture the reactiveness and proactiveness knowledge of the agents involved in the DM. In this model, roles that need to be played in order to achieve the goal(s) are also identified. The sub-goals as subsets of the goals are also identified. It describes the proactiveness of an agent. The *goal model* comprises the main goals and the sub-goals for each condition. The main goal is the goal that needs to be achieved by a set of activities represented as the sub-goals. In a DM, all entities (individuals/agencies/organisations) involved in all activities are required to have knowledge about their goals described in the DISPLAN. A particular goal might be pursued by more than one of the roles played by the agent(s). Sharing responsibility for how a goal should be achieved leads involved agents to refine each of their responsibilities for how they should perform. The consequence of more than one agent performing a goal is that the relationship needs be clear, as they might come from different level of hierarchies and jurisdictions. The customization process for the *goal model* is exemplified in Fig. 4.

***Role models**:* A *role model* is used to represent the responsibilities that need to be played by an agent and all the constraints of those responsibilities of a role. The *role models* are structured with respect to the *goal models*. As goals or sub-goals representing responsibilities of a role(s) to be pursued, in the *role models* all goal(s) and sub-goal(s) as well as roles adhered to are listed in the *role models*. They are all listed in the model with its constraint(s). The constraint defines the boundaries of a particular role in performing its responsibilities. The customization process for the *role model* is exemplified in Fig. 5.

***Organisational models**:* An *organisational model* is used to represent the relationships between roles, and to highlight how to take into account their relationships in a DM process. The model defines the communication channels between agents that may belong to different organisations or levels of command in a widely dispersed disaster. The relationships of the roles played by agents inform a hierarchy level that agents need to communicate, coordinate and negotiate within. The *organisational model* represents how an entity is approached by others. This knowledge informs how the entities communicate and negotiate with each other in pursuing a particular activity. For instance, in managing an aircraft to be used by a NSW SES local controller in evacuation, rescue or reconnaissance flood disaster activities, the local controller can only perform

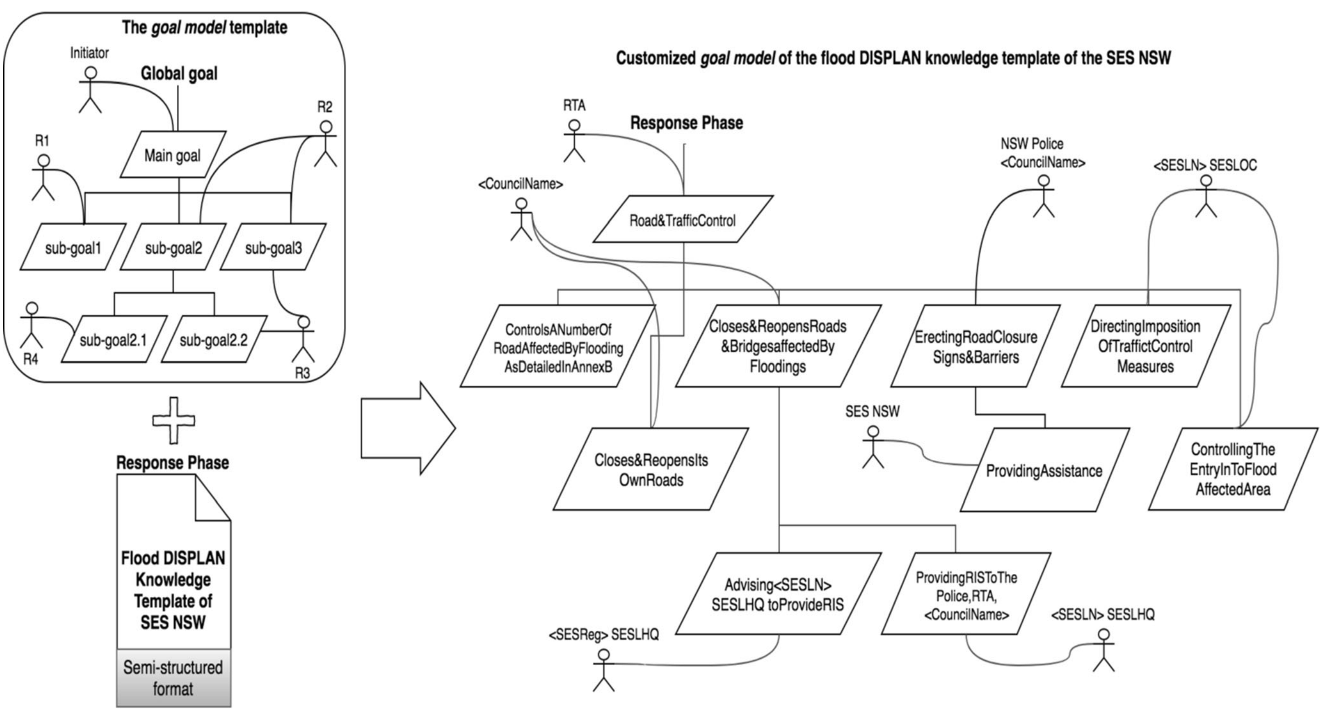


**Fig. 4** The *goal model* template and a DISPLAN template

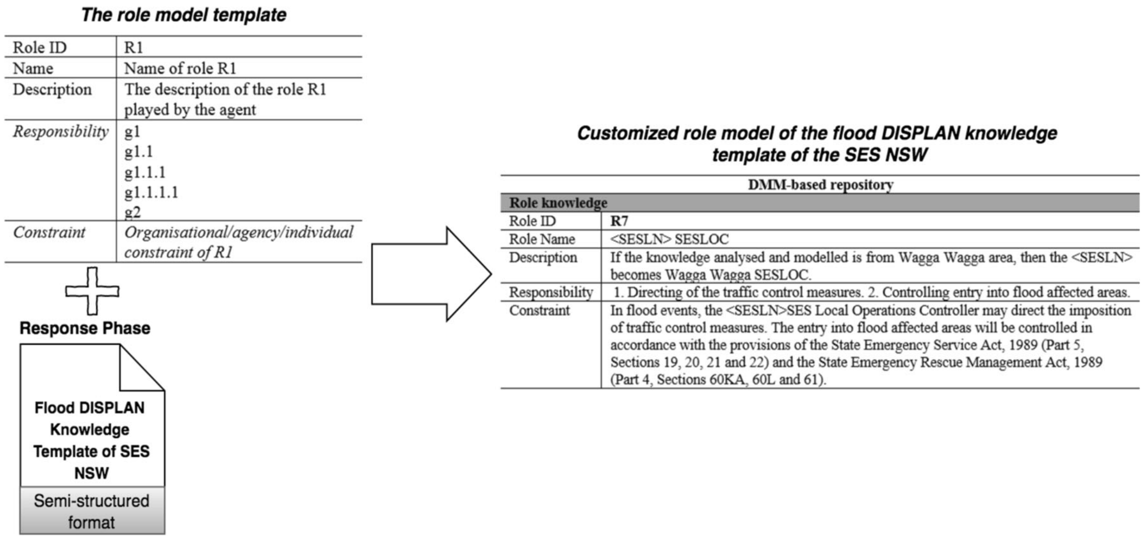


**Fig. 5** The *role model* template and a DISPLAN template

the operation with control and allocation of the aircraft from the SES division headquarter at a higher hierarchy administration level. Essentially, there are only two relationship types that can describe the organisation knowledge of the involved roles, they are: *Controls/isControlledBy* and *isPeer*. The *Controls/isControlledBy* means that of the interrelated roles, one of them is in a higher administration level that controls another. In other words, one is controlled by another. The relationship type *isPeer* means both interrelated roles are colleagues of each other.

***Interaction models:*** An *interaction model* is used to elaborate the specification of the communications between agents that play particular roles to pursue a goal. In other words, this model defines the goal on which agents need to interact. The *interaction model* represents the situation in which particular goals/sub-goals of two or more entities interact with each other. For instance, with respect to the NSW flood DISPLAN (SES NSW Australia 2010), in the context of hierarchy level the SES Local Controller and the SES Division Headquarters will be interacting each other in pursuing this particular goal: "*managing, operating and allocating the aircraft for either evacuation or rescue or re-supply or reconnaissance or emergency travel*" (SES NSW Australia 2010, p. 25). Thus, while the *organisation model* describes the hierarchy-level knowledge of the agencies/organisations/individuals, *interaction model* models the knowledge goals toward which of these agencies/organisations/individuals are interacted.

***Environmental models:*** An *environment model* elaborates on the resources, the activities and the roles required to achieve them. All the resources used by entities involved in the DM activities will be modelled and structured in the model. This model also specifies the environmental constraints on activities and resources of agents.

***Agent models:*** An *agent model* elaborates the type of agents involved, their DM activities and goals. Triggers are identified to represent event(s) that spur agents into actions. This is the manifestation of an agent's situatedness in an environment. This model expresses how an agent is not only reactive but also proactive to the triggers from the environment. All the main goals structured as objectives to be achieved, and all the activities as sub-goals of each of the main goals to be undertaken, will be listed for each of the agents. This defines a set of activities an agent reacts to, and to what objective all the activities aim for. The trigger is sensed by an agent, to react to and respond to the appropriate actions to pursue the goals. For instance, once the information about dam failure warning is received by the SES local controller then all the authoritative individuals and agencies will be contacted regardless of the location and severity of the warning (SES NSW Australia 2010).

***Scenario models:*** A *scenario model* binds all knowledge elements in other models as activities that need to be undertaken in pursuing a particular goal with specific triggers and agent types. The activities are preceded by a pre-condition and followed a post-condition, as a desired state of the goal that was pursued in the activities. Conditions of those activities are specified as parallel, sequential or interleaved. In this model the activities are listed as in the *agent model*. However, the activities in an *agent model* are focused only on one agent's responsibilities, whereas in a *scenario model* all the activities to achieve a particular objective are listed as well as the roles responsible for and the resources needed for each of them. Thus, the *scenario model*'s emphasis is on creating a DM activity scenario that needs to be pursued for a particular main goal. Therefore, in the *scenario model,* the condition whether activities should be performed in parallel, sequential or interleaved matters. In addition, in the *scenario model*, pre-condition as well as post-condition of a main goal to be achieved is important. It defines the condition right before and after the objective is pursued. It is worth noting that as the modelling in the research adopts the AO paradigm, the objective or motivation or main goal refers to the same thing.

### 4.2 Stage 2: Generating AB Model DISPLANs

The analysis process begins with generating the *goal model.* The seven adopted AB models share knowledge elements with each other. The AB models are generated from the DM plans in a depth-first manner. Once one main goal is completely modelled then a modeller can process the next models. By generating the *goal model* first, and reusing knowledge elements from the *goal model,* the number of revisits to the DISPLAN is reduced rendering the process more efficient. Following the *goal model*, the *role model, organisation model* or *interaction model* are generated. These three models can only be completed once the *goal model* is complete. Knowledge elements of these models are linked to the *goal model,* although they are structured differently. The three models are followed by the *environment model* which can only be completed once the *role model* is completed. For instance, the attribute *role* in the *environment model* needs to be extracted from the *role model*. The *agent model* and *scenario model* are the last two to be completed. The knowledge elements of these two models depend on the content of the other models hence they are generated once all five others are completed.

The analysis process is iterative. It can separate analysis of the main goals and each of their sub-goals. i.e. later activities are identified to support earlier activities. For instance, in Fig. 6, sub-goals *g3.1* and *g3.2* support the main goal *g3,* and/or the sub-goals *g3.2.1.1* and *g3.2.1.2* support *g3.2.1,* and so on. This enables a modeller to concentrate on completing one main goal at a time, without being distracted by the other goals/sub-goals. This can significantly reduce the complexities in the early requirement phase. The modeller analyses the main goal *g1,* and all its sub-goals from *g1.1* to *g1.1.1.1*, and roles *R1* and *R3*. All the sub-goals of a main goal can be traced as the activities to support and address the main goal. Since the role *R1* is responsible for the main goal *g1*, it also implies that the particular role is responsible for all the sub-goals of the main goal. Thus, the role *R1* is automatically responsible for *g1, g1.1, g1.1.1* and *g1.1.1.1*. The *goal model* informs that for the sub-goal *g1.1.1*, there is another role, *R3*, involved in pursuing it. This notifies the role *R1* is responsible as the initiator for the main goal while both *R1* and *R3* will interact, communicate and coordinate in pursuing the sub-goal *g1.1.1*. These elements of the *goal model* will be the basis to identify relationships between closely related ABMs.

The depth-first approach offers a systematic way to conduct a detailed agent oriented analysis. It shows not only where to start the modelling activities (Lopez-Lorca et al. 2016; Miller et al. 2014) in the AO paradigm, but also how to do it step by step. It offers a way to complete the analysis and modelling stages by reducing the expense and time involved in requirement specification. As shown in the Fig. 6, this illustrates that once the *goal model* is holistically analysed and modelled then a modeller can easily look at the model's elements as the cornerstone to process other ABMs without revisiting the knowledge in the document. For instance, the roles involved to pursue a sub-goal analysed in the *goal model* will be the basis to structure the *organisation model* and *interaction model*. The main goal and sub-goals of a *goal model* will be used to structure *action* in the *agent model* and *activity* in the *scenario model* and so on. In addition, these processes themselves are conducted iteratively, therefore the modellers can always go back the previous stage to improve the modelled models. By adopting the depth-first approach, the AOA can also be made more efficient by distributing the processes to a number of *modeller*s.

In this approach, distributing means that these *modeller*s can share the AOA tasks to be undertaken in parallel which: **1)** It will reduce the AOA's iteration step. For a large knowledge DISPLAN, each *modeller* will focus on only one particular main goal and all its sub-goals at a time. At the end, these goals will be combined to represent one complete *goal model*. In addition, once these *goal model*s are structured, the other AO models can be analysed easily as their knowledge attributes are obtained from the *existing model*s. **2)** Interleaving in the modelling processes. In this approach, a modeller can activate the other models, without waiting until others' main goals are fully analysed in a complete *goal model*. As shown in Fig. 6, the main goals will be placed along the *M1* layer of MOF. They are objectives that need to be pursued in a particular DM activity as they represent the policy/planning knowledge. These knowledge elements are the typical ones that each of the activity needs to be strived for. Moreover, the sub-goals will be positioned along the *M0* layer of MOF.

### 4.3 Stage 3: Knowledge Transfer

Once the ABMs corresponding to a particular DISPLAN are generated, their content is transferred into the knowledge repository. For this purpose, each concept in DMM is first annotated with pointers to potentially corresponding elements from the AB models. The steps involved are described in what follows.

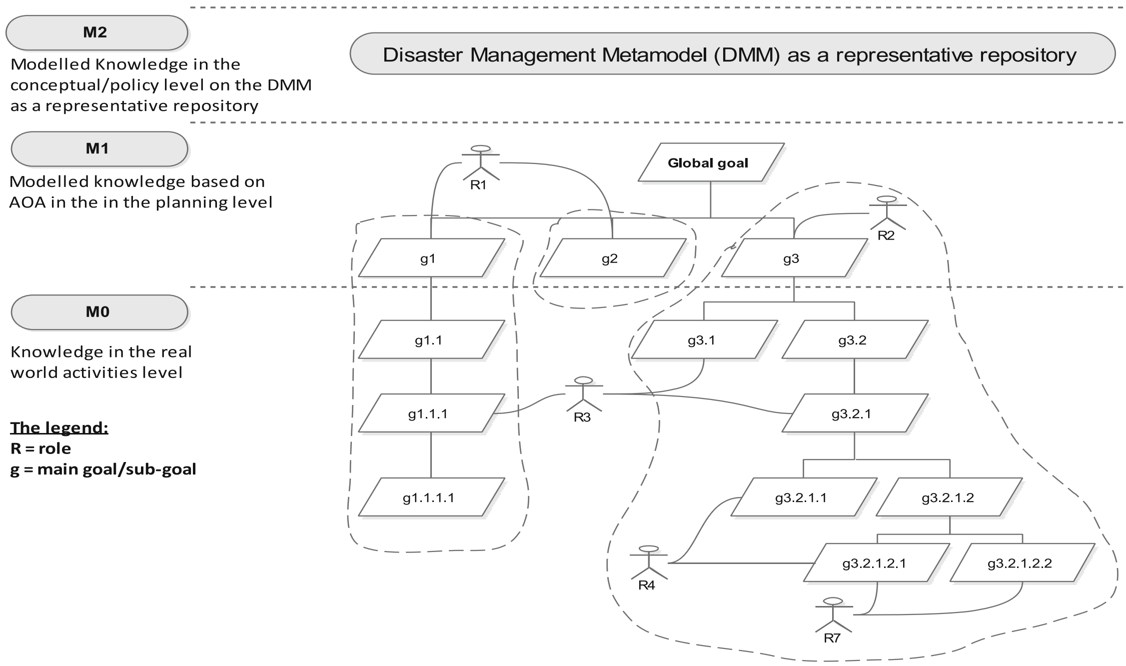


**Fig. 6** The AOA of a *goal model* in a depth-first search approach

### *4.3.1 Annotating DMM Concepts with the AO Concepts*

This step provides the basis of a semantic mapping between the elements of the ABM models and the DMM constructs. To ensure that the mapping preserves and is consistent with the abstraction layers defined by the MOF, a corresponding MOF-based agent metamodel is used as a basis for the annotation. The FAML metamodel (Beydoun et al. 2009) is used to provide a set of terms that are used to annotate DMM appropriately. This mapping between DMM and FAML is a one-off process. It is not a one-to-one mapping. In many case, DMM concepts are annotated with the multiple FAML concepts. That is, DMM concepts contents are sourced from multiple ABM models. For example, a number of DMM concepts are about activities and resources/environment. Thus, the Agent Oriented Software Engineering (AOSE) metamodel concepts of <<*Activity*> > and <<*EnvironmentEntity*> > are used to annotate DMM concepts repeatedly. The challenge in this step is to annotate each DMM concept appropriately. This annotation process is conducted only once but can be tuned as needed during the transfer process. For example, to describe the hierarchy level among agents involved in the DISPLAN as described in *organisation model,* then domain properties of the agents are added as *isPeer*, representing agents in the same hierarchy level, *Controls* and *IsControlledBy* represent an agent controls another agent or is controlled by others. Interactions in the *interaction model* between agents to pursue goal(s) are described by adding the relations *ParticipatesIn* to represent an agent participating in a particular activity, or in pursuing the activity that *Involves* the agent. For instance, if an agent A plays a role X and an agent B plays another role Y where they interact to a goal P, then this is described using the relationship *ParticipatesIn* to achieve goal P; or in another way, goal P *Involves* Agents A and B.

All 92 DMM concepts across all PPRR phases are annotated (21, 25, 25 and 21 concepts respectively in each DM phase). A knowledge modeller is required to link DMM concepts with the appropriate concepts in FAML. The *training* concept, for example, is defined as follows: "*An instruction that imparts and/or maintains the skills (and abilities such as strength and endurance) necessary for an individual, a community or an organization to perform their assigned disaster action responsibilities*" (Othman et al. 2014, p. 257). This is a set of activities to be undertaken to maintain the skills of DM stakeholders. This consists of a set of activities, hence, the corresponding concept from the AOSE metamodel is <<*Activity*>>: "*Describes a set of activities to be performed to achieve the goal(s)*". Therefore, the modeller annotates *Training* concept in DMM with the <<*Activity*>>. Another example is a *PreparednessTeam* defined as follows: "*A group of all agencies with a role in incident management that provide interagency coordination for domestic incident management activities in a non-emergency context to ensure the proper level of planning, training, equipping and other preparedness requirements within a jurisdiction or area*"" (Othman et al. 2014, p. 23). This concept describes a set of roles played by an agent(s) to pursue a goal(s) in a DM activity. As a role representing a set of capabilities played by an agent, the AOSE appropriate concept in the metamodel for *PreparednessTask* is <<*agent*>>: "*Represents an entity that* *having certain properties and can play one or more roles*". Therefore, a knowledge modeller annotates the *PreparednessTask* to the <<*agent*> > in the DMM. The annotation process produces a 3D knowledge structure that describes those three dimensions: DM phases, knowledge level and the annotated AO metamodel. The structure is readied to be utilised as a representative repository.

### *4.3.2 Transferring the DISPLAN into the Annotated DMM-Based Repository*

In this stage, every ABM acquired in Stage 2 is transferred into the annotated DMM-based representation following the mapping provided in Step 1 of Stage3. This part of the process is the foundation of the proposed knowledge analysis framework, as it allows the DM knowledge in the different conceptual levels to be both synchronised, and traceable for the purpose of the Disaster Management-Decision Support System (DM-DSS). This transforms DISPLAN content to its appropriate metamodel level (*M0 to M2*, with respect to MOF framework). By adopting the MOF in software engineering, tangled knowledge of DM can be pinpointed to the abstraction layer to which it belongs. The activities in this step are undertaken semi-automatically. The process still requires a DM expert intervention by pinpointing the similar concepts semantically at both ends. A DM practitioner is involved in transferring the models to their appropriate DMM constructs. The ABM elements are mapped to 92 DMM concepts across all phases in the DM. One element maps to multiple DMM concepts. The DM practitioner selects a subset of the possible DMM constructs for each element. They identify which concepts in the DMM-based repository are appropriate to capture the knowledge in the AB knowledge models.

To help the DM practitioner pinpoint the DMM concepts appropriately, the categorisation based on five AOSE metamodel concepts that can be applied across all phases. Thus, instead of examining all annotated DMM concepts in all phases that match with one in AB model, the annotations automatically help a modeller to narrow the searching process. This is conducted by limiting a set of most likely to-be-appeared concepts based on a particular AOSE metamodel concept. Eventually, a modeller can map an ABM to the only concept(s) that are semantically similar in the repository. For instance, if a modeller only requires depositing the *goal model* from a preparedness phase then the system is automatically narrowed; the AO metamodel concepts maps only to those annotated with <<*goal*>>. Since there is only one <<*goal*> >- in the preparedness phase, this can be done automatically. However, if there are more annotated concepts that match, for instance concepts *Training* and *PublicEducation* are annotated as the <<*activity*>>, then a modeller intervenes to determine the more suitable of the two concepts. With respect to the MOF hierarchy, not all customised ABM are represented equally. Some models favour *M0* level whilst others favour *M1* level. For instance, the scenario and agent models generate more constructs at *M0* while role and goal models generate more constructs at *M1* level. The process is evaluated engaging a DM practitioner from State Emergency Services of NSW in Australia. This case study is described in the next section.

## 5 Case Study: Transfer of Nsw Flood DISPLAN Knowledge

In this section, the framework of knowledge transfer analysis is evaluated. A case study from SES NSW is used. As earlier described, a DISPLAN template is first acquired. That is a flood DISPLAN knowledge template of the SES NSW acquired as the first input of the framework. This input is used to customize the ABM templates to enable their more effective and efficient use. The templates are then utilized to generate particular DISPLANs and these are then transferred into the repository. The DISPLAN instance aimed to generate is the Wagga-Wagga Municipality Flood Management DISPLAN. The Wagga-Wagga DISPLAN (Local Flood Plan (LFP)), the focus of this case study, is maintained to prepare for, manage the response to, and support recovery from flood disasters. It is maintained by SES NSW in conjunction with the Wagga-Wagga City Local Government and its representative Local Emergency Management Committee, comprising local stakeholders. The original plan can be downloaded freely from the SES website, www.floodsafe.com.au. The LFP covers knowledge in three phases: Preparedness, Response and Recovery. The modelling process shown in this section is applied only to the Preparedness and Response phases. The three stages of the transfer process for the Wagga-Wagga LFP are illustrated in details in this section.

### 5.1 Stage 1: Customising Agent-Based Models

In this stage, the seven ABMs are customised. The flood DISPLAN knowledge template of SES NSW is analysed and to identify commonalities and model the commonalities into the ABM templates. This includes four steps described in Section 4.1. (not all are shown due to space limitation).

**Customising the Goal Model** A main goal is identified. The goal "*Road and Traffic Control*" is identified as an example from the SES flood DISPLAN knowledge template in NSW. All instances produced from this customized *goal model* will subsequently contain this knowledge as class of a main goal. Once this goal is identified, the knowledge engineer then goes through the document to identify all other related knowledge elements for this particular main goal only, namely its subgoal(s) and role(s), and omitting the other elements that are not related.

Towards this, the knowledge engineer analyses the DISPLAN template to identify the supporting activities to achieve that goal and the role(s) responsible for each of them. All these knowledge elements in this process serve as common elements of the *goal model*. All subsequent instances will conform to the common elements of the customized template. In the final customisation step, the knowledge engineer marks every knowledge element to highlight the likely MOF abstraction layer of the element (M0 or M1). For instance, the main goal "*Road and Traffic Control*" is annotated *M1* as it represents the objective to be strived for, and all its remaining subgoals will be marked for *M0.* The customized *goal model* constructed following the MOF framework is shown in Fig. 7.

**Customising the Role Model** Similar to the customizing process of the *goal model*, in the *role model*, the knowledge engineer analyses the common knowledge in the flood DISPLAN knowledge template of the SES NSW NS subsequently structures the corresponding attributes in the model. As indicated previously, this model template of flood DISPLAN will serve as a class of the role model to instantiate a particular *role model* for a other municipality/area under the NSW authority, for instance, the Wagga-Wagga municipality, or Wollongong city and so on. Once the model is completely analysed the knowledge engineer specifies which of the knowledge element that will be marked as either *M0* or *M1.* Customizing the flood DISPLAN knowledge template of the SES NSW with respect to the *role model* template results in the *role model* template (shown in Table 1). Only one particular role R7: <*SES Local Name* > SES Local Operational Controller (<*SESLN* > SESLOC) is exhibited from the case study as an example. In the identified document, this role is a subject to change depending where the template will be instantiated to. In that case, the <*SESLN* > will be changed following the municipality name. For instance, if the template will instantiate the Wagga-Wagga flood DISPLAN knowledge then the role *R7* will be automatically adjusted to be the Wagga-Wagga SESLOC. Additionally, all the related knowledge element classes described in the customized *role model* template will also automatically change with new instantiated municipality.

The knowledge elements in the responsibility attribute of the customized *role model* template are obtained from the *goal model*. This implies that the knowledge element classes applied in the *goal model* are also applied in the *role model*. However, for the element attribute *constraint*, the knowledge engineer needs to revisit to document to obtain this as it is not structured in the *goal model*. The next step is determining whether each of the knowledge elements of the *role model* is placed as either *M0* or *M1*, following the MOF layer. As described in Table 1, the *role name* and *description* attributes are positioned as likely *M1* candidates*,* whereas, the *responsibility* and *constraint* attributes are placed as *M0* candidates.

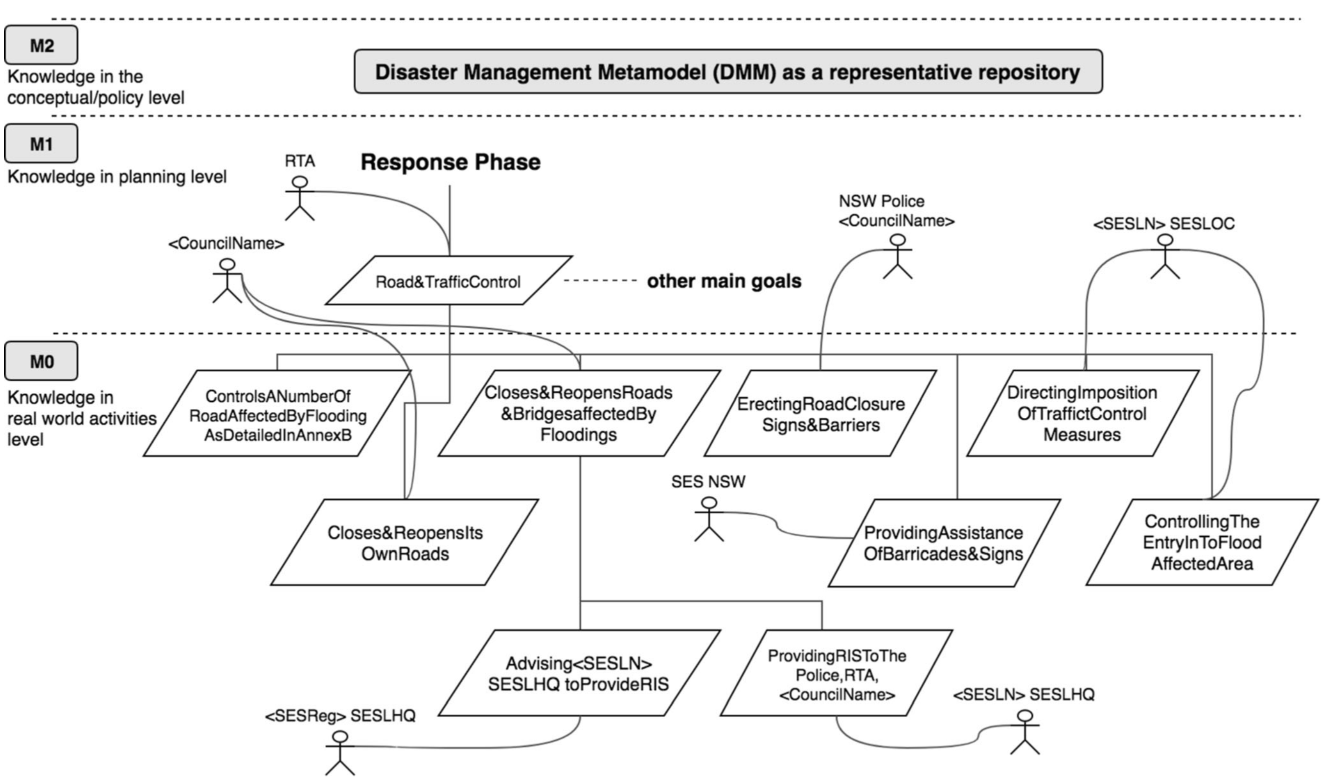


**Fig. 7** A customized *goal model* of the DISPLAN template of the SES NSW for a main goal "*Road and Traffic Control*"

**Table 1** A customized *role model* of the DISPLAN template of the SES NSW for a role “<*SESLN* > *SESLOC*”

| DMM-based repository Role knowledge | | M2 MOF layer |
|---|---|---|
| Role ID | R7 | M1 |
| Role Name | <SESLN> SESLOC | |
| Description | If the knowledge analysed and modelled is from Wagga Wagga area, then the <SESLN> becomes Wagga Wagga SESLOC. | |
| Responsibility | 1. Directing of the traffic control measures. 2. Controlling entry into flood affected areas. | M0 |
| Constraint | In flood events, the <SESLN>SES Local Operations Controller may direct the imposition of traffic control measures. The entry into flood affected areas will be controlled in accordance with the provisions of the State Emergency Service Act, 1989 (Part 5, Sections 19, 20, 21 and 22) and the State Emergency Rescue Management Act, 1989 (Part 4, Sections 60KA, 60 L and 61). | |

### 5.2 Stage 2: Generating Agent-Based Model DISPLANs

Each of the customized ABMs DISPLAN knowledge templates instantiates a particular ABM plan based on the local wisdom where it will be implemented to. In this case study, all NSW regions and their municipalities can adopt the same DISPLAN knowledge template to produce each of their local DISPLANs (LFPs). The template is used to instantiate local plans efficiently that share the various commonalities of knowledge across all areas within NSW with adjustable local context. Within state of NSW, there are 141 municipalities within 18 regions (SES NSW Australia 2016). In this case study, the Wagga-Wagga municipality is employed as an exemplar. This instance conforms and inherits all the commonalities of knowledge element classes of the ABM templates adaptable based on the local characteristics of Wagga-Wagga. The regional town of Wagga Wagga and surrounding rural area, in the state of NSW, is situated on the Murrumbidgee River floodplain, the second longest river in Australia. The history of flooding in Wagga Wagga is a good example of the low frequency of flooding in inland Australia. The sporadic nature of flooding presents major challenges for maintaining community and government awareness and knowledge of flooding, and of ongoing flood resilience, with large periods of drought between major floods. Flood DM in NSW is coordinated through a set of documented emergency/disaster plans and arrangements at the Local, Regional and State levels. The Wagga-Wagga LFP (SES NSW Australia 2006) is a flood hazard-specific sub-plan supporting a Regional Disaster Plan (DISPLAN).

As elaborated in the previous stage, the customized ABMs of flood DISPLAN of the SES NSW is resulted. As explained, the customization processes are essentially the analysis process of the flood DISPLAN template of the SES NSW utilizing the 7 (seven) ABM templates. Thus, in this stage, the generating process of the Wagga-Wagga in carried out, following the depth-first approach and based on the knowledge element classes in the DISPLAN template. The use of template instead of a unique plan means that the validation whether the knowledge elements in the DISPLAN have been completely customized and modelled into the ABMs can be performed in the first place. In other words, the involvement of a DM expert since the customizing process is with the aim to validate that the knowledge elements are entirely codified and structured into each of the corresponding ABMs. As such, this implies that instantiations of the ABMs will automatically have the same knowledge elements but specified for a particular city. In our case is the Wagga-Wagga Municipality. Generating each of the ABMs for the Wagga-Wagga LFP is detailed in what follows. The customized ABMs generated in the previous stage are used.

**Generating the Goal Model** This *model* fundamentally represents the same knowledge as its class (customized one), but in the context of the Wagga-Wagga municipality. The knowledge engineer substitutes all the knowledge classes from the customized version with the one representing the Wagga-Wagga municipality, accordingly. This then becomes the *goal model* of Wagga-Wagga flood DISPLAN knowledge as drawn in Fig. 8. Some of the knowledge elements are substituted to represent the characteristics of the Wagga-Wagga City whereas others generic ones remain applicable. In Table 2, the substitution process is shown. All the knowledge elements in the bracket “< >” are substituted with the ones represented the knowledge of the Wagga-Wagga municipality. A knowledge engineer goes through all the knowledge element classes of the customised *goal model* to generate the instance one. Once it is in place then it is ready to be transferred into the repository.

**Generating the Role Model** Generating the *role model* essentially is the process to instantiate a particular one from the customized one template. In this case study that is the

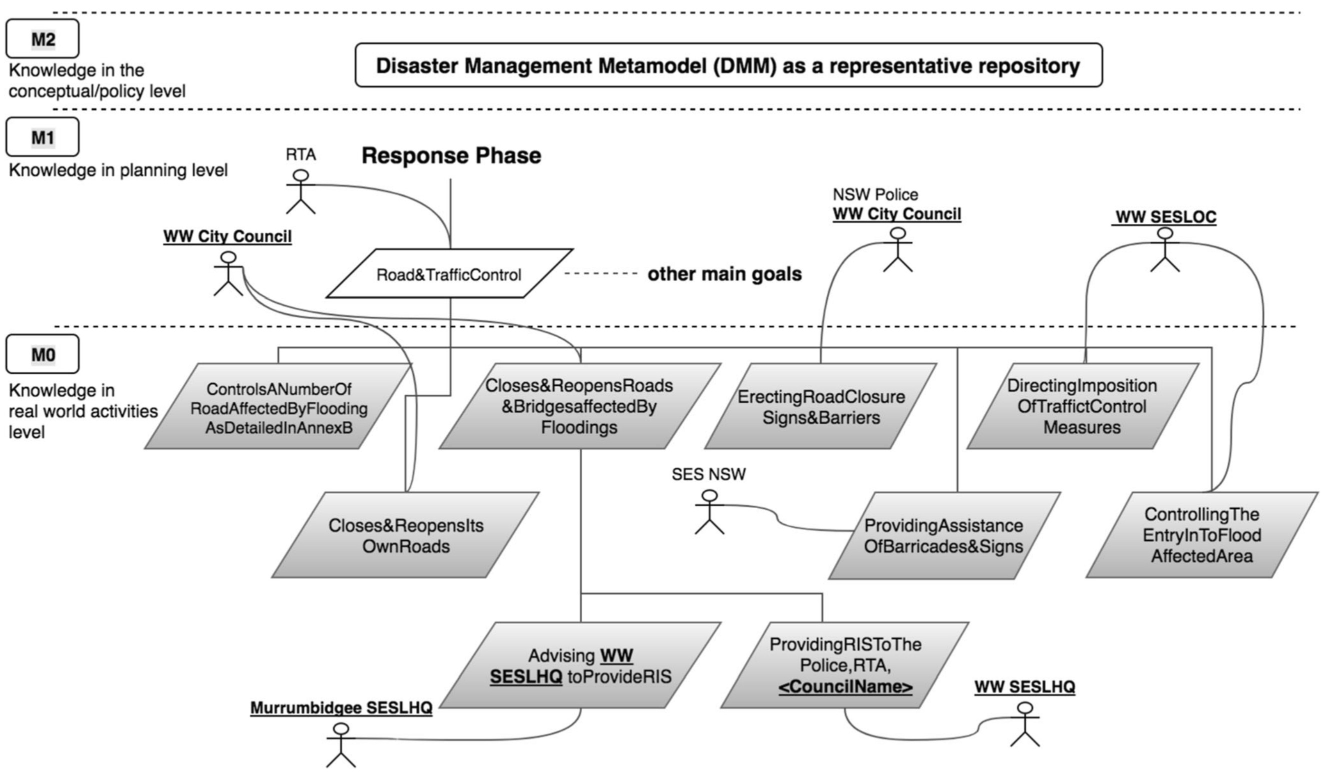


**Fig. 8** The *goal model* of Wagga-Wagga flood DISPLAN knowledge generated from the customized one of the SES NSW template. This only describes the goal knowledge of a main goal "*Road and traffic control*"

*role model* of Wagga-Wagga flood DISPLAN knowledge. As illustrated in generating the *goal model*, in this model, all the knowledge element classes of the customized one is substituted with the typical knowledge but associated with the Wagga-Wagga City. This is illustrated in Table 3. In the table, for instance, the role knowledge class is <SESLN> SES LOC (Local Operational Controller). As this is implemented in the context of Wagga-Wagga city then the <SESLN> will be replaced with Wagga-Wagga. This is means the role is the SESLOC of Wagga-Wagga. This will also be applied in the same way to other cities once those cities generate their *role models* from the customized one.

### 5.3 Stage 3: Knowledge Transfer

There are two activities in this stage, namely: 1) annotating the DMM to prepare the repository for the depositing process; and 2) the knowledge transfer process itself. They are both examined as follows:

**Table 2** Generating process of knowledge element instances from the *goal model* DISPLAN knowledge

| DISPLAN knowledge template | Wagga Wagga City DISPLAN instance |
|---|---|
| The ~~<SESLN>~~ SES Local Operations Controller may direct the imposition of traffic control measures | <SESLN> = SES Local Name = Wagga Wagga SES Local Operation Controller |
| ~~<SESLN>~~ SES Local Headquarter provides Road Information Service (RIS) to the Police, RTA and the ~~<CouncilName>~~ | <CouncilName> = Wagga Wagga City Council |
| Controls a number of ~~<roads>~~ within the ~~<council area>~~ that are affected by flooding as detailed in annex B | Roads of Wagga Wagga municipality:<br>Collingullie to Lockhart Rd., Sturt Hwy;<br>At Sandy Creek and between Wagga Wagga and Forest;<br>Hill Hampden Ave between Wiradjuri Bridge and Cartwrights Hill, etc.<br>Council area of Wagga Wagga municipality:<br>Central Wagga Wagga, Ashmont, Flowerdale, Tarcutta, etc. |
| ~~<SESReg>~~ SESLHQ | <SESReg> = SES Regional = Murrumbidgee SES Local Headquarter |
| ~~<SESLN>~~ SESLHQ | <SESLN> = SES Local Name = Wagga Wagga SES Local Headquarter |
| …and so on | |

**Table 3** The *role model* of Wagga-Wagga flood DISPLAN knowledge

| DMM-based repository<br>Role knowledge | | M2<br>MOF layer |
|---|---|---|
| Role ID | R7 | M1 |
| Role Name | ~~<SESLN>~~ Wagga-Wagga SESLOC | |
| Description | SES Local Operational Controller (SESLOC) of the Wagga-Wagga municipality | |
| Responsibility | 1. Directing the imposition of the traffic control measures.<br>2. Controlling the entry into flood affected areas. | M0 |
| Constraint | In flood events, the ~~<SESLN>~~ Wagga-Wagga SES Local Operations Controller may direct the imposition of traffic control measures. The entry into flood affected areas will be controlled in accordance with the provisions of the State Emergency Service Act, 1989 (Part 5, Sections 19, 20, 21 and 22) and the State Emergency Rescue Management Act, 1989 (Part 4, Sections 60KA, 60 L and 61). | |

### *5.3.1 Annotating DMM Concepts with the AO Concepts*

This activity aims to prepare the repository for enabling the transfer process. This is conducted by annotating all the concepts in the DMM with the corresponding ones of AOSE metamodel. This is a one-off process that results in the annotated DMM for all four phases. For the purpose of the case study in this paper, only the annotated DMM-based concept in the Response phase is shown as in Fig. 9.

A *goal model* will be mapped with a corresponding goal concept through <<*goal*> > to represent the goals to be pursued. Likewise, a *role model* will be mapped with a < <*role*> > concept, *environment model* with an <<*environemntEntity*> > concept, and so on. To describe

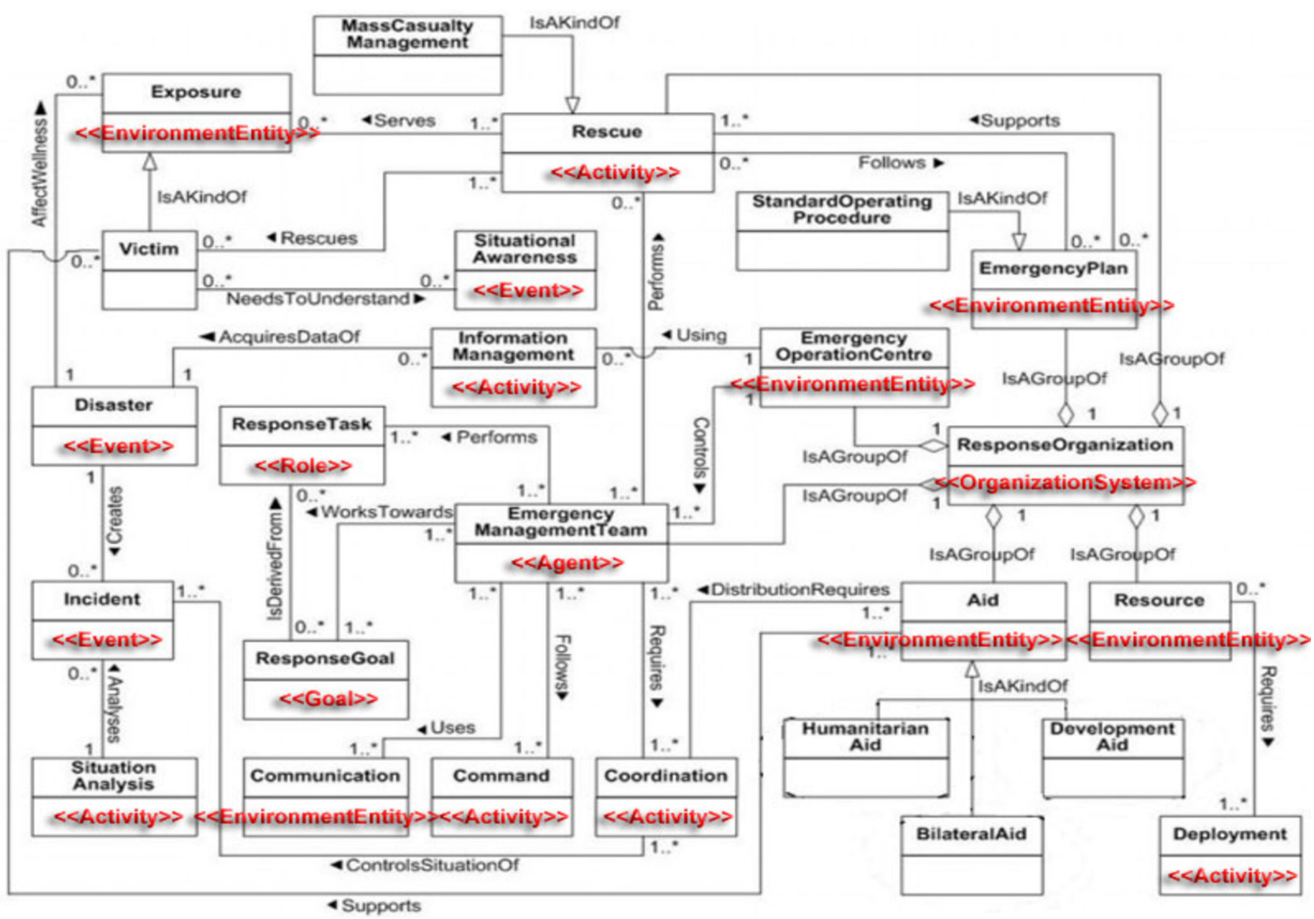


**Fig. 9** DMM-based concepts annotated with AOSE metamodel concepts in the response-phase

hierarchy level among agents involved in a DISPLAN (as described in *organisation model)* the domain properties of the agent are added as: *isPeer*, representing agents in the same hierarchy level; *Controls* and *IsControlledBy* represent where an agent controls another agent or is controlled by others. Interaction in the *interaction model* between agents to pursue goal(s) is described by adding the relations: *ParticipatesIn* that describes agents participated in a particular activity or in other words, that is described activity that need to be pursued that *Involves* agents. As mentioned, although this annotating process is prepared only one time, however, a knowledge engineer can always revisit the product to revise as necessary. Once the annotated DMM-based repository is considered ready, the transfer process can be enabled.

#### *5.3.2 Transferring the DISPLAN Knowledge into the Repository*

Once the annotated repository is in place, the transfer process commences. The seven ABMs of the Wagga-Wagga flood DISPLAN knowledge from the Stage 2 are transferred into the annotated DMM-based repository. This maps each of the ABMs of Wagga-Wagga DISPLAN knowledge to each of their corresponding concepts in the DMM-based repository. With respect to the MOF framework, essentially, the process is that the knowledge in the *M0* layer is modelled and structured in *M1* layer is transferred to its appropriate metamodel-based repository in *M2* layer, (*(M0*➔*M1)*➔*M2*). This process is intermediated by a knowledge engineer based on semantic meaning between each of the ABMs of DISPLAN knowledge and the most possible appropriate concept in the repository. A graphical-based tool is created to illustrate this knowledge transfer mechanism in a way it can be understood easily. This is implemented with a graphical web-based user interface that supports access to the DMM knowledge repository. The ABMs are made available in XML and they are the input to a MySQL database. MySQL is used in the prototype as it is a powerful, widely-used, open source database that harnesses a web-based technology to connect client requests to the server. Apache web server technology used in most web servers around the world, is chosen. In the repository, the three components: DM phases, the MOF framework and the ABMs construct the knowledge in a three-dimensional (3D) structure which allows the knowledge to be drilled down or rolled up easily in real time during the DM activities. To complete the 3D knowledge structure, these three stages are undertaken iteratively. Eventually, this knowledge structure allows the knowledge to be reused by pinpointing the appropriate knowledge through each cube of the structure as necessary as further details in (Inan et al. 2016).

Two scenarios can arise during the transfer: (1). If there is only one appropriate annotated DMM-based concept in the repository to which an ABM is match with, then the transfer process can be proceeded automatically and directly. (2). If there is more than one possible appropriate annotated DMM-based concept in the repository, then a DM expert intervention is required to determine which concept, among all possibilities, is more appropriate for the ABM to be positioned and transferred to. An example of the first transfer scenario consider the annotated DMM where there is only one <<*goal*> > concept in it. As such, the *goal model* can be transferred directly to that particular concept goal: <<*goal*> > in the repository without any intervention from the knowledge engineer.

In scenario 2, however, if there is more than one corresponding DMM-based concept in the repository where the knowledge can be transferred to, then a knowledge engineer intermediates the process by examining semantically the most appropriate concept in the repository that fit for the one of the ABMs. Subsequently, that particular ABM of flood DISPLAN knowledge will be transferred to most suitable concept in the repository. For instance, the concept in the repository representing environment entity is <<*EnvironmentEntity*>>. As can be seen in the annotated DMM-based repository for Response-phase in Fig. 9, there are 11 concepts representing <<*EnvironmentEntity*>>, they are: *Aid, Humanitarian Aid, Bilateral Aid, Development Aid, Resource, Emergency Plan, Standard Operating Procedure, Emergency Operating Centre, Exposure, Victim, Communication*. Therefore, in this case, a knowledge engineer will judge and position the *environment model* of the Wagga-Wagga DISPLAN knowledge to be mapped to one of them that is considered the most appropriate one, semantically. For instance, for this typical knowledge, "*List of roads and bridges affected by flooding used by the roles to achieve the goal*" from the *environment model* of Wagga-Wagga flood DISPLAN knowledge. Of all possibilities semantically, the *resource* concept "*Personnel and major items of equipment, supplies, and facilities available or potentially available for assignment to incident operations and for which status is maintained*" is considered as the most appropriate.

Once the knowledge transfer process is completed, then the knowledge in the repository is ready to be (re)used by the stakeholders for the decision-making mechanism. Figure 10 shows that once all the ABMs of flood Wagga-Wagga DISPLAN knowledge is deposited completely to the repository, a comprehensive knowledge for that particular DM can be retrieved from the repository. As the knowledge is deposited in a holistic format, it is easy to share and reuse by other. To help it is understood effectively, a web-based technology tool is developed. The knowledge stored in the repository is structured so that it can be understood comprehensively by the stakeholders. The stakeholders can also identify not only the missing and incomplete knowledge from the repository, but also the other knowledge concepts that need to be provided for a comprehensive knowledge structure.

**Concept relationship**

| # | Domain Relation | Concept Relation | Annotated Concept | Ralationship 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 | ParticipatesIn | ResponseTask | <<Activity>> | 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 |

1

**M1: Disaster Management (DM) Model**

| | | | | | |
|---|---|---|---|---|---|
| Model Name | **Wagga-Wagga SES NSW Flood DISPLAN** | DM phase | **Response** | Disaster Category | **Hydrological Disasters** |
| Country Origin | **Australia** | Disaster Type | **Flood** | Class of Disaster | **Natural** |

2

| | |
|---|---|
| **Initiator** | : RTA NSW |
| **Pre-condition** 3 | : Road Information Service has passed to NSW Police, RTA and Wagga-Wagga City Council, Local Emergency Service, Public and Murrumbidgee SESRH |
| **Post-condition** | : Road and traffic are under controlled |
| **#** | **Scenario Name : ResponseTask** 4 |
| 1 | Road and traffic control 5 |

**M0: Disaster Management (DM) real world knowledge model**

| # | The Trigger of the Activity(ies) |
|---|---|
| 1 | On receipt of a Bureau of Meteorology Preliminary Flood Warning, Flood Warning, Flood Watch, Severe Thunderstorm Warning or a Severe Weather Warning for flash flooding 6 |
| 2 | On receipt of a dam failure alert |
| 3 | When other evidence leads to an expectation of flooding within the council area |

| Condition 7 | # | Activity(ies): Road and traffic control 8 | Activity(ies) Involves Role(s) 9 | Activity(ies) Needs Environment 10 |
|---|---|---|---|---|
| parallel | 1 | Controls A number of roads within the council area are affected by flooding as detailed in annex B | Role | Env |
| | 2 | Closing or re-opening roads or bridges affected by flooding | Role | Env |

**Fig. 10** The knowledge is structured for decision making in the Response phase of flood DM. The knowledge is traceable up and down from the conceptual (*M2*) the planning/policy (*M1*) and real world activity (*M0*)

For instance, In Fig. 10: (1) shows all the related concepts to the *ResponseTask*, they are *Coordination, Command, Communication, ResponseGoal, ResponseTask, Rescue, EmergencyOperationCentre and ResponseOrganisation*. This relation shows the benefit of the DMM as a repository, as it can pre-empt the knowledge that needs to be completed to get a broader understanding of the management process. (2) informs where the knowledge comes from and in which disaster is used for, while (4) shows the knowledge in the conceptual layer (*M2*), and its instance type at the *M1* layer in (5). (3) informs the initiator, pre-condition and post-condition of the objective to be pursued. (6) defines the time as the trigger when the activities are performed. (7), (8), (9) and (10) subsequently inform the stakeholder the condition that the activities will be performed, the activities themselves, the roles involved and responsible for each of the activities, and the environment knowledge (resources) required and used by each the roles in each of those activities.

### *5.3.3 Discussion and Limitations*

The case study shows how the ABMs of flood DISPLAN template of the SES NSW is able to effectively and efficiently instantiate the Wagga Wagga DISPLAN knowledge for the typical flood events. This process can be applied to other cities under the same jurisdiction by following the same process. Although this paper successfully shows the developed framework, there are some limitations identified so far, as follows:

1. In the semantic mapping process stage, a DM expert intervention is required to ascertain whether the knowledge concepts are mapped appropriately. Originally, knowledge in the document plan template is produced by the DM agency where the DM expert resides. Therefore, a DM expert in this context is to assure that the DM knowledge from the document is correctly interpreted and intended. Although this research successfully develop a framework

of knowledge transfer process by harnessing ABMs, the framework is not processed in a fully automatic fashion as it still requires human intervention in some extent. For its effectivity, it should be intervened by a person who is also a DM expert. In other words, this process can only be processed accompanied by a DM expert.

2. In the modelling process, one of the knowledge elements representing that needs to be analysed and modelled appropriately into the corresponding ABM is a time-sensitivity characteristic. It is the knowledge element that describes agent is situated in an environment therefore it will be reacted to. Other characteristics, for instance, the objectivity/main goal that is structured in the *goal model*. This model has a representation in the DMM-based repository as <<*goal* > > concept. Thus, at the end, both concepts: *goal model* and <<*goal*> > can be mapped accordingly. The time-sensitivity element has also a representation in the repository namely <<*trigger*> > concept. However, this element is not modelled as an independent model rather it is part of the elements in *agent model* and *scenario model*, called the trigger element. Thus, the concept <<trigger> > in the DMM-based repository is not affected in the transferring process. In other words, the DMM, in somehow, can be improved to simplify its structure for the best use.
3. In this paper, the main goal is to develop a framework for which the intertwined and fuzziness knowledge in the DISPLAN can be disentangled to represent its urgency and relevancy in the DM timeline. Subsequently, it can be deposited in a representative repository to facilitate sharing and reusing activities. Even though the framework has successfully developed and evaluated with a real case study and by the DM expert from an authoritative agency, however, in the sense to investigate the developed framework further, it is necessary to examine it in a real disaster situation.

Notwithstanding these limitations, this study successfully illustrates the knowledge transfer framework by generating the actual Wagga-Wagga flood DISPLAN knowledge from its template of the SES NSW. The case study shows that the use of a template to instantiate DISPLANs helps the stakeholder to recognise and develop the knowledge for the particular areas, effectively and efficiently. As can be seen from the processes elaborated previously, the knowledge analysis transform is initiated by customizing all the knowledge elements in the DISPLAN template and subsequently modelling them into the corresponding ABMs. The knowledge elements in the DISPLAN template are essentially the relevant and essential flood DISPLAN knowledge from the deep and broad diligently investigation lead by authoritative agency, the SES NSW. Once the customization processes of all the ABMs are completed, the process of generating a particular DISPLAN based on the template is commenced. As all the knowledge elements of this particular DISPLAN is conforming to the ones in the template, all the common and essential characteristics from the template will be automatically inherited to the particular one. The next, this unique DISPLAN is then stored into the repository to be shared and reused by others. In the process, the approach allows the development of the flood DISPLAN knowledge for the typical disaster becoming effective and efficient. All the stakeholders, the environments, as well as the activities in the specific areas, can be easily identified. Finally, they can be easily adopted and adapted for the best-fit usage.

## 6 Summary and Conclusion

The knowledge analysis framework described in this paper addresses the challenges of converting DM knowledge into a format that can be more easily shared and reused by others in a typical DM resilience framework. This research employs Design Science Research (DSR) methodology (Gregor and Hevner 2013; Hevner et al. 2004) to build the framework. The format used to represent the knowledge in the plans is a unifying metamodel, DMM. AOA is used as part of the framework to convert the plans to DMM. To ensure the efficiency of the analysis to process the required number of DISPLANs, templates of the plans are used to adjust the AO modelling templates. The transfer of the resultant AOMs from the plans is facilitated using a mapping process between an existing AO metamodel, FAML and DMM. This enables a semi-automated process of the transfer between the agent elements and DMM elements.

The framework is applied on converting DISPLANs of the SES NSW (in Australia) to DMM. A case study illustrates the framework and shows how the Wagga-Wagga (from NSW) flood DISPLAN knowledge can be effectively and efficiently generated from the DMM repository after the knowledge has been transferred. The process accurately models knowledge contained in the SES DISPLANS. Knowledge that is modelled from the SES DISPLAN can be instantiated into disaster plans for other areas while maintaining accuracy of the context. The paper also contributes to AB analysis by introducing the depth-first approach for analysing and modelling stages. By adopting this approach, the analysis process can be performed more efficiently as it can be done parallel and distributed by some modellers at the same time. This approach shows not only where to start but most importantly the details of how to do the AB modelling

The study shows that employing DMM format as a representative repository enables better decision-making process. Once the knowledge is deposited into the repository, multiple stakeholders can see the relationships they have with other entities in achieving goals or undertaking tasks across the various phases of DM. The stakeholders can reconstruct the knowledge based on the context of the ongoing event. DMM guides the stakeholders to identify the relevant concepts based on the relations in the DMM. For example, Fig. 10 in the previous section shows that there are eight additional concepts directly related to the *ResponseTask* that are necessary to get a comprehensive understanding of the task. The knowledge analysis framework contributes to this by providing the knowledge holistically from its conceptual to real world activities. By developing the DMM based repository and using ABM, gaps where actions or tasks have not been planned for can be elicited. This presents opportunities to improve the conceptual completeness of the DM by organisations.

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