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# Metamodelling Approach To Support Disaster Management Knowledge Sharing

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# Metamodelling Approach To Support Disaster Management Knowledge Sharing

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## Abstract

*Handling uncertain events that could happen anytime and anywhere and dealing with many complex systems interconnected physically and socially makes Disaster Management (DM) a multidisciplinary endeavor and a very difficult domain to model. In this paper we present a development and validation of a Disaster Management Metamodel (DMM), a language that we develop specific for describing DM domain. The metamodel, a precise definition of the constructs and rules needed for creating the semantic models of DM domain consists of four views based on four DM phases including Mitigation, Preparedness, Response and Recovery-phase classes of concept. A Model Importance Factor (MIF) criterion is used to identify 10 existing disaster management models to evaluate the expressiveness and the completeness of DMM. The paper presents the synthesis process and the resulting metamodel, as a foundational component to create a Disaster Management Decision Support System (DMDSS) to unify, facilitate and expedite access to DM expertise.*

### Keywords

Metamodelling, Modelling language, Metamodel, Disaster management, Decision Support System, Knowledge Sharing

## INTRODUCTION

DM is defined as a management of all aspects of planning and responding to all phases of a disaster, including *mitigation, preparedness, response* and *recovery* activities (W3C Incubator Group, 2008). This definition includes the management of risks and consequences of a disaster. Large disasters cut across many boundaries including organizational, political, geographical, topical and sociological. Managing disasters often depends on various types of information systems such as modelling, simulation, visualization or geographical information systems, in allowing its decision makers to make many solutions and decisions in all stages of disaster (Sotoodeh and Kruchten, 2008). This presents serious challenges in interoperability between various teams and creates difficulties in collaboration and cooperation across authorities, countries and systems. Moreover, data collection and integration problems arise as various technologies and tools are typically involved in data gathering and monitoring e.g. Geographical Information Systems (GIS), data collection platforms or early warning systems. A solid, general and global framework for coordinating people involved and interoperates with data, during and after disaster through is still inadequate. Towards this, we introduce a DMM to represent this domain through dividing all identified common concepts that exist in many DM models into four different views to clearly group concepts classes according to disaster management phases.

Our work also draws on research from method engineering (Brinkkemper, 1996) and metamodelling (Nordstrom, Sztipanovits et al., 1999). *Method engineering* is an application of knowledge based technology underpinned by software engineering results for completion of knowledge representation and acquisition. *Metamodelling*, a central activity promoted by the efforts of the Object Management Group (OMG) (Object Management Group (OMG), 2003), has also been promoted in method engineering. It aims to create interoperable, reusable, portable software activities and components. In this context, a metamodel is a fundamental building block that makes statements about the possible structure of models (Stahl, Voelter et al., 2005). It is usually defined as a set of constructs of a modelling language and their relationships, as well as constraints and modelling rules without necessarily the concrete syntax of the language (Beydoun, Low et al., 2009; Beydoun, Hoffmann et al., 2005). We use metamodelling in our work to develop existing tentative attempts to represent DM knowledge in a reusable metamodel to give a unified point of access supported by an intelligent DM DSS. The metamodel of a language describes the vocabulary of concepts provided by the language, the relationships existing among those concepts and how they may be combined to create models (Gargantini, Riccobene et al., 2009).

This paper aims to use a generic representational layer (a metamodel) to give a unified view of common concepts and actions applied in various disasters. Failures in preventing disasters or failures in their subsequent management are rarely caused by a single factor (Aini, Fakhrul-Razi et al., 2005) and every disaster is unique in some ways and requires its own management process. However, the impact of disasters on human lives and businesses are often similar and many response actions are transferrable. For example, evacuation of personnel is a DM action that is applicable in many disaster situations. We use existing DM models and DM literature as a starting point towards creating a repository of past DM experiences to be stored as reusable components and expressed using concepts identified in a generic DMM. The DMM developed will provide a set of generic concepts useful to a DM modelling language, while not necessarily providing all required details demanded by every single specific disaster on hand. Some details are hidden behind the general concept we use and we leave them to each individual user to extend it based on specific disaster problem they need to handle. This will be the first step to create a DMDSS to enable formulating DM approaches as new situations arise. The rest of this paper is structured as follows: First part of this paper describes the metamodel-based decision support system for disaster management. Second part describes the creation processes of the initial version of DMM. Third part describes the validation and refinement of the metamodel with a comparative study using other existing disaster models encompassing all disaster phases and different models focus. Fourth part presents the resultant and evaluation of DMM. Finally, the paper concludes with a discussion of future work.

## METAMODEL-BASED DISASTER MANAGEMENT DECISION SUPPORT SYSTEM

Developing a DMM is our first step towards creating a DMDSS, to unify, facilitate and expedite access and sharing of DM expertise (see Figure 1). The metamodel describes various DM activities and desired outcomes and serves as a representational layer of the expertise, enabling an appropriate DSS based on combining and matching different activities according to the scenario on hand. Different countries have their own organization in coordinating and act as an advisory board for handling disaster activities. For example, in Australia, there is EMA (*Emergency Management Australia*), in the USA there is FEMA (*Federal Emergency Management Agency*) in Canada there is the PSC (*Public Safety Canada*). Hence for the purpose of developing the DMM, models of different DM activities as applied by different countries are to be combined and stored into one database namely *DM Knowledge Repository*. This will be a collection of organizational, operational, planning, logistics and administration procedures and policies executed by these countries through their DM processes.

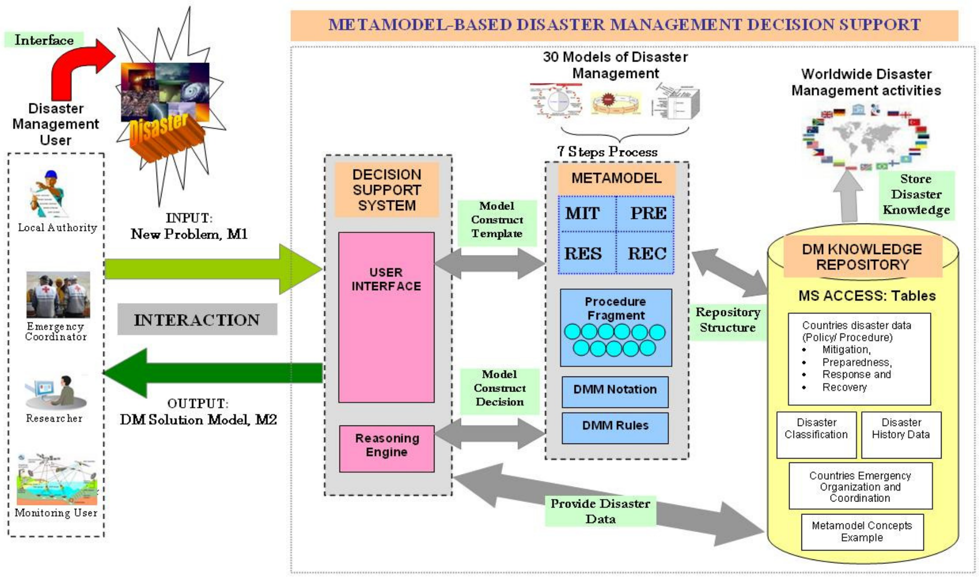



Figure 1: The use of metamodel approach in Disaster Management Decision Support System (DMDSS)

These will be identified and organized according to the DMM consisting of common concepts used in all four disaster phases. The generic DMM based on identified common concepts is the *destination point* of scattered concepts used in many DM activities worldwide. A process towards concept generalization is applied to make DMM more applicable. Activities from different sources (and countries) will be stored as *Procedure Fragments* in the *DM Knowledge Repository*. The DMDSS will assist in deriving the best disaster procedure fragment solution according to the disaster on hand. It will use a set of rules that will specifically determine what is the best solution based on disaster description input entered by a user of the system (e.g.: local disaster manager, emergency coordinator or researcher) and the repository.

## DM METAMODEL SYNTHESIS PROCESS

To construct our DMM, a set of common and frequently used DM concepts is first determined. A *concept*, the main components in a metamodel is an abstract object which represents an entity, action or a state (Sowa, 1984). Our identified DM concepts and their definitions are rooted in the existing DM literature. Relationships amongst these concepts are then identified. The metamodel creation process is an iterative process with continuous refinement of new concept performed. To create the DMM, we use a 7 steps metamodelling process adapted from (Beydoun, Low et al., 2009):

**Step 1**: *Identifying models by using MIF to find the best collection of DM models.* A set of 10 high impact models is identified (Table 1).

**Step 2**: *Extraction of general concepts in models identified in Step 1.* Disaster-specific concepts were omitted e.g.: *earthquake magnitude*, *tsunami warnings, fire danger index, Haiti earthquake victims* or *bushfire evacuation*. Chosen concepts are disaster type independent (shown in Table 2).

**Step 3**: *Short-listing candidate definitions.* A greater weight is given to sources with clearer definitions (in favor of those considered implicit definitions that can be subject to interpretation). Widespread occurrence of any particular DM definition is also taken into account leading to adopting a set of general concept grounded in commonly agreed meaning in DM community.

**Step 4**: *Reconciliation of definitions where possible.* In choosing the common concept definition to be used, consistency with earlier choices is maintained. Further, if there is inconsistency between two or more sources occurs (especially because DM involved various kind of disaster), we choose the concept which has more coherent usage with the rest of the chosen concepts.

**Step 5**: *Designation of concepts into 4 DM relevant sets: Mitigation, Preparedness, Response and Recovery.* This is a common DM abstraction corresponding to DM phases and is common to most of the models we considered. Output of this step is our derived concepts categorized as such (Table 3).

**Step 6**: *Identification of relationships within and across Mitigation, Preparedness, Response and Recovery diagram and relationships interfacing the categories.* Output of this step is the initial DMM.

**Step 7**: *Validating the metamodel. As for an e*xample, we show the validation technique of *Comparison to other metamodels* against Disaster Operation Management (DOM).

## DM METAMODEL DEVELOPMENT

In this section, we detail our DMM development (Steps 1 to 5). We later in Section 4 present the actual metamodel (result of Step 6) and undertake its initial validation (Step 7).

### Step 1: Identifying models by using Model Importance Factor (MIF)

Many disaster models have been developed by many researchers and organizations worldwide. To select a subset of most influential models to be an input for our metamodelling process, we formulate a new criterion as *Model Importance Factor* (MIF) to calculate a heuristic measure to compare the relevancy of various models. The top 10 most influential models are used as input for Step 2 (shown in Table 1), the rest are used for validation in order of most relevant. In developing this MIF, we adapt the idea of *Journal Impact Factor* measuring the frequency of which the average article in a journal has been cited in a particular year and we add additional weight to the size of the organization publishing the model. Our MIF will compare the impact of the models in the same domain. MIF is defined as follows:

$$\textbf{Model Importance Factor} = \frac{(T_{cited} * (E_{level} * P) * R_{coverage})}{((Y_{current} + 1) - Y_{published})} \quad (1)$$

| | | |
|---|---|---|
| $T_{cited}$ | : | The total number of Times the model or metamodel is *cited* (Paper & Journal); For a model appear in a publication without a citation, default weight is used as: Research thesis is *10*; Academic report is *15*; |
| $Y_{current}$ | : | The *current* Year calculation is made; |
| $Y_{published}$ | : | The Year model is *published*; |
| $E_{level}$ | : | Weight of Effort is calculated based on *level* of model developer by using weight: *0.1* for Individual; *0.2* for National Organization, *0.3* for International Organization; |
| $R_{coverage}$ | : | The weight of Relevancy represents how pertinent and applicable the model to the DMM development requirement; |
| P | : | The number of Participants involved in developing a model. |

Table 1. The list of 10 DM models with their respective MIF value

| Model Source | $T_{cited}$ | $Y_{current}$ | $Y_{published}$ | $D_{standard}$ | P | $R_{coverage}$ | MIF |
|---|---|---|---|---|---|---|---|
| (World Health Organization (WHO)) | 15 | 2010 | 2001 | 0.3 | 15 | 0.3 | **2.03** |
| (W3C Incubator Group, 2008) | 10 | 2010 | 2005 | 0.3 | 9 | 0.3 | **1.35** |
| (Emergency Management Australia (EMA), 2004) | 10 | 2010 | 2004 | 0.3 | 10 | 0.3 | **1.29** |
| (Manitoba Health Disaster Management, 2002) | 15 | 2010 | 2002 | 0.2 | 10 | 0.3 | **1.00** |
| (Modoc County Disaster Council, 2000) | 15 | 2010 | 2000 | 0.2 | 10 | 0.3 | **0.82** |
| (Russo, Raposo et al., 2006) | 10 | 2010 | 2006 | 0.1 | 4 | 0.3 | **0.24** |
| (Cutter, Barnes et al., 2008) | 8 | 2010 | 2008 | 0.1 | 7 | 0.1 | **0.19** |
| (Kruchten, Monu et al., 2008) | 3 | 2010 | 2008 | 0.1 | 4 | 0.3 | **0.12** |
| (Benaben, Hanachi et al., 2008) | 1 | 2010 | 2008 | 0.2 | 5 | 0.3 | **0.10** |
| (Asghar, Alahakoon et al., 2008) | 2 | 2010 | 2006 | 0.1 | 2 | 0.3 | **0.02** |

**Step 2: Extraction of Concepts**

The chosen 10 DM models inform the selection of the common DM concepts. From this collection of models, a set of concepts is listed for further investigation (Table 2).

Table 2. The sample of first four candidate concepts that we derive from 10 DM models in Step 1

| Model | First concept | Second concept | Third concept | Fourth concept |
|---|---|---|---|---|
| **WHO** | Search | Lifelines | People | Property |
| **W3C Incubator Group** | Deployment | Demobilization | Task Reviews | Victims |
| **EMA** | Evacuation | Warning System | Training Programs | Public Education |
| **Manitoba Health** | Vulnerability | Hazard Assessment | Structural Mitigation | Non Structural Mitigation |
| **Modoc County** | Command | Planning | Incident | Operations |
| **Russo** | Activity | Decision Maker | Collaborative Work | Response Team |
| **Cutter** | Resilience | People | Social Learning | Post Event |
| **Kruchten** | Disaster Event | Residential Cell | Agent | Infrastructure |
| **Benaben** | Effect | Trigger | People | Resource |
| **Asghar** | Education | Communication | Evacuation | Coordination |

**Steps 3 and 4 Short-listing and Reconciliation of Candidate Concept Definitions**

A total of 137 concept definitions have been short listed for the purpose of this paper (step 3). When there are two or more concepts sharing the same definition or even two or more concept sharing the same concept name, a process to harmonize and fit the definition to the metamodel is required. For example the concept of *disaster* has already existed in many models that we have investigated. However, the definitions of the concept in each model are defined differently. Thus the reconciliation of this concept is demanded and tabled above (Step 4). Some examples of *disaster* concept definitions are defined in 3 models and they are as follows: In EMA model, disaster is defined as "*A serious disruption to community life which threatens or causes death or injury in that community and/or damage to property which is beyond the day-today capacity of the prescribed statutory authorities and which requires special mobilization and organization of resources other than those normally available to those authorities",* in Kruchten model as "*Is events that have impacts on people, directly or indirectly through the infrastructures"* and in Benaben model as "*Occurs due to one or several triggers and once appeared, is composed with effect, complexity factors and gravity factors"*. After the reconciliation process, we have selected the definition used in EMA as the best concept to represent the closest definition of the disaster concept.

**Step 5: Designation of Concepts into DM Phases**

Many extant disaster models reflect that emergency groups and researchers organize their DM activities in four disaster phases including *Mitigation*, *Preparedness, Response* and *Recovery*. *Mitigation* is a phase of seeking to eliminate or reduce the impact of disasters themselves and/or to reduce the susceptibility and increase the resilience of the community subject to the impact of those hazards. *Preparedness* is a phase seeking to establish arrangements, plans and to provide education and information to prepare the community to deal effectively with disasters as they may eventuate. *Response* is phase seeking to activate preparedness arrangements and plans to put in place effective measures to deal with emergencies and disasters if and when they do occur. Finally *Recovery* is a phase seeking to assist a community affected by a disaster in reconstruction of the physical infrastructure and restoration of emotional, social, economic and physical well-being. Thus, we designate each DM concept derived according to its applicable DM phase (shown in Table 3).

Table 3. Concepts reconciled in Step 4 are designated into four DM-phase classes

| Mitigation | Preparedness | Response | Recovery |
|---|---|---|---|
| *MitigationPlan* | *PreparednessActionPlan* | *EmergencyPlan* | *RecoveryPlan* |
| *MitigationOrganization* | *PreparednessOrganization* | *ResponseOrganization* | *RecoveryOrganization* |
| *TrainerTask* | *VolunteerTask* | *ResponderTask* | *Demobilization* |
| *NeedsPlan* | *SuppliesRegistry* | *Deployment* | *LongTermPlan* |
| *InformationUpdates* | *EarlyWarningSystem* | *SituationalAwareness* | *RecoveryGoal* |
| *MitigationGoal* | *PreparednessGoal* | *ResponseGoal* | *Reconstruction* |
| *RiskReduction* | *Evacuation* | *Rescue* | *AfterDisaster* |
| *People* | *BeforeDisaster* | *DuringDisaster* | *DamageAssessment* |
| *Property* | *Event* | *SituationAnalysis* | *TaskReview* |
| *Lifeline* | *DecisionMaking* | *Incident* | *Resilience* |
| *NaturalSite* | *Finance* | *Coordination* | *Victims* |
| *StrategicPlanning Commitee* | *EmergencyPublic Information* | *Command* | *EmergencyManagement Team* |
| *RiskAnalysis* | *Pre-Position* | *Communication* | *Resource* |
| *StructuralMitigation* | *DisasterFactor* | *StandardOperatingProcedure* | *Effect* |
| *HazardAssessment* | *Training* | *EmergencyManagementTeam* | *ResettledEvacueesTask* |
| *Non-structuralMitigation* | *DisasterRisk* | *Victim* | |
| *DisasterRisk* | *PreparednessTeam* | *EmergencyOperationCentre* | |
| *Vulnerability* | *Media* | *Resource* | |
| *BuildingCodes* | *MutualAidAgreement* | *Aid* | |
| *Legislation* | *PublicEducation* | | |
| *LandUsePlan* | *PublicAwareness* | | |

**Step 6: Identifying Relationships between Concepts**

In Step 6, after reconciliation of the DM concepts to its designated diagram, we could determine that there is a relationship between all concepts based on the connection between these concepts in all observed models. For instance in Figure 2c, we use the *Association* (——) relationship symbol, '*AffectWellness*' to indicate that a disaster could affect all elements which are at risk by a disaster between *Disaster* and *Exposure* concept based on Kruchten's model. Another example is the using of *Specialization* relationship (—▷) to signify a *Lifeline*, *Property, NaturalSite* and *People* concepts as '*is a kind*' of elements for *Exposure* concept as defined in Benaben's model. Another example can be shown in *Coordination* concept. In almost all DM models observed we found the existence of emergency management team during response phase of DM. Thus we could relate the *EmergencyManagementTeam* and *ResponseOrganization* concepts with an *Aggregation* relationship (—◇) that provides a definition of emergency team as a 'grouping of' organization in DM during the response phase. Table 4 shows some of the other examples of relationships that we observed between the DMM concepts. Concept 1 represents the first concept and Concept 2 represents the second concept which is tied up together with a meaningful and appropriate relationship that existed between them.

Table 4. The example of relationships among concepts in DMM

| Concept 1 | Relationship | Concept 2 | Phase/in Figure |
|---|---|---|---|
| *EmergencyManagementTeam* | Association - '*Requires*' | *Coordination* | Response/2c |
| *StrategicPlanningCommittee* | Association - '*Creates*' | *InformationUpdates* | Mitigation/2a |
| *PreparednessTeam* | Association - '*Creates*' | *Training* | Preparedness/2b |
| *PublicEducation* | Association - '*Supports*' | *PublicAwareness* | Preparedness/2b |
| *Evacuation* | Association - '*Follows*' | *PreparednessPlan* | Preparedness/2b |
| *NeedsPlanning* | Association - '*Creates*' | *RiskReduction* | Mitigation/2a |
| *Aid* | Aggregation - '*isAGroupOf*' | *ResponseOrganization* | Response/2c |
| *Legislation* | Aggregation - '*isAGroupOf*' | *StructuralMitigation* | Mitigation/2a |
| *NaturalSite* | Specialisation - '*isAKindOf*' | *Exposure* | Mitigation/2a |
| *Demobilization* | Specialisation - '*isAKindOf*' | *Resource* | Recovery/2d |

## RESULTANT DISASTER MANAGEMENT METAMODEL

This section presents and validates the DMM. The metamodel is presented in four different diagrams to clearly group the classes into four areas of concern: the Mitigation-phase (Figure 2a), the Preparedness-phase (Figure 2b), the Response-phase (Figure 2c) and the Recovery-phase (Figure 2d) class. Each figure shows classes referring to the concepts that should existed during a corresponding phase of DM. The resultant metamodel contains the relationships among concepts and represents the semantic of the DM domain.

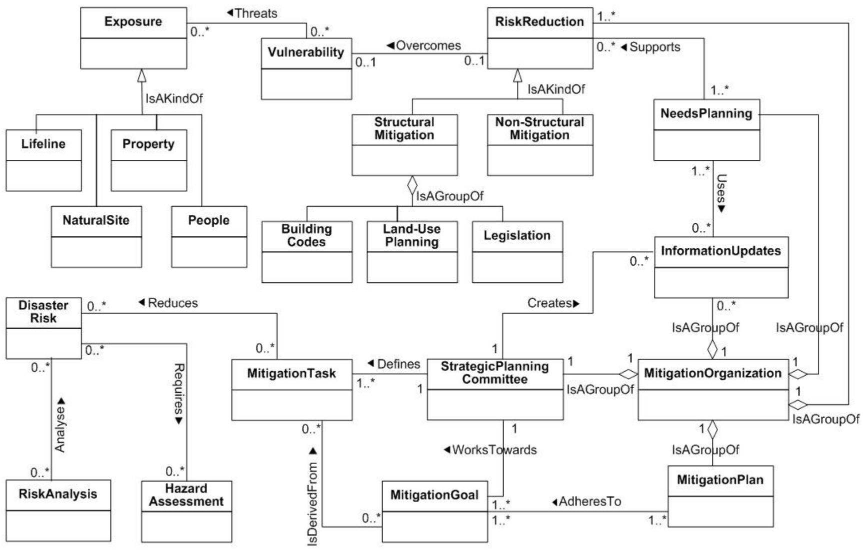



Figure 2a: Mitigation-phase class of DMM

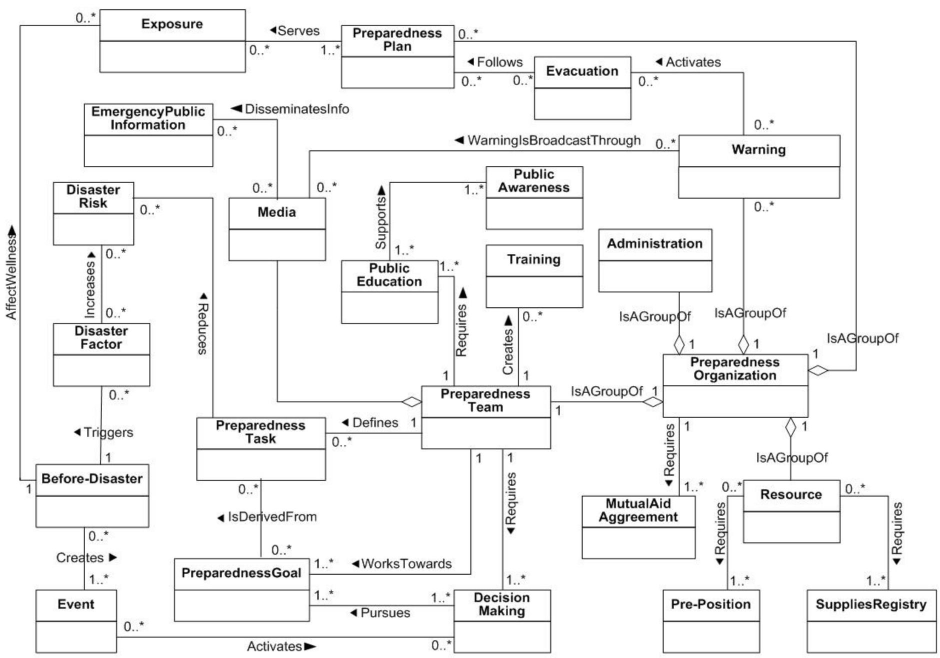
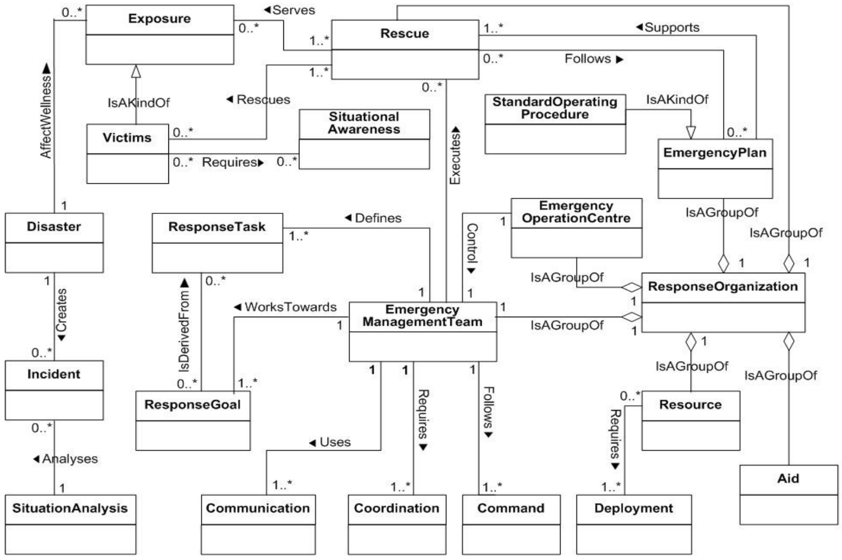



Figure 2b: Preparedness-phase class of DMM

For example, Response-phase class (in Figure 2c) has a central concept which is defined as a *ResponseOrganization*. An Aggregation symbol is attached to this concept (——◇) to show the relationships that existed between *ResponseOrganization* and six other concepts including *Resource*, *EmergencyManagementTeam*, *EmergencyOperationCentre*, *EmergencyPlan, Aid* and *Rescue*. These relationships show that in any response phase of DM, the organization of emergency management requires resource, emergency team, centre to control rescue coordination, emergency plan, aid and rescue tasks. Another example of a relationship between concept is Association (denoted by symbol of (——)). For example, we use this relationship between *EmergencyManagementTeam* and *ResponseTask* concepts. This shows that in DM, the task of emergency responder (actor) is defined by the emergency management team. Other example is the *Resource* concept 'requires' *Deployment* concept to indicate that in any response phase of DM, emergency resources such as rescue equipments, police transportation, fire equipments or medicine have to be deployed to help a disaster victims.



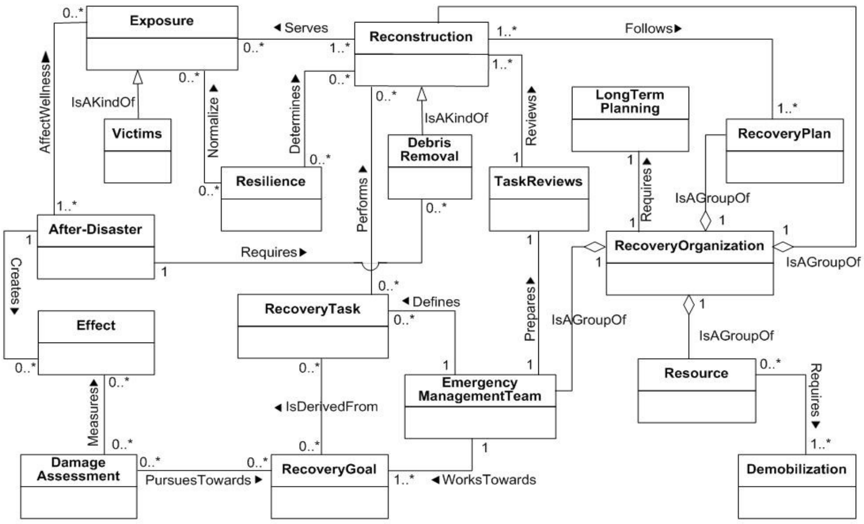




Figure 2d: Recovery-phase class of DMM

Table 5. Concept definition sample for concepts exist in Mitigation-phase class of DMM

| Mitigation Concept | Concept Definition |
|---|---|
| *MitigationPlan* | A document prepared by an authority, sector, organization or enterprise that sets out goals and objectives for reducing disaster risks specifically for mitigation phase together with related actions to accomplish these objectives. |
| *Mitigation Organization* | The organization of components and activities to lessening or limitation of the adverse impacts of hazards and related disasters. |
| *NeedsPlanning* | Tasks of preparing, describing, identifying the needs of individuals, households, institution or resources materials that could be needed in the event of a disaster. |
| *MitigationGoal* | A description of the end state of recovery phase where the organization wants to be at the end of the activity, program, or other entity for which the goal was defined. |
| *RiskReduction* | The concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events. |
| *People* | Collections of human in local communities who are threaten to disaster. |
| *Lifeline* | The public facilities and systems that provide basic life support services such as water, energy, sanitation, communications and transportation which the well-being of the community depends. |
| *Hazard Assessment* | A designed process to identify factors contributing to the possible adverse effects of a substance, which a human population or an environmental compartment could be exposed. |

| | |
|---|---|
| *RiskAnalysis* | A detailed examination performed to understand the nature of unwanted, negative consequences to human life, health, property, or the environment; an analytical process to provide information regarding undesirable events; the process of quantification of the probabilities and expected consequences for identified risks. |
| *Structural Mitigation* | Any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard-resistance and resilience in structures or systems. |
| *Non-Structural Mitigation* | Any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education. |
| *Vulnerability* | The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. |
| *DisasterRisk* | The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period. |
| *Strategic Planning Committee* | The interagency group which develop a systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster. |

**Step 7: Validation of DMM**

Metamodel requires a validation to satisfy the generality, expressiveness and completeness of the concepts it uses. *Conceptual metamodel validation* was discussed (Sargent, 2005) and is defined as a process to determine that the theories and assumptions of the underlying concepts in the metamodel are correct and the representation of metamodel of the problem entity and the structure of the metamodel, logic and causal relationships are *reasonable* for the intended purpose of the metamodel. Validation also determines that an agreement is achieved among all concepts in the metamodel against real data of a domain. Commonly used validation techniques are shown in Table 6.

Table 6. Conceptual validation techniques of metamodel concepts (Sargent, 2005)

| Technique | Validation Definition |
|---|---|
| **Comparison to other metamodels** | Derived concepts of the developed metamodel are validated and being compared to concepts of other (valid) existing similar domain models or metamodels. |
| **Multistage validation** | Combination of three historical methods of rationalism, empiricism, and positive economics into a multistage process of validation. |
| **Tracing** | The behavior of different types of specific entities in the model is traced (followed) through the model to determine if the logic of the model is correct and if the necessary accuracy is obtained. |
| **Face validity** | Asking individuals knowledgeable about the domain application whether the model and/or its behavior are reasonable. |

Other than these four identified techniques, there are three other validation techniques being used including a Formal Ontology (Giancarlo, 2007), a Machine-Aided (Nordstrom, 1999) and a Case Study (Ahmad, 2010) to refine the concepts in metamodel. In real validation process of DMM, we adapt a combination of few validation techniques to ensure the completeness of domain concept presented by DMM. In this paper, we adopted the first technique, 'Comparison to other metamodels' to show how the validation is performed. For example, we show a validation against the Disaster Operation Management (DOM), a model which appears in (Altay and Green Iii, 2006). Each concept in the DOM has been analyzed and the concepts used are similar to the concepts used in DMM. Besides scrutinizing the concepts, we also thoroughly check the definitions of each concept that appeared in each model that we validated. For example, in DOM model, it has the process of '*Activating emergency operation plan'*. We cover this concept by *EmergencyPlan* concept in Response-phase class. Similarly, with '*Constructing of emergency operation centre'* process in DOM, we support this concept with an *EmergencyOperationCenter* concept. However, we discovered that our DMM metamodel failed to spot mass casualty activity/concept in its early version through a '*Provision of Mass Casualty'* concept appeared in DOM. Therefore, we evaluated the newly identified concept with few other models that we validated. After the reconciliation of this concept, we have decided to use a '*MassCasualtyManagement*' as the best new concept to represent the '*Provision of Mass Casualty'* which we believe should existed in our Response-phase class of metamodel. Observations to other DM models have shown that mass casualty is one of an operation that normally resides under rescue and search operation during response phase of disaster (World Health Organization (WHO), 2007). For that reason, we tie this concept with *Rescue* concept to represent the '*is a kind of*' relationship between these two concepts. Figure 3 illustrates this scenario.

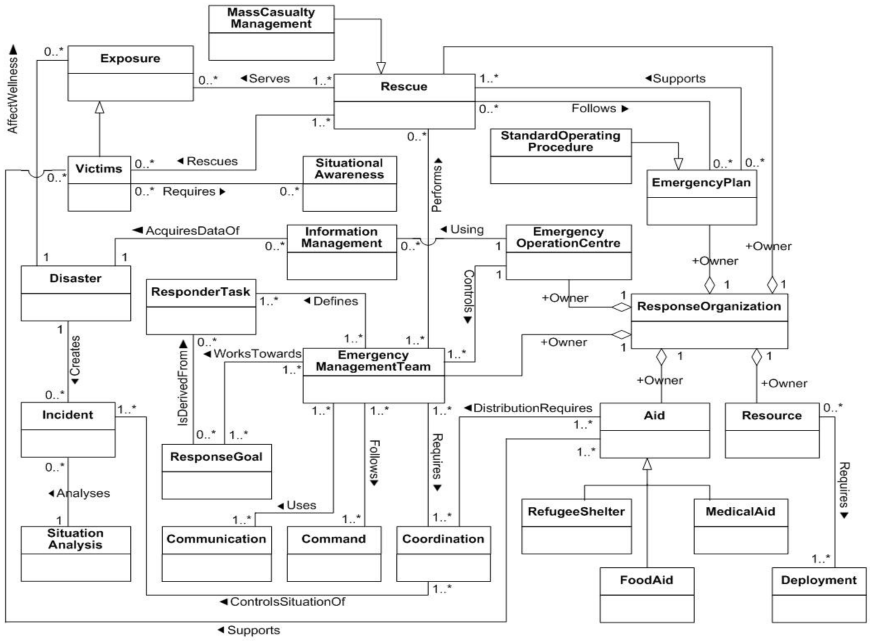


Figure 3: This figure presents the validated version of Response-phase class as a new version of Figure 2c. By executing the validations against DMM, we have identified five new concepts (as shown in circle) that have not been covered in the initial development of Response-phase class. This indicated how important the validation is to ensure the completeness of the metamodel being developed by the metamodel developers in any domain

## CONCLUSION AND FUTURE WORKS

This paper presents the development and validation of a Disaster Management Metamodel (DMM) to serve as a platform for sharing and integrating DM knowledge from varying sources. It will allow interoperability of DM solutions and sharing knowledge across international boundaries. Our metamodelling approach decreases the time and implementation costs of DM systems and allows various DM approaches to be easily shared and communicated. Following further evaluation against 10 existing DM models, we will create a DM knowledge repository to allow a responsive and flexible disaster management approach; one that is based on mixing and matching disaster management actions as disaster contexts change. Our approach will also be explored to facilitate team organisation guided by an optimal knowledge sharing arrangement. A DMM Library Notation and Rules will be required to complement the presented metamodel (DMM). There are some issues that need to be investigated to fully realize the potentiality of this approach. These include: (i) a complete set of rules, processes and methodologies for instantiating user domain models; (ii) the limitations and the constraints of the metamodel; (iii) tools that existed to facilitate the extension of metamodel; (iv) methodology existed in validating the user domain models and (v) appropriate reasoning techniques to manipulate the metamodel.

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