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Development and validation of a disaster management metamodel (DMM)

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Abstract

Disaster Management (DM) is a diffused area of knowledge. It has many complex features interconnecting the physical and the social views of the world. Many international and national bodies create knowledge models to allow knowledge sharing and effective DM activities. But these are often narrow in focus and deal with specified disaster types. We analyze thirty such models to uncover that many DM activities are actually common even when the events vary. We then create a unified view of DM in the form of a metamodel. We apply a metamodelling process to ensure that this metamodel is complete and consistent. We validate it and present a representational layer to unify and share knowledge as well as combine and match different DM activities according to different disaster situations.

Development and Validation of DMM

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Abstract Disaster Management (DM) is a diffused area of knowledge. It has many complex features interconnecting the physical and the social views of the world. Many international and national bodies create knowledge models to allow knowledge sharing and effective DM activities. But these are often narrow in focus and deal with specified disaster types. We analyze thirty such models to uncover that many DM activities are actually common even when the events vary. We then create a unified view of DM in the form of a metamodel. We apply a metamodelling process to ensure that this metamodel is complete and consistent. We validate it and present a representational layer to unify and share knowledge as well as combine and match different DM activities according to different disaster situations.

1 Introduction

Disaster Management (DM) involves collaborative decision making activities often characterised by a high level of complexity involving different sources of knowledge distributed across time, space and people. In other words, not all situational knowledge is immediately available, not one person will be positioned to make all decisions, and not all knowledge is coming from the same place (recall the false Tsunami alert due to data not being available immediately, and ocean level checked at various points, and various people on various coasts analyzing incoming data). In this paper, we advocate the use of a middle knowledge layer to enable DM practitioners to discern disaster dependent and disaster-independent features in the challenges that they face. We introduce this middle layer of knowledge in the form of a disaster-independent metamodel to unify knowledge from different disaster experiences.

Our generic DM Metamodel (DMM) that we present in this paper will help resolve the complexity of access to DM knowledge through dividing all identified common concepts which exist in many DM models into four different views (*Mitigation, Preparedness, Response* and *Recovery*-phase class of concepts) to clearly group concepts according to DM phases. This paper aims to use the generic representational layer (a metamodel) to give a unified view of common concepts and actions that apply in various disasters. This research was initiated in [1], where we illustrated examples of the commonality of concepts across four different disaster areas (an *Evacuation Procedure*, a *Mitigation Analysis*, a *Rescue Procedure* and a *Recovery Procedure* of bushfire disaster). 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.

Metamodelling has been promoted by the efforts of the Object Management Group (OMG) [8]. We use it in our work to unify existing attempts to represent DM knowledge in a reusable form and to give a unified point of access. We illustrate our unification approach by presenting the result and validation of the metamodel which generalizes most of the concepts used in existing DM practices as described in existing models. The rest of this paper is organized as follows: In Section 2, we provide some background and related works to this research. Section 3 provides the actual development process of our Disaster Management Metamodel (DMM) based on a metamodelling approach. Section 4 presents a DMM, the resultant metamodel. Section 5 validates the DMM using three validation techniques: *Comparison against other models, Frequency-based*

1

Selection and *Tracing* in real world disasters. Finally, Section 6 concludes this paper with a discussion of possible future work related to this research.

2 Background and Related Work

Various kinds of modelling languages have been created for different disciplines including systems engineering [2], software engineering [3] and business process modeling [4]. These languages are typically used to specify systems so that stakeholders can better understand them. This paper aims at developing a modelling language to describe the domain of DM and draws on research from metamodelling [5, 6] to develop a process to create such a language. A m*etamodelling* process generally aims to create a collection of *classes* to describe domain concepts to represent domain entities, actions or states [7]. This collection of concept is the *metamodel*. The language which we seek is underpinned by the *metamodel* that has a capability to generalize the domain through collecting all domain concepts and partitioning the domain problems into sub-domain-problems. A harder task in the development of a domain description is how the end user will build his/her own model with the concepts and notation from a domain *language* [9]. In software engineering, a metamodel aims to create interoperable, reusable, portable software activities and components. A metamodel also contains the specification of modeling environment for certain domain, and defines the syntax and the semantics of the domain. It can be viewed from three different perspectives: i) as a set of building blocks and rules used to build new models, ii) as a model of a domain of interest and iii) as an instance of another model. In our context, a metamodel is a fundamental building block that makes statements about the possible structure of DM models [10].

Various metamodelling frameworks have been defined by many information systems researchers e.g. [17-24]. In this paper, we follow a metamodelling framework based on the Meta Object Facility (MOF) [19, 24] offered by Object Management Group (OMG). Our DM metamodel (DMM) will be a set of constructs of the DM Language and their relationships corresponding with the Metamodel layer of MOF. Through the use of DMM, it will be easier to manage multiple requirement perspectives as advocated in [11, 12]. DMM will specify the relationships between DM models and indirectly define possible relationships between the various perspectives described by the models. In earlier work, [13, 14], we adapted an iterative metamodelling process to the domain of DM. This paper will further develop this process to ensure that it becomes domain independent. In other words, the resultant process will not require in-depth knowledge of DM to enable producing the metamodel. We will apply it to generate a complete and a comprehensive DM metamodel, which will be the final product of an iterative process. Its evolution will be interleaved with the validation process of the metamodel. Any amendments resulting from the validation process (e.g. concept amendement/deletion/addition) will immediately feed into the iterative process. In [14], we identified a number of techniques which use external sources to validate the concepts in the metamodel (e.g. other existing models or disaster descriptions). Specifically, we illustrated the '*Comparison against other models*' [15, 16] using one external source to validate a part of the preliminary version of the metamodel. For the purpose of the validation in this paper, we refine 20 DM models in details using our metamodel and applying multiple validation techniques.
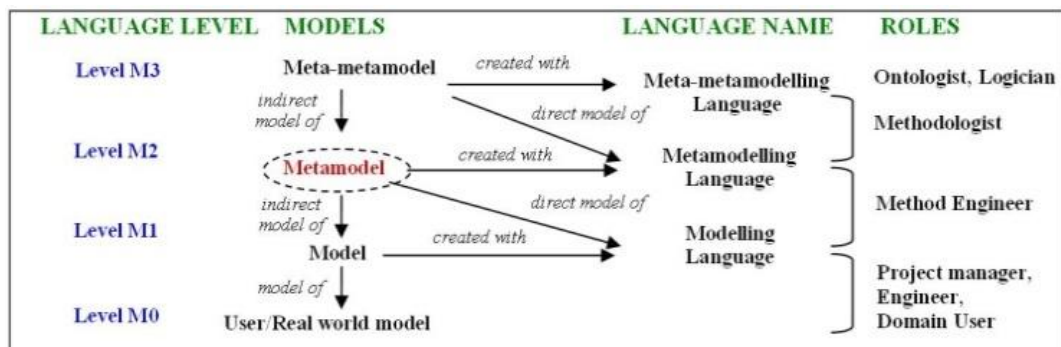

Fig. 1. MOF Modeling Hierarchy [24]

The quality of the metamodel is measured based on how it can fulfill the purpose of its development [25, 26]: addressing the needs of domain practitioners, increasing the transparency to the knowledge encoded within the domain applications and how amenable to be validated by experts in the domain area. Our *end users (domain practitioners)* include emergency managers,

DM coordinators or safety managers for various public and private organizations seeking to create a DM model to manage anticipated disasters. Disaster Management (DM) includes all aspects of planning and responding to all phases of a disaster, including *mitigation, preparedness, response* and *recovery* activities [27]. United Nations International Strategy for Disaster Risk [28] defines four phases of disasters: (1) **Mitigation**: The lessening or limitation of the adverse impacts of hazards and related disasters. (2) **Preparedness**: The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current hazard events or conditions. (3) **Response**: The provisions of emergency services and public assistance during or immediately after a disaster in order to save lives, reduces health impacts, ensure public safety and meet the basic subsistence needs of the people affected. (4) **Recovery:** The restoration, and improvement where appropriate of facilities, livelihoods and living conditions of disaster-affected communities including efforts to reduce disaster risk factors.

This paper targets at reducing interoperability challenges and facilitating knowledge sharing similar to [29] but in DM. It is common wisdom that no two disasters are exactly the same, and that every disaster requires its own management process. However, the way disasters impact human lives and business processes are similar and responses are often transferrable between disasters. For example, *evacuation of personnel* is a DM action that is applicable in many disaster situations [14]. We use a variety of models which have been developed by many domain experts on the subject of DM studies (see Appendix I). Existing DM models which exist nowadays can be categorized as *requirements models* because of abstract representations of an existing or a desired model in the real world (e.g.: warning system [30], planning, response [31], decision making [32], technology tools [33], evacuation [33] and disaster risk reduction [34]). The meaning and definition of specific concept terminologies and their relationships may differ from one observer to another [35]. Domain concepts can have multiple descriptions. Some concepts are observed to represent similar DM activities which are expressed differently. For example, in a Circular Model for Disaster [36], the terminology '*Emergency Response*' is being used to represent the response and rescuing activities of victims. The same activity however is represented by using '*Emergency State*' in the Ibrahim-Razi Model [37]. A specific domain modelling language expressed as a metamodel offer an alternative and better approach resolving this kind of problem. Our approach unifies the various terminologies used. The DM Metamodel (DMM) developed in this paper describes all the DM model concepts and the way they are arranged, related and constrained. It also provides a flexible structure to facilitate storage and retrieval of DM knowledge.

3 Metamodelling Disaster Management

To construct our DMM, a set of common and frequently used DM concepts is first determined. Our identified DM concepts and their definitions are rooted in the existing DM literature. A study of the DM domain is first performed by investigating a large collection of existing DM models (85 in total). This gives us a broad knowledge of the DM activities and operations. Relationships amongst these concepts are then identified. The metamodel creation process is iterative with continuous refinement of new concepts. To create the DMM, we use an *8 step Metamodelling Creation Process* adapted from [38] and [14]:

Step 0: **Models collection and preliminary domain study:** This prepares the knowledge source, namely, collecting relevant models from the public domain.

Step 1: **Identifying sets of model.** We use the overall coverage of DM models to select 37 DM models to initiate the metamodelling process and to prepare two validation sets (as shown in Table 1). We also ensured that all highly cited models are included (as per Google Scholar at the time of submission of the paper).

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

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

Step 4: Reconciliation of definitions. 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 (especially because DM involved various kinds of disasters), we choose the concept which has more coherent usage with the rest of the chosen concepts.

3

Step 5: Designation of concepts into 4 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 shown in 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 version of our DMM (Figure 2 – 5).

Step 7: Validating the metamodel. Step 7 will be detailed in Section 4. The rest of this section will detail each of the steps 1 to 6.

3.1   Step 0: Preparing knowledge sources

This step includes collecting the knowledge sources to be used. We undertake a meta study on how to distinguish between them. This also enhances our domain awareness as recommended in [39] as an initial step for any metamodelling process. In total we collected 85 DM models from a variety of sources: journals, conference papers, government, non-government and disaster agencies organization reports, online disaster-related websites, books etc. Collecting these models was done in two stages. In the first stage, we focused on discovering categories of DM models and ascertained that there are sufficient DM models in the literature for metamodelling to be a feasible path. We first used the following academic collections of journals: Scopus, Web of Science and Google Scholar. For this purpose, we used the search keyword 'disaster management model'. This effort led to the discovery of 30 DM models (out of the 85). With this number, we became more confident that the literature on DM modeling is sufficiently mature to apply a metamodelling process. We continued our searching using Google pursuing DM models from government reports, DM-related websites and online databases. This led to discovering another 20 models. We categorized these 55 models according to following seven different perspectives: i) phase-based (e.g.: mitigation, response), ii) organization-based (e.g.: Red Cross, FEMA), iii) user/role-based (e.g. Emergency Manager, Monitoring User, Fire department), iv) disaster-based (e.g.: Bushfire, Air Crash, Tsunami, Earthquake), v) technology-based (e.g.: Satellite for monitoring, fire extinguisher), vi) activity-based (e.g.: Damage assessment, evacuation), and vii) decision-based (e.g.: disaster declaration method, deliverable of humanitarian aid).

In the second stage, we aimed to ensure that every perspective is sufficiently covered. We used the same knowledge sources (Scopus, Web of Science, Google Scholar and Google). However, this time, the keywords that we used were based on the seven perspectives above. For examples, to find DM models for the user/role-based models, we used the keyword 'firefighter + disaster management model'. The models available covering the seven perspectives turned out to be numerous. For our metamodelling goal, we chose further 30 new models to cover all seven perspectives. These models were selected based on their clarity and how well documented they were. Priority was also given to higher cited models.

3.2   Step 1: Identifying the development and the validation model sets

From the 85 DM models collected in Step 0, three sets of models are filtered through for the metamodelling-based synthesis of DMM: Set I is used to initiate the metamodelling process and this includes 17 models that cover all phases of DM. Another two sets, Set V1 and V2, are used to undertake two validations of the DMM (Step 7 in the process). The sets are formed according to how broadly they cover the four phases of DM. Some models cover all four phases, some cover 2 to 3 phases, others focus on only one phase. Some models focus on a specific DM perspective and do not pay too much attention to the boundaries of the DM phases rather than (e.g.: evacuation operation (*operation*-based)). If a model does not cover any DM phase or perspective, we exclude it from any further investigation. The models included in each set are shown in Table 1.

For Set I, we require wide coverage across the concepts and as our aim is to create a DMM that can be widely applicable. Using the coverage measure alone, we quickly get an indication of how widely applicable the sourced model is. The model is said to have a high coverage value if the model can cover the whole phases of DM (*general model*). Whereas, a model has less coverage value if the model only describes a specific DM phase such as mitigation (*specific model*). As supported by Kelly et. al in their discussion regarding the practices for a development of domain-specific modeling, "*Finding the proper **generic-specific balance** is a key-success factor in domain-specific modelling development…" [39 pp. 25]*. For example, a 'Manitoba Health Disaster Management Model [40] could cover most of the whole DM aspect in the model, whereas a 'Place-based Model for Understanding Community Resilience' [41] covers a small portion of the DM domain. In the selection of models for Set I, we ensured that selected models can cover all

4

phases in DM (Mitigation, Preparedness, Response and Recovery). The initial metamodel development requires the combination of all generic concepts existing in the domain. The combination of concepts that comes from all DM phases will provide generic concepts for our DMM.

Table 1. The 37 DM models for development (Set I) and two validations (Set V1 and Set V2). Phases they cover are denoted by 'X'.

	SET I (To be used to develop the initial DMM)	T_{cited}	$Y_{published}$	Preparedness	Response	Recovery.	Mitigation
1	Concepts in Emergency Management [44]	15	2001	X	X	X	X
2	Emergency Information Interoperability Frameworks, [27]	10	2005	X	X	X	X
3	Emergency Management In Australia [45]	10	2004	X	X	X	X
4	Manitoba Health Disaster Management Model, [40]	15	2002	X	X	X	X
5	Emergency Operations Plan, [46]	15	2000	X	X	X	X
6	A Metamodel for Disaster Management of Oil & Gas Offshore Structures, [47]	10	2006	X	X	X	X
7	A Place-Based Model for Understanding Community Resilience to Natural Disasters, [41]	8	2008	X	X	X	X
8	A Conceptual Model of Disasters Encompassing Multiple Stakeholder Domains, [48]	3	2008	X	X	X	X
9	A Metamodel to Guide Crisis Characterization and its Collaborative Management, [49]	1	2008	X	X	X	X
10	A Comprehensive Conceptual Model for Disaster Management, [50]	2	2006	X	X	X	X
11	Simplifying Disasters: Developing a Model for Complex Non-Linear Events [51]	20	1999	X	X	X	X
12	The Expand-Contract Model [52]	10	2008	X	X	X	X
13	An Integrated Approach to Natural Disaster Management, Public Project Management and its Critical Success Factors [53]	28	2006	X	X	X	X
14	Knowledge Management for Tourism Crises and Disasters [54]	16	2005	X	X	X	X
15	Information,Education and Communication for Urban Risk Reduction [55]	1	2009	X	X	X	X
16	GIS And Disaster Management Cycle, South Asian Disaster Network [56]	10	2009	X	X	X	X
17	The Role Of Local Institutions in Reducing Vulnerability to Recurrent Natural Disasters and in Sustainable Livelihoods Development: Vietnam [57]	10	2003	X	X	X	X
SET V1 (To be used for first validation)							
1	Community Resilience as a Metaphor, Theory, Set of Capacities and Strategy for Disaster Readiness, [58]	31	2008			X	
2	Using SDI and Web-Based System to Facilitate Disaster Management, [59]	28	2006		X		X
3	A Framework for Modeling and Simulation for Emergency Response, [31]	55	2003		X		
4	Chaos, Crisis and Disaster Management: A Strategic and Holistic Framework, [60]	79	2004	X	X		
5	Humanitarian Logistics in Disaster Relief Operations, [43]	24	2007			X	
6	Computer-Based Model for Flood Evacuation Emergency Planning, [42]	17	2005	X			
7	OR/MS Research in Disaster Operations Management, [61]	17	2006		X	X	
8	Integrated Community-based Disaster Management in Taiwan, [62]	12	2006				X
9	Disaster Mitigation: The Concept of Vulnerability Revisited, [63]	57	2001				X
10	Cyclone Warning Markup Language, CWML, [30]	15	2006	X			
SET V2 (To be used for second validation)							
1	Disaster Risk Management & Mitigation Management, [52]	15	2006	X	X	X	X
2	Policies for Guiding Planning for Post-Disaster Recovery and Reconstruction, [64]	15	2005			X	X
3	Disaster Risk Management Working Concept, [65]	15	2002	X	X	X	X
4	Disaster Information, Innovative Disaster Information Service, [66]	10	2008	X	X	X	X
5	Situation-Aware Multi-Agent System for Disaster Relief Operations Management, [67]	5	2006	X	X		
6	An Approach to the Development of Commonsense Knowledge for Disaster Management, [68]	1	2007	X	X	X	X
7	Earthquake Protection, [69].	10	1992	X	X	X	X
8	Disaster Stage and Management Model, [37]	4	2008	X	X	X	X
9	Teaching Disaster Nursing by Utilizing the Jennings Disaster Nursing Management Model, [70].	8	2004	X	X	X	X
10	Disaster Management – a Theoretical Approach, [71]	1	2008	X	X	X	X

For validating our DMM, two validation sets are needed as our two validation processes have different *objectives*. The objective of the first validation is to identify *any missing concepts* in the initial metamodel and ensure the broad coverage of the metamodel. No existing model, as earlier discussed, provides a complete coverage. However, collectively in Set V1, the 10 models together ensure that all DM phases are adequately represented in this validation. The objective of our second validation is to evaluate the importance of individual concepts included in the DMM. If a concept is rarely used, we want to delete it or replace it with a more general concept. To enable

such evaluation, we ensure that the models of V2 have wider coverage to provide overlaps and to enable a frequency count of the individual DMM concepts.

3.3 Step 2: Extraction of Concepts

Similar to [72], [73] and [38], we manually extracted concepts from each model in Set I (containing 17 models in total). This is a laborious process where every model in Set I is used to identify potentially concepts that are required in our DM generic metamodel. The outcome of this process is shown in Table 2. We illustrate this process in the rest of this section with examples.

Table 2. Candidate concepts from 17 DM Models from Set I

Source	Derived Candidate Concepts	Total concept
WHO [44]	Search and Rescue; Lifelines; People; Property; Evacuation; Politics; Coordination; Communication; Rehabilitation and Reconstruction; Command; Emergency Operation Centre; Risk Reduction	12
W3C Incubator Group [27]	Mitigation; Preparedness; Response; Recovery; Trainers; Volunteers and Evacuees; Responder; Returned and Resettled Evacuees; Needs Resource Planning; Information Updates; Early Warning System; Situational Awareness; Deployment; Demobilization; Long Term Planning; Needs Planning; Equipment; Supplies Registry; Damage Assessment; Disaster; Task Reviews; Decision Making; Coordination; Victims; Response Team; Pre-Position Resource	26
EMA [45]	Evacuation; Warning system; Training Programs; Mobilize; Resource; Damage Assessment; Search and Rescue; Long-Term Planning; Restore; Review Development Plan; Reconstruction Task; Registration and Tracing; Before-Disaster; During-Disaster; After-Disaster; Public Education; Training Programs; Emergency Communication; Building Code; Legislation; Mutual Aid Agreement; Aid; Insurance	23
Manitoba [40]	Strategic Plan; Vulnerability; Hazard Assessment; Structural Mitigation; Non-Structural Mitigation; Training; Education; Vulnerability; Emergency Response; Preparedness Planning	10
Modoc County[46]	Command; Planning; Finance and Administration; Operations; Resource; Communication; Incident	7
Russo [47]	Activity; Decision Maker; Collaborative Work; Disaster; People-Centered; Technical-Team; Response-Team	7
Cutter [41]	Resilience; People; Post-Event; Coping Responses; Recovery; Mitigation; Preparedness; Social Learning; Disaster; Vulnerability	10
Kruchten [48]	Disaster Event; Residential Cell; Agent; Infrastructure; Resource; Rescue Team	6
Benaben [49]	Flow; Task Of Actor; Actor On Site; Responders; Returned and Resettled Evacuees; Resource; Crisis; Danger; Trigger; Effect; Risk; Gravity Factor; Complexity Factor; Infrastructure; Natural Site; People; Service of Actor; Good; Risk Analysis; Event	20
Asghar [50]	Mitigation; Preparedness; Response; Recovery; Early Warning; Coordination; Resource Management; Hazard Assessment; Damage Assessment; Training; Education; Risk Analysis; Communication; Evacuation; Reconstruction; Restoration; Evacuation; Structural Mitigation; Non-Structural Mitigation; Exercise; Environmental Affects; Exposure; Strategic Planning; Debris Removal	24
Kelly [51]	Warning; Preparedness; Mitigation; Reconstruction; Rehabilitation; Response	6
in Ahmed [52]	Mitigation; Preparedness; Response; Disaster; Recovery	5
Moe [53]	Preparedness; Warning; Response; Rehabilitation; Reconstruction; Before Disaster; During Disaster; After Disaster; Mitigation; Preparedness; Recovery	11
Mistilis [54]	Domain knowledge/Disaster Information; Disaster; Recovery Plan; Aid Agency; Emergency Management Team; Insurance company; Disaster Analysis Tool; Knowledge Processing; DM User; DM Policy; DM Legislation/DM Regulation; DM Plan; Information Dissemination; Emergency Operation Centre; Situational Awareness; Warning; Media; Recovery Plan; Disaster Factor	19
Shaw [55]	Before Disaster; Mitigation; Risk reduction; Preparedness; Warning; After Disaster; Recovery; During Disaster; Emergency Task; Rescue; Damage Assessment	11
SADKN [56]	Mitigation; Hazard analysis; Risk Analysis; Vulnerability; Risk Analysis; Structural mitigation; Non-structural; Preparedness; Needs Planning; Pre-position; Resource; Evacuation; Communication; Warning; Forecasting; Early warning; Situational Analysis; Response; Emergency Plan; Information; Communication; Evacuation; Pre-position; Damage assessment; Recovery; Rescue; Debris removal; Resource; Aid Distribution; Reconstruction; Spatial planning; Exposure	32
ADPC [57]	Preparedness; Warning; Disaster Factor; Disaster; Response; Emergency; Recovery; Reconstruction; Mitigation	9

The first model we process is Benaben's [49] expressed using Ontology Web Language (OWL) focusing on crisis management. This metamodel elaborates a common and sharable reference model built to characterize crisis situations in three interrelated views namely *System*, *Treatment System* and *Crisis Description*. Benaben's model characterizes crises and collaborative processes that deal with them, aiming to integrate partners through information system interoperability. 20 concepts are derived from Benaben's model: *Flow, Task Of Actor, Actor On Site, Responders, Returned and Resettled Evacuees, Resource, Crisis, Danger, Trigger, Effect, Risk, Gravity Factor, Complexity Factor, Infrastructure, Natural Site, People, Service of Actor, Good, Risk Analysis* and *Event*.

The second processed model is Kruchten's [48] which conceptualises disasters as encompassing multiple stakeholder domains depicted in four main views: Disaster Visualization,

Physical View, Communication and Coordination Simulator, and Disaster Scenario. It aims to create a common language to communicate, analyze and simulate interdependencies about disaster scenario without having to disclose all critical and confidential data between the parties involved. Six concepts are derived from Kruchten's model: *Disaster Event, Residential Cell, Agent, Infrastructure, Resource* and *Rescue Team*. The third processed model is Asghar's [50] focusing on the arrangement of disaster activities in a logical sequence. It is built by linking DM actions with appropriate hazard and risk assessment activities. It also incorporates environmental conditions, making it possible to analyse and separate the environmental issues from a disaster. From this model 24 further concepts are identified: *Mitigation, Preparedness, Response, Recovery, Early Warning, Coordination, Resource Management, Hazard Assessment, Damage Assessment, Training, Education, Risk Analysis, Communication, Evacuation, Reconstruction, Restoration, Evacuation, Structural Mitigation, Non-Structural Mitigation, Exercise, Environmental Affects, Exposure, Strategic Planning* and *Debris Removal* are derived.

3.4 Step 3: Short-listing Candidate Concept Definitions

The collection of concepts derived from Set I is refined and revised during this step. This step yields a total of 240 common concepts from 17 models identified to be reconciled. For every concept we short list several definitions to use towards deriving a common definition. When two or more concepts share the same definition or even two or more concepts share the same concept name, a process to harmonize and fit the definition in the metamodel is required. For example in Kructhen's model, we short list only five from the concepts originally chosen (Table 2). We omit the concept '*Residential Cell*' as it is too specific to one kind of disasters. As another example, from Emergency Management Australia (EMA) [74], we short list only the following concepts and definitions:
- *Evacuation* concept which is defined as '*The planned relocation of persons from dangerous or potentially dangerous areas to safer areas and eventual return*';
- *Event* as '*An incident or situation, which occurs in a particular place during a particular interval of time*';
- *Emergency Plan* as '*A documented scheme of assigned responsibilities, actions and procedures, required in the event of an emergency*';
- *Aid* as '*Free material or financial assistance or other support given to an organization, community or country* and
- *Damage Assessment* as '*A report on the extent of damage caused by an event*'.

This step requires specifying a list of candidate definitions of all short-listed concepts (the definitions will be reconciled in Step 4). e.g.: a '*Disaster Event*' is defined as '*An event which its characteristics will instantaneously or over time change the wellness of cells or the state of infrastructure elements*'; a '*Resource*' is defined as '*Something that contributes significantly to wellness*', an *Infrastructure*' as '*The thing that produces and transports a given resource to the cells*'.

3.5 Steps 4: Reconciliation of Candidate Concept Definitions

Differences between definitions are reconciled in this step. In choosing or synthesizing the common concept definition to be used, definitions shortlisted in Step 3 are considered. The definitions are developed by various people with varying backgrounds and perspectives. If there is a contradictory use of concept definition between two or more sources, then a process to harmonize and fit the definition in the metamodel is required. Some models omit explicitly defining some of their concepts. In such cases, they do not provide any input to the reconciliation process. As an example, the concept of *People* is defined differently in three models: Benaben [49] defines it as '*All the group of persons which can be threatened by the crisis situation*'. Kructhen [48] defines it as '*Cell that contains people*'. EMA [74] denotes this by "Victim" as "*A person directly affected by a disaster*". EMA's is too specific to one of the phases (response), Kruchen's is too specific to their model, therefore we choose Benaben's as the basis of our generalized definition within our DMM. As a result, the People concept in our metamodel is defined as "*Collections of human in local communities who are threatened by disaster*".

3.6 Step 5: Designation of Concepts into DM Phases

Reconciled concepts are designated into one of the DM phases: *Mitigation*, *Preparedness, Response* or *Recovery* [28]. *Mitigation* is a phase in which DM seeks 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 the phase to establish arrangements and plans. It provides education and information to prepare the community to deal effectively with disasters as they may eventuate. *Response* phase will activate preparedness arrangements and plans to put in place effective measures to deal with emergencies and disasters if and when they do occur and lastly *Recovery* will assist a community affected by an emergency or disaster in reconstruction of the physical infrastructure and restoration of emotional, social, economic and physical well-being [45]. Designation into the phases is shown in Table 3.

3.7 Step 6: Identifying Relationships between Concepts and resultant DMM

We now determine the relations between our DMM concepts. As shown in Figures 2 to 5, we use the (——), (——▷) and (——◇) symbols to denote *Association, Specialization* and *Aggregation* relationships respectively. As an association example, '*AffectWellness*' between *Disaster* and *Exposure* concepts indicate that a disaster could affect all elements which are at risk by a disaster. As specialization relationships, *Lifeline*, *Property, NaturalSite* and *People* specialize the *Exposure* concept. As an aggregation example, *EmergencyManagementTeam* and *ResponseOrganization* are related by the relation '*a grouping of*' during the response phase. In almost all DM models observed, we found the existence of emergency management team during response phase of DM. More examples of binary relationships are shown in Table 4. For each pair of related concepts, semantics of the relationships are identified and depicted with a specific symbol.

Table 3. Concepts from Step 4 designated into four phases

| Phase	Reconciled Concepts
Mitigation	MitigationPlan; MitigationOrganization; MitigationGoal; MitigationTask; RiskReduction; InformationUpdates; People; Property; NeedsPlan; Lifeline; NaturalSite; HazardAssessment; RiskAnalysis; StructuralMitigation; StrategicPlanningCommitee; Non-StructuralMitigation; DisasterRisk; Vulnerability; BuildingCodes; Legislation; LandUsePlan, Insurance
Prepared-ness	PreparednessActionPlan; PreparednessOrganization; PreparednessTask; SuppliesRegistry; EarlyWarningSystem; PreparednessGoal; Evacuation; BeforeDisaster; Event; DecisionMaking; Finance; EmergencyPublicInformation; Pre-Position; DisasterFactor; Training; DisasterRisk; PreparednessTeam; Media; MutualAidAgreement; PublicEducation; PublicAwareness; Resource
Response	EmergencyPlan; ResponseOrganization; ResponseTask; Deployment; SituationalAwareness; ResponseGoal; Rescue; DuringDisaster; SituationAnalysis; Incident; Coordination; Command; Communication; StandardOperatingProcedure; EmergencyManagementTeam; Victim; EmergencyOperationCentre; Resource; Aid
Recovery	RecoveryPlan; RecoveryOrganization; RecoveryTask; Demobilization; LongTermPlan; RecoveryGoal; Reconstruction; AfterDisaster; DamageAssessment; TaskReview; Resilience; Victims; EmergencyManagementTeam; Resource; Effect

DM is a continuous process with activities linking phases at different points. Correspondingly, in our DMM, relationships between concepts are identified not only between concepts within the same phase, but also between concepts from different phases. Concepts from classes in different phases can be linked and the continuous process in DM can be formed. For example, *LongTermPlanning* (in Recovery phase) is a concept designating an activity to formulate a plan to meet future DM needs, based on extrapolations from the present needs. Planning begins with the current status and charts out a path to a projected status, including short-term plans for achieving interim goals. Linkages across phases are established either through relationships between concepts from different phases or through common concepts between phases. Table 4 shows examples of relationships that link concepts from different phases. For example, an association relationship can link the concept of *StrategicPlanningCommittee (*from the Recovery phase) to the concept describing an ongoing plan *MitigationPlan* (from the Mitigation phase). Another example of a relationship that ties two concepts across two phases is the *InitiateDeliverableOf* relationship (also shown in Table 4). This can be used to create a link between the concept *MutualAidAgreement* in the Preparedness-phase class and the '*Aid*' concept in the Response-phase class.

Linkages across phases are also established through common concepts between phases. The use of the concept *EmergencyManagementTeam* shows that the activation of emergency management service should start from the preparedness stage in any disaster management process. Whereas the use of the concept *Resource* is to show that the three phases require overlapping sets

of resources for their phase activities. These resources will support the DM_*plan* concept in each phase. The plan for each phase is emphasized as a specific concept in each: for the Mitigation-phase class we have the *MitigationPlan*, in Preparedness-phase class – the *PreparednessActionPlan*, in Response-phase class – the *EmergencyPlan* and in the Recovery-phase class – the *RecoveryPlan*.

Table 4. Relationships among concepts in DMM

Concept 1	Relationship	Concept 2	Phase/in Figure
EmergencyManagementTeam	Association - 'Requires'	*Coordination*	Response/7
Disaster	Association - 'AffectWellness'	*Exposure*	Response/7
StrategicPlanningCommittee	Association - 'Creates'	*InformationUpdates*	Mitigation/5
PreparednessTeam	Association - 'Creates'	*Training*	Preparedness/6
PublicEducation	Association - 'Supports'	*PublicAwareness*	Preparedness/6
Evacuation	Association - 'Follows'	*PreparednessPlan*	Preparedness/6
NeedsPlanning	Association - 'Creates'	*RiskReduction*	Mitigation/5
Aid	Aggregation - 'isAGroupOf'	*ResponseOrganization*	Response/7
Legislation	Aggregation - 'isAGroupOf'	*StructuralMitigation*	Mitigation/5
NaturalSite	Specialisation - 'isAKindOf'	*Exposure*	Mitigation/5
Demobilization	Specialisation - 'isAKindOf'	*Resource*	Recovery/8
StrategicPlanningCommittee	Association - 'Requires'	*MitigationPlan*	Recovery to Mitigation (Inter phases) / 2 and 5
MutualAidAgreement	Association - 'InitiateDeliverableOf'	*Aid*	Preparedness to Response (Inter phases) / 3 and 4
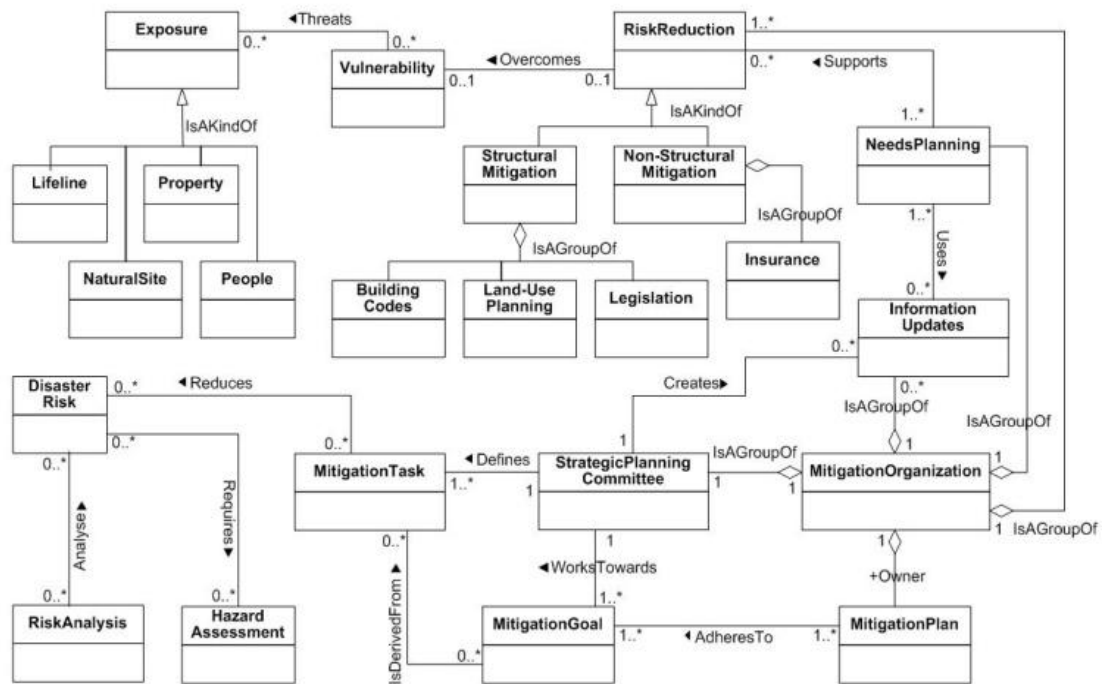
Fig. 2. DMM 1.0: Mitigation-phase class of concepts

DMM clearly presents classes of concepts in the four DM phases: *Mitigation*-phase (Figure 2), *Preparedness*-phase (Figure 3), *Response*-phase (Figure 4) and *Recovery*-phase (Figure 5). The metamodel may also be used as a tool to determine the completeness of a given DM solution. To show how the metamodel can be used, the next effort of this research is to create the *Metamodel-based Disaster Management Knowledge Repository* (DMKR) as a system prototype to demonstrate the usefulness of DMM. This system will utilise DMM as a foundational representation to store varying and existing DM solutions and activities. The development of DMKR will also illustrate the applicability of DMM in modelling real-world DM situation by providing DM practitioners with quick access to relevant knowledge and enable them to develop new and disaster specific processes for their problems. The use of this DMKR will be illustrated in both storing DM knowledge, and later retrieving this knowledge in a context driven manner. The stored DM knowledge will be reused to allow a flexible mixing and matching of different DM actions as disaster contexts change.

9

The resultant metamodel is represented in four different diagrams to clearly group classes into four phases of DM: *Mitigation*-phase (Figure 2), *Preparedness*-phase (Figure 3), *Response*-phase (Figure 4) and *Recovery*-phase (Figure 5) class of concepts. Each figure shows classes which refer to the concepts that should exist during a corresponding phase of DM. The resultant metamodel contains the relationships among concepts and represents the semantics of the DM domain. For example, the *Response*-phase class (Figure 6) has a central concept, *ResponseOrganization*. The aggregation symbol (___<>) is used to describe relationships between *ResponseOrganization* concepts and other concepts including *Resource*, *EmergencyManagementTeam*, *EmergencyOperationCentre*, *EmergencyPlan, Aid* and *Rescue*. Another example of relationship between concepts is the association (denoted by the symbol (___)). This describes relations between *EmergencyManagementTeam* and *ResponderTask* concepts. It indicates that the task of response actor (person) is defined by the emergency management team. Another example, a *Resource* concept 'requires' *Deployment* concept, indicating that during any response phase, emergency resources such as rescue equipment, police transportation, fire equipment or medicine have to be deployed to help the disaster victims.
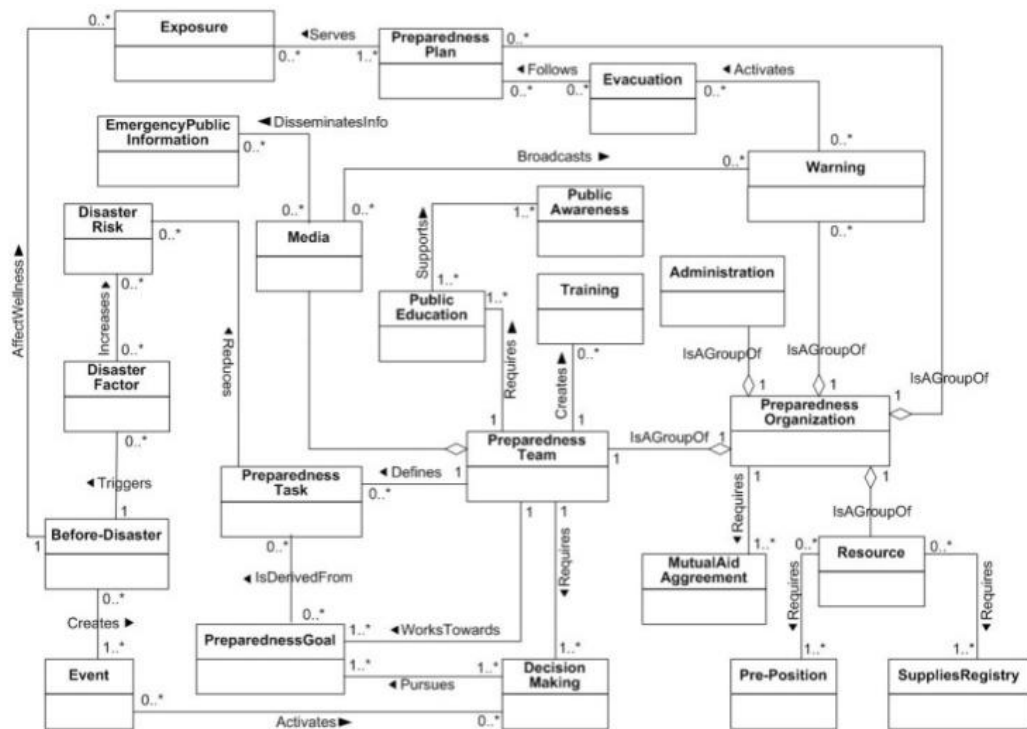
Fig. 3. DMM 1.0: Preparedness-phase class of concept
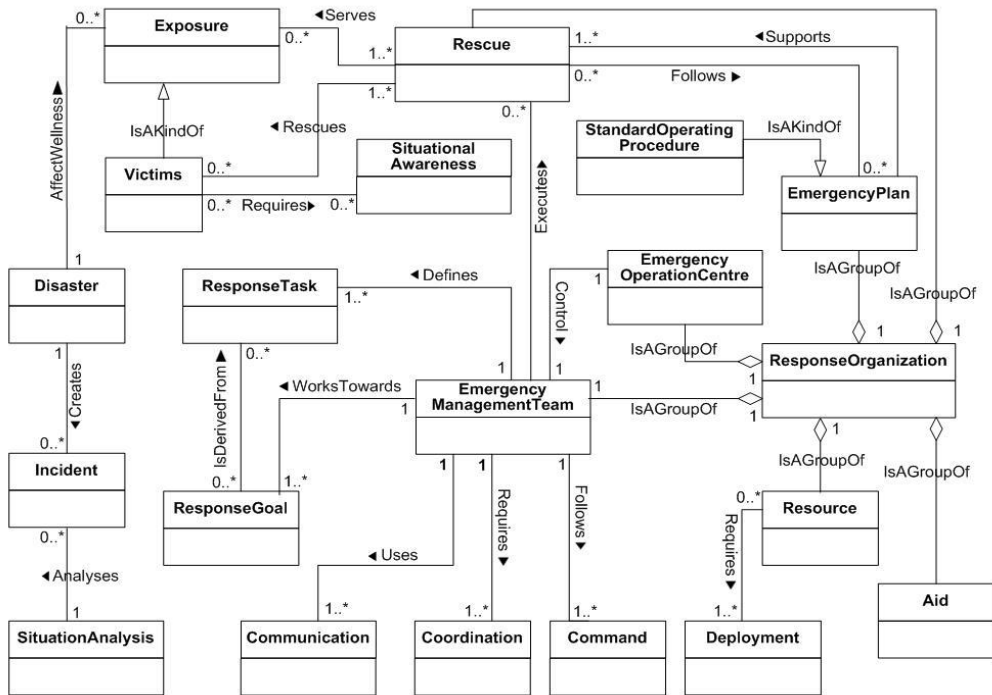
Fig. 4. DMM 1.0: Response-phase class of concept
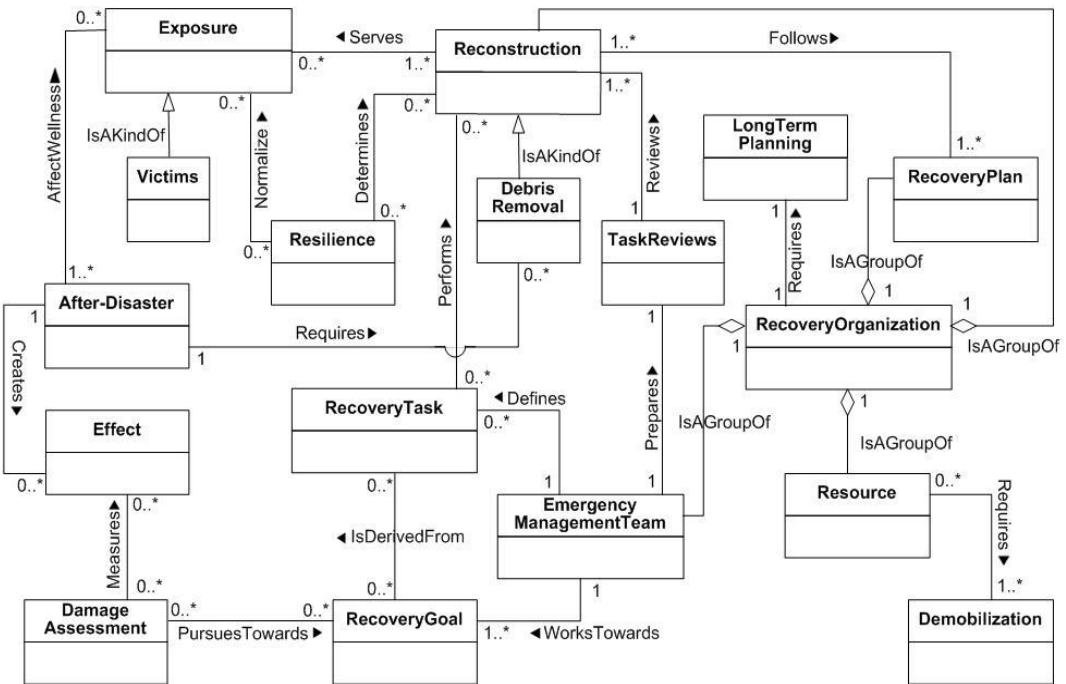
Fig. 5. The DMM 1.0: Recovery-phase class of concept

4 Validation of DM Metamodel (DMM)

We validate our DMM for generality, expressiveness and completeness. This determines that the theories and assumptions underlying the concepts in the metamodel are correct; the representation of metamodel of the problem entity; the structure of the metamodel, and that the logic and causal relationships are suitable for the intended purpose of the metamodel [16]. We apply the following three commonly used validation techniques:

(i) ***Comparison against other models -*** Derived concepts of the developed metamodel are validated and compared to concepts from other (valid) existing similar domain models or

11

metamodels [16]. For this we use a set of 10 DM models in Set V1 (as listed in Table 3 and Appendix I (Table I.1)). We thoroughly ensured that each concept in each of the models can be appropriately derived from a concept within DMM. Where required, we modified the DMM to ensure that it can represent all models in the validation sets. This is described in sub-section 4.1 where we also list the changes we made to first version of DMM yielding DMM 1.1.

(ii) *Frequency-based selection* - The importance of the individual concepts included in DMM is evaluated as advocated in [75] and [76]. The second set of 10 models in Set V2 is used (see Table 3 and Appendix I (Table I.2)). This validation is described in sub-section 4.2 where we also list the changes we make to DMM1.1 yielding DMM 1.2.

(iii) *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 [16]. This tracing validation will determine that an agreement has been achieved between the concepts in the metamodel and real DM scenarios (e.g: bushfires). It is shown in Section 4.3.

4.1 DMM Validation 1 - *Comparison against other models*

The first validation ensures that DMM can represent each of the models in Set VI (shown in appendix I). Where applicable, DMM was modified to ensure that every model can be represented. DMM was revised by adding 11 new concepts (listed in Table 5). Not all phases were changed to the same extent e.g.: the *Mitigation*-phase of DMM only gained the *Insurance* concept as shown in Figure 6). The validation also confirmed the use of all relationships between all concepts (also shown in Table 6). None of the existing relationships were deleted.

Table 5. Eleven new added concepts based on validation over comparison to 10 models of Set V1

Concepts	Set V1	DMM Phase	Concept Definition
Monitoring	(10)	Preparedness	An observation, measurement and valuation of progress in order to identify change of disaster.
AidAgency		Preparedness	An organization dedicated to distributing aid includes within government, between governments as multilateral donors or private voluntary organizations
Information Management	(2)	Response	A process of collecting, analyzing, formatting and transmitting data and information about disaster
Refugee Shelter	(7)	Response	An accommodation provided over an extended period of days, weeks or months, for individuals or families affected by an emergency
MassCasualty Management	(7)	Response	A multi-sectoral coordination system based on daily utilized procedures managed by skilled personnel in order to maximize the use of existing resources, provide prompt and adapted care to the victims and ensure emergency services and hospital return to routine operations as soon as possible.
FoodAid	(7)	Response	Assistance rendered on an organized basis, either free or on concessional terms, to provide food to a population group, community or country suffering from food shortage or insufficient development
Medical-Aid	(7)	Response	A form of aid in types of medical supplies such as medicine, emergency first aid, healthcare equipment to help assist people who are injured and suffered after a disaster hit.
Economic Restoration	(7)	Recovery	A response and recovery action which actively support the recovery of business, industry and economic structure.
Financial Assistance	(7)	Recovery	A provincial cost-sharing program with local government and private sector claimants based on provincial legislation provided to emergency affected persons, communities or organizations to assist their recovery from an emergency
Mental-Health Recovery	(7)	Recovery	A program that provides short-term, in-person, disaster-oriented, emotional support and problem solving assistance in a variety of settings for individuals and families who are attempting to deal with their fears and other negative psychological after-effects of a major disaster or large-scale emergency such as post-traumatic stress disorders, depressive or anxiety disorders, somatic complaints and general mental morbidity that disrupts the normal functioning of a community.
Aid-Distribution	(7)	Recovery	A process of distributing aid in types of food, medical, accommodation and utilities which are supplied by any local and foreign agencies or government to the victims of a disaster.

Table 6. List of Relationships Modifications between Concepts in DMM

	Concept1	Concept2	Modification
Phase: MITIGATION			
1	*Insurance*	*Non-Structural Mitigation*	Add (Aggregation) - '*isAGroupOf*'
Phase: PREPAREDNESS			
1	*Reconstruc-tion*	*Resilience*	Change relationship '*Determines*' to '*Supports*'
2	*Monitoring*	*Warning*	Add (Association) -'*SendsObservationInfoTo*'
3	*Event*	*Monitoring*	Add (Association) - *Monitors*'
4	*AidAgency*	*MutualAidAgreement*	Add (Association) - '*SignedBetween*'
Phase: RESPONSE			
1	*Coordination*	*Incident*	Add (Association) – '*ControlSituationOf*'
2	*FoodAid*	*Aid*	Add (Specialization) - *isAKindOf*
3	*MedicalAid*	*Aid*	Add (Specialization) - *isAKindOf*
4	*Refugee-Shelter*	*Aid*	Add (Specialization) - *isAKindOf*
5	*MassCasualtyManagement*	*Rescue*	Add (Specialization) - *isAKindOf*
Phase: RECOVERY			
1	*MentalHealthRecovery*	*Reconstruction*	Add (Specialization) - *isAKindOf*
2	*Financial-Assistance*	*Reconstruction*	Add (Specialization) - *isAKindOf*
3	*Economic-Restoration*	*Reconstruction*	Add (Specialization) - *isAKindOf*
4	*Aid-Distribution*	*Recovery-Organization*	Add (Aggregation) - *isAGroupOf*

4.2 DMM Validation 2- Frequency-Based Selection

In this second validation, we perform a *Frequency-Based Selection* (*FBS*) technique using 10 models (Set V2 in Table 1). This is a *Feature Selection* technique that evaluates the importance of individual concepts in the model developed in [76]. It is based on the premise that the best model is formed using the most common features [77] and it is commonly used e.g. in data mining [78], software analysis [75], and medical retrieval systems [79]. By performing FBS, we remove *features* (*concepts*) that do *not have correlations (or a need)* to the classification from DMM.

We first collate concepts from the models in the validation Set V2 and in doing so we also ensure that they can all be refined using DMM 1.1 (see Appendix II). As expected, most concepts, in eight of the ten models, were easily derived and only three concepts were added to DMM (see Figure 7). The second task in our FBS validation is to score each concept according to its frequency. Concepts that have a low score are revisited and are liable for deletion. The frequency results obtained for all DMM concepts are shown in Table 7 (Mitigation and Preparedness concepts) and Table 8 (Response and Recovery concepts).

Table 7. Frequency result of Mitigation and Preparedness-phase concepts

	DMM 1.1 Concepts	Model Set V2										Frequency of Concept
		1	2	3	4	5	6	7	8	9	10	
MITIGATION CONCEPTS												
1	MitigationPlan	√	√	√	√	√	√		√	√	√	**9**
2	MitigationOrganization	√	√	√	√	√	√	√	√	√	√	**10**
3	MitigationTask	√	√	√	√	√				√	√	**7**
4	NeedsPlanning	√		√		√				√		**4**
5	InformationUpdates					√	√		√	√		**4**
6	MitigationGoal			√		√	√					**5**
7	RiskReduction	√	√	√	√	√	√		√		√	**9**
8	People					√		√	√	√		**4**
9	Property											**0**
10	Lifeline		√		√	√						**3**
11	NaturalSite				√							**1**
12	HazardAssessment		√	√	√		√	√	√	√	√	**8**
13	RiskAnalysis	√	√	√	√	√	√		√	√	√	**9**
14	StructuralMitigation		√								√	**2**
15	Non-StructuralMitigation		√								√	**2**
16	Vulnerability		√			√				√	√	**4**
17	DisasterRisk	√	√	√			√		√	√		**6**
18	StrategicPlanning Organization	√		√	√		√		√		√	**6**
19	BuildingCodes											**0**
20	Legislation		√			√						**2**
21	Land-UsePlanning											**0**
22	Insurance						√					**1**
PREPAREDNESS CONCEPTS												
1	PreparednessPlan	√	√	√	√	√	√	√	√	√	√	**10**
2	PreparednessOrganization	√	√		√	√	√	√	√	√	√	**9**
3	PreparednessTask	√	√		√	√				√	√	**6**
4	SuppliesRegistry					√	√			√	√	**4**

	DMM 1.1 Concepts	1	2	3	4	5	6	7	8	9	10	Frequency
5	Warning	√	√			√			√	√	√	**6**
6	PreparednessGoal			√		√	√			√	√	**5**
7	Evacuation		√		√	√				√	√	**5**
8	Before-Disaster	√	√		√	√	√		√			**6**
9	Event					√			√		√	**3**
10	DecisionMaking					√			√	√		**3**
11	Administration					√			√	√		**3**
12	EmergencyPublicInformation		√	√	√	√		√		√	√	**7**
13	Pre-Position				√	√		√		√		**4**
14	DisasterFactor	√	√	√	√			√				**5**
15	Training	√	√		√	√			√	√		**6**
16	Media	√	√			√		√	√			**6**
17	MutualAidAgreement					√		√				**2**
18	PublicEducation		√		√	√				√		**4**
19	PublicAwareness	√	√		√	√			√			**5**
20	Resource			√	√	√		√		√	√	**6**
21	Monitoring	√	√			√		√		√	√	**6**
22	AidAgency				√	√		√				**3**

Using the concept frequency, we estimate an importance value for each concept in DMM, 'Degree of Confidence (DoC)'. This value designates the expected probability that a DMM concept is used in a randomly chosen disaster model. It is defined as follows:

$$\text{Degree of Confidence} = \frac{\text{Frequency of Concept}}{\text{Total of Set V2 Models}} \times 100\%$$

Table 8. Frequency result of Response and Recovery-phase concepts

	DMM 1.1 Concepts	Model Set V2										Frequency of Concept
		1	2	3	4	5	6	7	8	9	10	
RESPONSE CONCEPT												
1	EmergencyPlan	√	√	√	√	√	√	√	√	√	√	**10**
2	ResponseOrganization	√	√	√	√	√	√	√	√	√	√	**10**
3	ResponseTask	√	√	√		√				√	√	**6**
4	Deployment		√			√		√		√		**4**
5	SituationalAwareness		√			√						**2**
6	ResponseGoal			√		√	√			√	√	**5**
7	Rescue	√				√		√			√	**4**
8	Disaster	√	√		√			√				**4**
9	SituationAnalysis		√		√	√		√				**4**
10	Incident							√				**1**
11	Coordination		√		√	√		√		√		**5**
12	Command		√			√						**2**
13	Communication		√			√		√		√		**4**
14	StandardOperatingProcedure				√					√		**2**
15	Victim									√		**0**
16	EmergencyManagementTeam	√	√		√	√		√		√	√	**7**
17	EmergencyOperationCentre		√					√				**2**
19	Aid				√	√		√			√	**4**
20	InformationManagement		√		√	√		√		√		**5**
22	RefugeeShelter				√					√		**2**
23	MassCasualtyManagement				√					√		**2**
24	FoodAid				√			√	√		√	**4**
25	MedicalAid		√		√	√		√	√		√	**6**
RECOVERY CONCEPTS												
1	RecoveryPlan	√	√	√	√	√	√			√	√	**8**
2	RecoveryOrganization	√	√	√	√		√	√	√	√	√	**9**
3	RecoveryTask	√	√	√	√	√				√	√	**7**
4	Demobilization		√		√			√				**4**
5	LongTermPlanning		√	√						√		**3**
6	RecoveryGoal			√		√	√			√	√	**5**
7	Reconstruction	√	√	√	√	√	√	√		√	√	**9**
8	After-Disaster	√	√				√	√	√			**5**
9	DamageAssessment	√	√			√	√	√		√		**7**
10	TaskReview	√	√	√						√		**4**
11	Resilience	√	√	√	√		√	√			√	**7**
12	Effect		√							√	√	**3**
13	EconomicRestoration		√	√				√	√	√	√	**6**
14	FinancialAssistance		√	√				√	√	√	√	**6**
15	MentalHealthRecovery	√	√	√	√			√		√	√	**7**
16	AidDistribution							√	√		√	**3**
17	Exposure		√		√			√				**3**

14

Table 9 shows the result of this calculation for every DMM concept. We define five categories of concepts based on their DOC value:

      i)   Very Strong (DoC result: 100 – 70 %),
      ii)   Strong (69 – 50 %),
      iii)   Moderate (49 – 30 %),
      iv)   Mild (29 – 11 %)
      v)   Very Mild (10 – 0 %).

Very Strong refers to the concept that many times appears in Set V2 models, whereas Very Mild is the other end of the scale. For example, the DMM concept, *MitigationPlan*, has a strong concept DOC value of 90%:

$$\textbf{DoC } (\textit{MitigationPlan}) = \quad \frac{9}{10} \text{ X } 100\% \ = \ \textbf{90 \%}$$

Aiming for absolute theoretical completeness is cited as a common bad practice in metamodel development [39]. As discussed in [39, pp. 23], similar to the development of domain-specific modelling, metamodel development is not about achieving perfection. We concur with these views and if a DMM concept has a 'zero' DoC score, it gets deleted only after due consideration. Concepts with zero values are instead revisited and liable for deletion. DOC classification for all DMM concepts is shown in Table 9: 19 concepts in DMM 1.1 are categorized as 'Very Strong', 23 are "Strong", 25 are 'Moderate', 13 are 'Mild' and 4 concepts are 'Very Mild' (Table 9).

    The four very mild concepts are *Property, NaturalSite, BuildingCodes* and *Land-UsePlanning*. We reassess including them in DMM. We delete *BuildingCodes* and *Land-UsePlanning*, as they are deemed as too specific to one kind of disasters (Bushfires). Revisiting DMM, we also found that the *StructuralMitigation* is in fact more generic to represent the *BuildingCodes* and *LandUsePlanning*. As for the other two (*Property* and *NaturalSite*), we opt to keep them as they are common across varying disasters.

    As a result of FBS, classes for the Mitigation-phase and Response phases are changed. The classes for Preparedness and Recovery phases remain unchanged. Figure 7 and Figure 9 show the new validated version of Response concepts and Mitigation concepts, respectively.

Table 9. Degree of Confidence for DMM Concepts after FBS

Percentage Degree (Degree of Confidence)				
100 – 70 % (Very Strong)	69 – 50 % (Strong)	49 – 30 % (Moderate)	29 – 11 % (Mild)	10 – 0 % (Very Mild)
MitigationPlan, MitigationOrganization MitigationTask, RiskReduction HazardAssessment RiskAnalysis PreparednessPlan Preparedness-Organization EmergencyPublic-Information EmergencyPlan ResponseOrganization EmergencyManagement Team RecoveryPlan RecoveryOrganization RecoveryTask Reconstruction DamageAssessment Resilience MentalHealthRecovery	MitigationGoal DisasterRisk StrategicPlanning-Organization PreparednessTask Warning PreparednessGoal Evacuation BeforeDisaster DisasterFactor Training Media PublicAwareness Resource Monitoring ResponseTask ResponseGoal Coordination Information-Management **MedicalAid (modify)** RecoveryGoal After-Disaster EconomicRestoration FinancialAssistance	NeedsPlanning InformationUpdates People Lifeline Vulnerability SuppliesRegistry Event DecisionMaking Administration Pre-Position PublicEducation AidAgency Deployment Rescue Disaster SituationAnalysis Communication Aid **FoodAid (modify)** Demobilization LongTermPlanning TaskReview Effect AidDistribution Exposure	StructuralMitigation Non-Structural Mitigation Legislation Insurance MutualAid-Agreement SituationAwareness Incident Command StandardOperating-Procedure Victim Emergency-OperationCentre **RefugeeShelter (modify)** MassCasualty-Management	**Property (√) NaturalSite (√) BuildingCodes (x) Land-UsePlanning (x)**

Legend: *(modify) = modification is made to the concept, (√) = Keep the concept, (x) = Delete the concept*
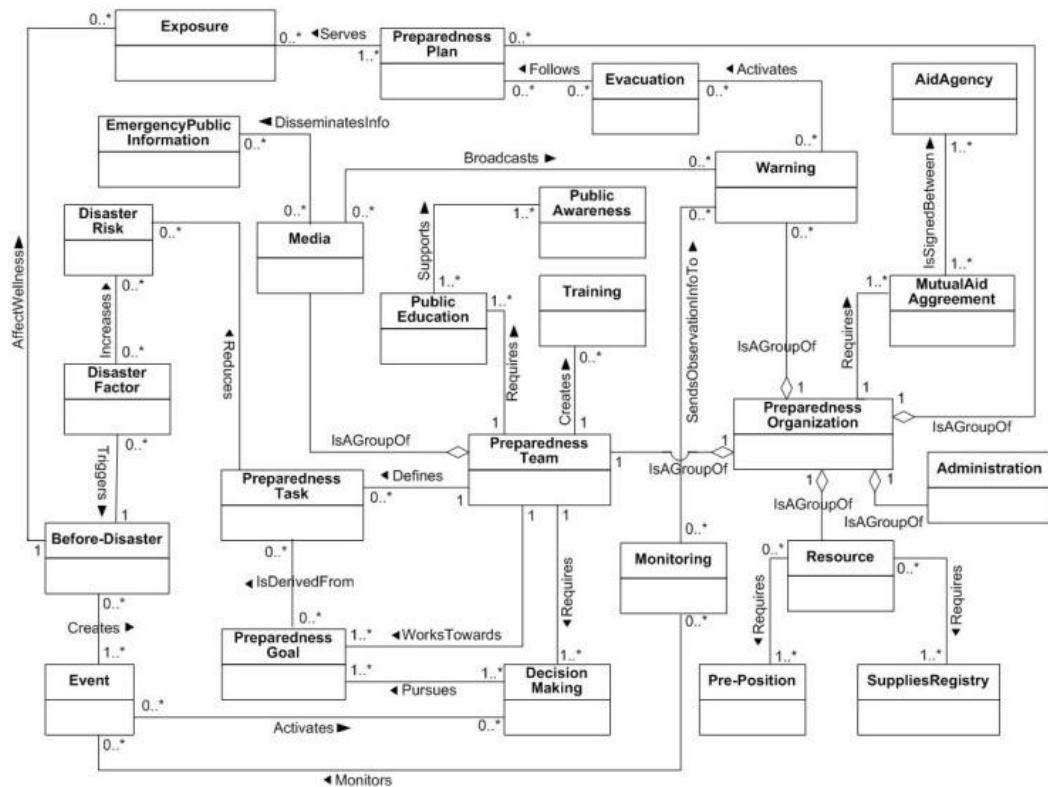
Fig. 6. A validated version of Preparedness-phase class of concepts

As a result of ensuring that DMM represents each of the models in V2, we also added three concepts to the Response-phase class (encircled in Figure 7):

- *HumanitarianAid* - A material or logistical assistance provided for humanitarian purposes, typically in response to an event or series of events which represents a critical threat to the health, safety, security or wellbeing of a community or other large group of people, usually over a wide area.
- *DevelopmentAid* - An aid given by governments and other agencies to support the economic, environmental, social and political development of developing countries
- *BilateralAid* - An aid or funds that are given to one country from another.

As a result of the refinements described in Sections 4.1 and 4.2, the DMM classes of concepts are shown in Figures 6 to 9. Figures 7 and 9 are annotated to clarify the impact of the FSB validation.

The next validation will confirm the representational adequacy of DMM, in a DM common scenario, namely, bushfires. Furthermore, it will highlight how this representation can be used in a specific instance of bushfires, the devastating bushfires in Australia in 2008.
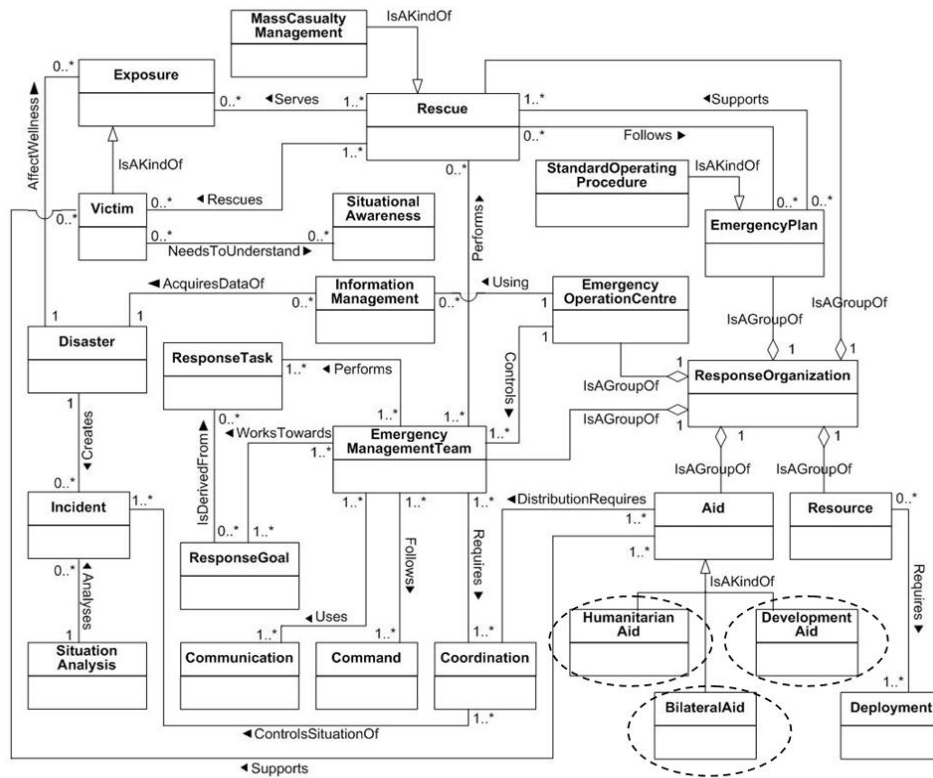
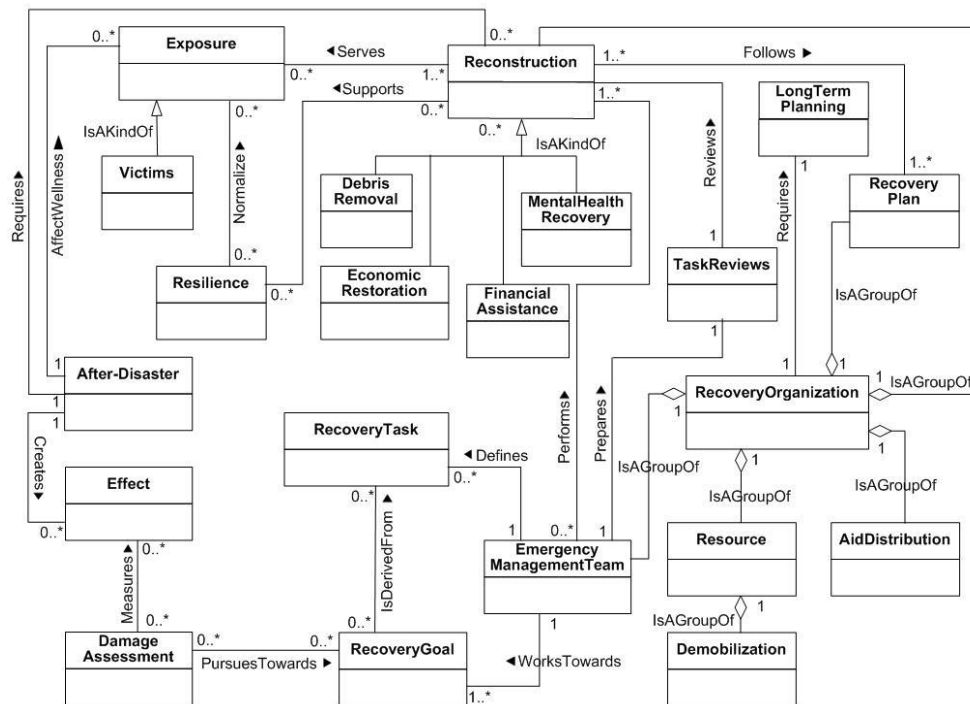**Fig. 7.** A validated version of Response-phase class of concepts

Fig. 8. A validated version of Recovery-phase class of concepts
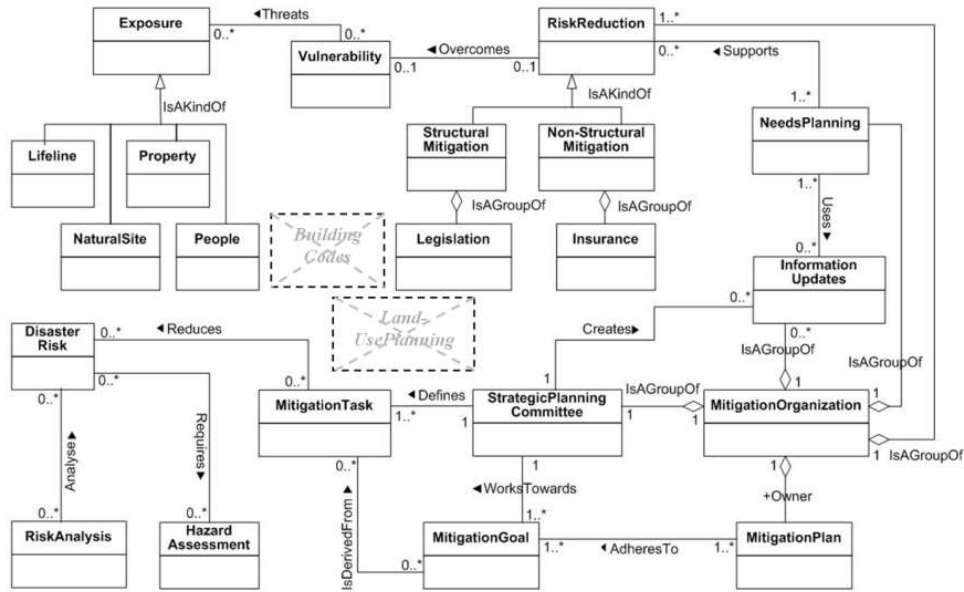
17

Fig. 9. A validated version of Mitigation-phase class of concepts

4.3 *Tracing* in Bushfire as a Validation for DMM

In this last validation, we use DMM to instantiate a specific disaster. This will ensure that the concepts are indeed usable by DM practitioners. We seek to instantiate from our DMM the preparedness against bushfires, by Australian state government schools. Figure 10 illustrates the abstraction layers involved in this validation. DMM artifact descriptions show a situation of how one possible instantiation of model can be made from DMM at M2 level, to another model in level M1. This is followed by the instantiation to user or real world model at level M0.

In the aftermath of the devastating bushfires of 2008[1], the Department of Education and Early Childhood Development (DEECD) in Victoria (Australia) mandated that every school review its emergency management plan and address any priority maintenance works [80] according to newly formed guidelines. Our metamodel is at M_2 Level, the model (guidelines) developed by the government is at M_1 (Figure 11) and the actual DM application for bushfire is at M_0 (Figure 12).

Fig. 10. DMM artefact descriptions show a situation of how one possible instantiation of model can be made from DMM at M2 level, to another model in level M1. This is followed by the instantiation to user or real world model at level M0

Figure 11 depicts the guidelines described in the *Emergency Response Coordination* model (at M1 level) to coordinate response activities during DM. This represents a particular DM response-phase model clearly derivable from DMM (at M_2 level). This particular M_1 model is later usable by a DM user (the followers of the *Victoria Bushfire Coordination Workflow*). A state bushfire engineer can map their own bushfire organization problem by adopting class model as produced in Figure 11. For example, as shown in Figure 12, a *Rescue* class can be used as *Marysville Bushfire Rescue* to

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[1] In 2008, devastating bushfire hit the state of Victoria in Australia and led to a catastrophic loss of life, nearly 200.

represent the instance of *Rescue* concept. In order to create a new model element, we use *stereotype* (<<Rescue>>), a special notation for expressing the extensibility mechanism in UML. Similarly, *EmergencyManagementTeam* class could be used as *Victoria Fire & Emergency Unit* in Victoria bushfire case model, M_0. As can be seen, the concepts directly derived from DMM (shown in Figure 11) adequately generate all concepts required in this instance of Bushfire Management identified without any need for further amendments.
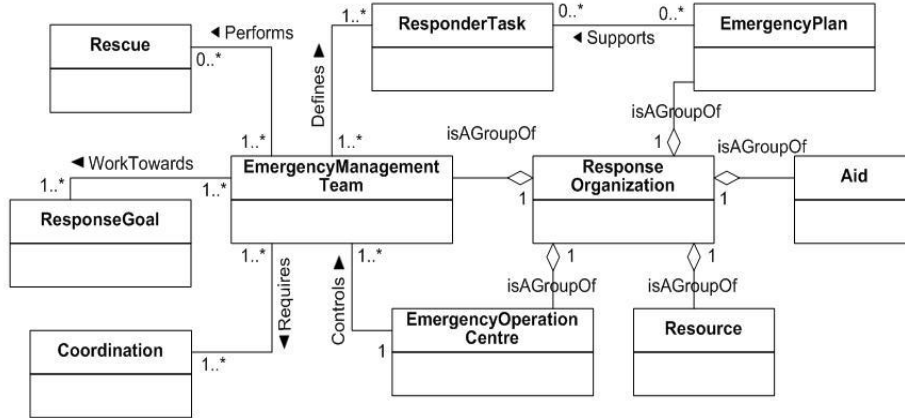
Fig. 11. Abstraction Levels in DMM Tracing Validation
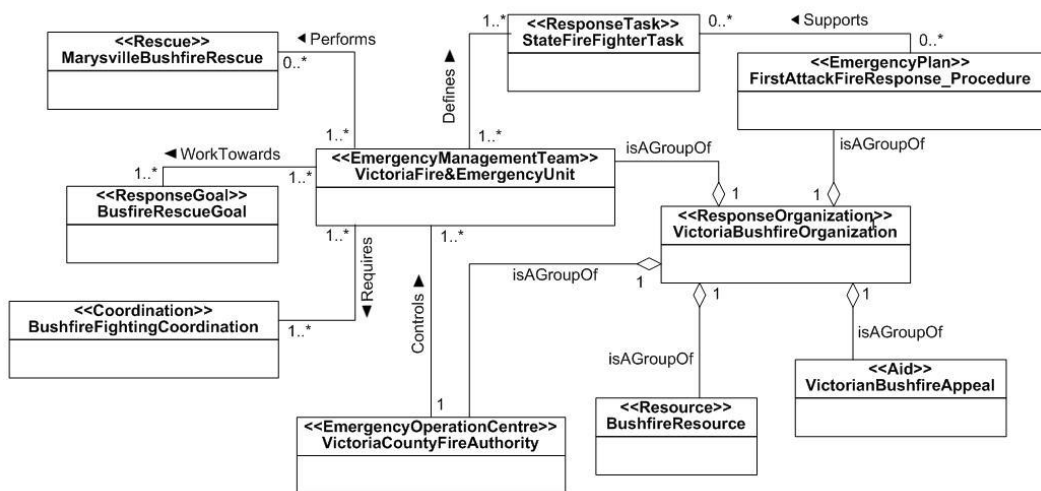
Fig. 12. The Emergency Response Coordination Model (M_1) Instantiated from DMM

4.4 Limitations of the Model

Our disaster management metamodel (DMM) has been developed based on a careful analysis of the existing literature and domain specific disaster models. It has been validated through a couple of iterations and applied to a specific case. While the DMM is generic and domain-independent and can be instantiated for specific DM scenarios, it has some drawbacks that need to be addressed as the DMM is evolved.

The following are some of the limitations which will be taken into account in the next iteration of the DMM refinement.

- In developing our DMM, we have considered only the models presented in English which could lead to a cultural bias. In the next stage of our model refinement, we will consider a more diverse set of models from different geographic regions, which will improve the completeness and applicability of the model.

- While we sought input from practitioners and experts during the DMM development, validated the model against two sets of models from the literature and applied it to a specific DM case, there was no formal evaluation of the model done by the experts in disaster management. As part of future work, the DMM and the results will be validated by a group of DM experts.

- In the second part of the DMM validation process (section 4.2), we used frequency-based-selection. In this process, we were interested in knowing whether a particular concept appeared in a model or not and did not focus on how many times it appeared. In information retrieval, this frequency is used to indicate the importance of a concept. In the next iteration of the DMM development, we will consider this fact and refine the model accordingly.

- In developing the DMM, our goal was to create a model that is general and complete. Hence, we tried to include all the concepts that occurred in all or most of the models. While, this resulted in a broad model that represents common practice, it might not be the "best practice" model. Our DMM might be construed as a model that is useful for training novices but may not be useful in helping organizations develop a state-of-the-art or best practice model. While specialized (best practice) models can be instantiated from the general DMM, in our future work, we will take a synthesis approach and incorporate most important concepts from the various models in order to produce a class of best practice models.

- So far, we did not investigate how the retrieval process for a DM repository (developed using DMM) can be enacted. We still need to further investigate how a DM practitioner can articulate his/her queries using constructs that can be mapped to our metamodel. This will require the creation of a repository using the metamodel and engaging actual DM practitioners. We are currently in a dialog with the New South Wales State Emergence Services (NSW SES) towards this.

- As, the DMM is designed to support DMM knowledge reuse, the ultimate test of DMM would be in the deployment of a knowledge repository developed using DMM. In other words, using DMM-based repository to support DM business processes. This will first test the expressivity of DMM through interactions with domain experts from different disasters and the reusability of the stored knowledge. For instance, in this work, we assume that DM knowledge is symbolic (similar to other existing models). Whether this assumption will hinder the applicability of the approach and to what extent, can only be assessed empirically once a knowledge repository is deployed using the metamodel.

- The DMM could evolve over time. Currently, we have not incorporated specific mechanisms for evolving the DMM in a consistent manner. While some human intervention would be necessary, automating or partially automating this process would be beneficial. This would make the DMM stay current and be useful in managing DM activities. Our future work will include developing feedback mechanisms that will facilitate the evolution of our DMM.

5 Conclusion and Future Works

This paper has discussed the development and validation of the Disaster Management Metamodel (DMM). The metamodel presented is intended to become an effective platform for sharing and integrating DM knowledge from varying sources. Existing disaster models are not based on any metamodels or standards but rather constitute proprietary solutions mainly focused on frameworks and other model aspects. This is the first work that develops a DM metamodel across the four established phases of disaster management. Our DMM can unify these works as a navigation metamodel. More importantly, the DMM is the first step to allow interoperability of DM solutions and effective transfer of knowledge across international boundaries. It may also be used as a tool to determine the completeness of any DM solutions.

We presented the metamodel in a familiar format, UML, to increase its ease of use and broaden its appeal. In synthesizing our metamodel, we used 17 models (Set I) for the initial development of DMM. In the second iteration, 10 models (Set V1) were used to validate (using *comparison against other models* technique) and refine the DMM. As a result, 11 new concepts were identified. In the third iteration, we used another 10 models (Set V2) for a second validation (using *frequency-based selection*) of DMM which resulted in minor change to DMM (two concepts were deleted and three new concepts were added). The first two validations improved the

expressiveness and the completeness of the concepts in DMM. We applied a third validation (tracing technique) to ensure and illustrate the applicability and utility of our DMM in a real disaster management modeling exercise, namely, the bushfire management in the state of Victoria in Australia.

Our metamodelling approach can decrease time and implementation costs of DM systems and allow various DM approaches to be easily shared and communicated. The metamodel can describe various DM activities and desired outcomes and serve as a representational layer of DM expertise. It can facilitate appropriate decision making based on combining and matching different DM activities according to the disaster scenario on hand. A unified DM metamodel can ensure that the key concepts are easily presented to newcomers of the domain, create better communication amongst practitioners, and research could then focus on improving and/or realizing a unified body of knowledge [8]. For instance, the unified DMM can facilitate global communication among different disaster emergency users as the metamodel has generalized all the concepts that must exist in this domain. With guidelines for creating a comprehensive DM model which can cover all the phases of DM (e.g: *Earthquake Emergency Response Model* - Response phase and *Bushfire Risk Reduction Model* - Mitigation phase), users can create new customised DM model based on combining sets of suitable concepts based on their own disaster management requirement. To this end, our future work will aim to create a repository based on the DMM to store DM knowledge and to allow a responsive and flexible DM approach; one that is based on mixing and matching DM actions as disaster management contexts change.

Acknowledgement

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Table I.1 Validation summary against Model Set V1

Set V1 Model	(A) SUPPORT Set V1 Concepts (DMM Support Concept)		(B) NOT SUPPORT Set V1 Concept (Phase)	(C) MODIFY change type: New DMM Concept
Set V1(1): CRM	- Responsible media (*Media*) - Community competence (*Resilience*) - Community action (all-phaseTask)	- Social capital (*Resilience*) - Fairness of risk & vulnerability to hazards (*Vulnerability*)	- Economic Development	- Add: "Economic Restoration
			- Information & Communication	- Add: "Information Management"
Set V1(2): SDI	- Policies (all-phasePlan) - People (*People*) - Capacity building (*Resilience*) - Communication system (*Communication*) - SDI Organization (all-phase Organization)	- Environment preparation (*HazardAssessment*) - Response time (*Rescue*) - Network mechanism (*Resource*) - Interoperability (*Coordination*) -Guides and specification (all-phasePlan)	- Data include database management, access and analysis tool, metadata content.	- Add: "Information Management"
Set V1(3): iERF	- Disaster event (Event) - Man-made disaster including NBC bomb, Conventional bomb, Fire, Hijacking etc (Disaster) - Natural disaster including Tornado, Hurricane, Wild fire, Floods etc (Disaster) - Population (People) - Entities of Interest (Exposure) - Planning (all-phasePlan) - Vulnerability analysis (*Vulnerability*)	- Training (Training) - Response (Rescue) - Define response (ResponseTask) - Defines impact (Incident) - Response agents including Police, FireEngines, Ambulances, Hospitals, Agencies and etc (EmergencyManagementTeam) - Resource including Telecom, Power plants, power distribution, government bridge (Resource, Lifeline)	All supported	No
Set V1(4): SHFM	- Pre-Event Stage (*MitigationOrganization*) - Prodromal (*PreparednessOrganization*) - Emergency (*ResponseOrganization*) - Intermediate (*RecoveryOrganization*) - Long-Term Recovery (*LongTermPlan*) - Resolution (*Resilience*) - Proactive planning and strategy (all-phasePlan, all-phaseTask, *RiskAnalysis, SituationalAnalysis*) - Scanning to Planning (*StrategicPlanningCommittee,* all-phasePlan)	- Strategy Evaluation and Strategic Control (*DecisionMaking, Coordination and EmergencyOperationCentre*) - Crisis communication and control (*Communication, Coordination, Command*) - Resource Management (*Resource, NeedsPlanning, SuppliesRegistry, Deployment, Demobilization*) - Understanding and collaborating with stakeholders (*Coordination*) - Resolution and Normality (*Recovery, Resilience*) - Organizational Learning and Feedback (*TaskReview, LongTermPlan*)	All supported	No
Set V1(5): HLDRO	- Preparation stage (*MitigationOrganization, PreparednessOrganization*) - Immediate Response stage (*ResponseOrganization*) - Reconstruction stage (*RecoveryOrganization*)	- Disaster prevention Risk Management (*RiskReduction*) - Strategic Planning (all-phasePlan) - Coordination and Collaboration (*Coordination*) - Supply Management (*Resource, Aid, SuppliesRegistry*) - Demand Management (*NeedsPlanning, Deployment, Demobilization*) - Continuity Planning (*LongTermPlan*)	All-supported	No
Set V1(6): CFEP	- Concern (*PublicAwareness*) - Danger recognition (*SituationAwareness and Warning*)	- Acceptance (*Resilience*) - Evacuation (*Evacuation*)	All-supported	No
Set V1(7): DOM	- Constructions of emergency operations centre (*EmergencyOperationCentre*) - Activating emergency operation centre (*EmergencyOperationCentre*) - Evacuation of threatened population (*Evacuation*) - Emergency rescue and medical care (*Rescue*) - Fire fighting (*ResponseTask*)	- Urban search and rescue (*Rescue*) - Emergency infrastructure protection and lifeline recovery (*Reconstruction*) - Disaster debris cleanup (*DebrisRemoval*) - Sustained mass care for displaced human and animal (*Reconstruction*) - Full restoration of lifeline services (*Reconstruction*)	- Opening shelters (RES)	- Add: "RefugeeShelter"
			- Provision of mass casualty (RES) - Fatality management (RES)	- Add: "MassCasualty Management"
			- Reburial of displaced human remains (REC)	
			- Financial assistance to individual and governments (REC)	- Add: "AidDistribution" - Add: "FinancialAssistance"
			- Mental health and pastoral care (REC)	- Add: "MentalHealth Recovery"

Set V1(8): **ICDM**	- Local groups (*People*) - The planning team and the advisory team (*StrategicPlanningComittee*) - Public agencies (*PreparednessTeam*) - Expert or specialist (*EmergencyManagementTeam*) - Hazard mitigation (*StructuralMitigation, Non-StructuralMitigation*) - Emergency management (*EmergencyManagementTeam*) - Landslide, debris flow, flood, earthquake (*Disaster*) - Search and rescue (*Rescue*)	- Communication (*Communication*) - Emergency medical services (*Rescue*) - Fire fighting agencies (*EmergencyManagementTeam*) - Transportation (*Resource*) - Public health (*PreparednessTeam, EmergencyManagementTeam*) - Public utilities (*Lifeline*) - Water resource (*Lifeline*) - Education centres (*PublicEducation*)	**All-supported**	**No**
Set V1(9): **Mitigation**	- Mitigation (*MitigationOrganization*) - Vulnerability assessment (*MitigationOrganization*) - Risk management (*MitigationOrganization*) - Prevention (*MitigationOrganization*) - Preparedness(*Preparedness Organization*) - Disaster response (*ResponseOrganization*) - Hazard analysis (*HazardAssessment*) - Non-structural measures identification (*Non-StructuralMitigation*) - Structural measure identification (*StructuralMitigation*)	- Identification of awareness (*PublicAwareness*) - Identification of warning and evacuation structures (*Warning, Evacuation*) - Identification of disaster relief structures (*RecoveryOrganization*) - Rescue and relief (*Rescue, Reconstruction*) - Humanitarian assistance (*Aid*) - Recovery and reconstruction (*Reconstruction*) - Preparedness assessment (*RiskAnalysis, HazardAssessment*) - Re-evaluation of measures (*TaskReviews*)	**All-supported**	**No**
Set V1(10): **CWML**	- Severe Weather Advisory and Centre (*EmergencyOperationCentre*) - Applicable Area (*Exposure*) - Warning and WarningSignal (*Warning*) - Action (*PreparednessTask*)	- Threat (*DisasterFactor*) - Media (*Media*) - Flood (*Event*) - Precaution (*RiskReduction*) - Broadcast (*Media*)	- Observation and Watch concept	- Add: "Monitoring"

Notes: MIT - Mitigation, PRE - Preparedness, RES - Response, REC - Recovery and Add - Add new concept to initial DMM

- *Set V2 is not shown due to space constraints (available on request).*

Appendix II
Concepts of DMM Version 1 and their definitions

Table II.1 Initial set of Mitigation-phase concepts

No	CONCEPT	DEFINITION
1	**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.
2	**Mitigation Organization**	An organization of components and activities to lessening or limitation of the adverse impacts of hazards and related disasters.
3	**MitigationTask**	A task and responsibility that needs to be accomplished by Mitigation team.
4	**NeedsPlanning**	A task of preparing, describing, identifying the needs of individuals, households, institution or resources materials that could be needed in the event of a disaster.
5	**Information Updates**	A process of updating disaster management data towards creating a collection of current information that is up-to-date.
6	**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.
7	**RiskReduction**	A 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.
8	**People**	Collections of human in local communities who are threaten to disaster.
9	**Property**	A thing that is owned by a person or entity which are threatened to disaster.
10	**Lifeline**	A 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.
11	**NaturalSite**	A part of elements at risk which are not man-made.
12	**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.
13	**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.
14	**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.
15	**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.
16	**Vulnerability**	A characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.
17	**DisasterRisk**	A potential disaster loss, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.
18	**Strategic Planning Committee**	An 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.
19	**BuildingCodes**	A set of ordinances or regulations and associated standards intended to control aspects of the design, construction, materials, alteration and occupancy of structures that are necessary to ensure human safety and welfare, including resistance to collapse and damage.
20	**Legislation**	A law enacted by a legislative body.
21	**LandUse Planning**	A process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses.
22	**Insurance**	A policy that is designed to provide an insurance alternative to disaster assistance to meet the escalating costs of repairing damage to properties and their contents caused by disasters.

Table II.2 Examples of the initial set of Preparedness-phase concepts

No	CONCEPT	DEFINITION
1	PreparednessPlan	A plan prepared by an authority, sector, organization or enterprise that address the preparedness of organizations for emergency response and recovery that includes a training plan, exercise plan, and others. Developing, documenting and revising response and recovery plans and all their components.
2	Preparedness Organization	An organization of knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.
3	PreparednessTask	A task and responsibility that needs to be accomplished by Preparedness team.
4	SuppliesRegistry	A task of recording the resources including equipment and supplies that needs to be supplied to the incident place.
5	Warning	A set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.
6	Preparedness Goal	A description of the end state of preparedness phase where the organization wants to be at the end of the activity, program, or other entity for which the goal was defined.
7	Evacuation	An organized, phased, and supervised withdrawal, dispersal or removal of civilians from dangerous or potentially dangerous areas, and their reception and care in safe areas.
8	Before-Disaster	A time before a disaster hits and it lasts until a warning or alert is announced.
9	Event	An incident or situation, which occurs in a particular place during a particular interval of time.
10	DecisionMaking	A process of identifying and choosing alternatives based on the values and preferences of the decision maker.
12	EmergencyPublic Information	Information which is disseminated primarily in anticipation of an emergency or at the actual time of an emergency and in addition to providing information as such, frequently directs actions, instructs, and transmits direct orders.
13	Pre-Position	An arrangement to ensure that should an emergency occur, all those resources and services which are needed to cope with the effects can be efficiently mobilized and deployed.
14	DisasterFactor	An event, danger or occurrence of something that can contribute to the cause of disaster.
15	DisasterRisk	A potential disaster loss, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.
16	Training	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.
17	PreparednessTeam	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.
18	Media	A communication channel through which news, education, data, information or warning messages are disseminated. Media includes every broadcasting and narrowcasting medium such as newspapers, magazines, TV, radio, billboards, direct mail, telephone, fax, and internet.
20	PublicEducation	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.
21	PublicAwareness	An extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually and collectively to reduce exposure and vulnerability to hazards.
22	Resource	A personnel and major items of equipment, supplies, and facilities available or potentially available for assignment to incident operations and for which status is maintained. Resources are described by kind and type and may be used in operational support or supervisory capacities at an incident or at an Emergency Operation Centre.
23	Information Management	A processes that collect, analyze, format and transmit data and information during an incident
24	RefugeeShelter	An accommodation provided over an extended period of days, weeks or months, for individuals or families affected by an emergency
26	FoodAid	An assistance rendered on an organized basis, either free or on concessional terms, to provide food to a population group, community or country suffering from food shortage or insufficient development
27	MedicalAid	A form of aid in types of medical supplies such as medicine, emergency first aid, healthcare equipment or other emergency health supplies to help assist people who are injured and suffered after a disaster hit.
28	Monitoring	An observation, measurement and valuation of progress in order to identify change of disaster event.
29	AidAgency	An organization dedicated to distributing aid includes within government, between governments as multilateral donors or private voluntary organizations

Table II.3 Initially set of Response-phase concepts

| No	CONCEPT	DEFINITION
1	**Emergency Plan**	The guidance that an entity (State, organization, jurisdiction) maintains that describes intended response to any emergency situation during the response phase.
2	**Response Organization**	The organization of provisions of emergency services and public assistance during or immediately after a disaster in order to save lives reduces health impacts, ensure public safety and meet the basic subsistence needs of the people affected.
3	**ResponseTask**	Tasks and responsibilities that need to be accomplished by responders in emergency team within a defined period of time.
4	**Deployment**	The process and procedures used by all organizations (including Federal, State and local) for activating, assembling and transporting all resources that have been requested to respond to or support an incident.
5	**Situational Awareness**	A person's state of knowledge or mental model of the situation around the individual and/or his/her operating unit, including an understanding of the evolving state of the environment.
6	**ResponseGoal**	A description of the end state of response phase where the organization wants to be at the end of the activity, program, or other entity for which the goal was defined.
7	**Rescue**	The process of locating and recovering victims and the application of first aid and basic medical assistance as may be required.
8	**Disaster**	A situation where serious disruption of the functioning of a community or a society occurs, involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.
9	**Situation Analysis**	The process of evaluating the severity and consequences of an incident and communicating the results.
10	**Incident**	An event, accidentally or deliberately caused, which requires a response from one or more of the statutory emergency response agencies.
11	**Coordination**	A system to manage incident prioritization, critical resource allocation, communications systems integration, and information coordination which includes facilities, equipment, personnel, procedures and communications during a disaster.
12	**Command**	An act of directing, ordering, or controlling by virtue of explicit statutory, regulatory, or delegated authority.
13	**Communication**	A system of dissemination of any kinds of emergency information using a variety of means to people and organizations during disaster.
14	**Standard Operating Procedure**	A complete reference document that details the procedures for performing a single function or a number of interdependent functions.
15	**Victim**	A person adversely affected by an incident.
16	**Emergency Management Team**	The organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps.
17	**Emergency Operation Centre**	A facility, either static or mobile, from which the total operation or aspects of the emergency operation are managed.
18	**Resource**	Personnel and major items of equipment, supplies, and facilities available or potentially available for assignment to incident operations and for which status is maintained. Resources are described by kind and type and may be used in operational support or supervisory capacities at an incident or at an Emergency Operation Centre.
19.	**Aid**	Voluntary aid and assistance through the provision of services and resources between like organizations, including but not limited to fire, police, medical and health, communications, transportation, and utilities agencies.

Table II.4 Examples of the initial set of Recovery-phase concepts

| No	CONCEPT	DEFINITION
1	**RecoveryPlan**	A plan developed by a state, local or tribal jurisdiction with assistance from responding Federal agencies to restore the affected area.
2	**Recovery Organization**	The organization of restoration and improvement activities where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.
3	**RecoveryTask**	A task and responsibility that needs to be accomplished by Recovery team.
4	**Demobilization**	An emergency response stage that addresses transition of resources, and eventually the Emergency Management Team itself, from incident activities back to normal operations or to a baseline standby state as operational objectives are attained and the resources are relieved of incident responsibilities.
6	**RecoveryGoal**	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.
7	**Reconstruction**	A recovery action which begins soon after the emergency phase has ended and based on pre-existing strategies and policies that facilitate clear institutional responsibilities for recovery action and enable public participation.
8	**After-Disaster**	A time after the disaster hits and people put their lives, likelihoods and homes back to normal.
9	**Damage Assessment**	An appraisal or determination of the effects of the disaster on human, physical, economic, and natural resources.
10	**TaskReview**	A process of evaluating, assessing and analyzing all activities which have been performed by the emergency services in order to judge the performance and consistency with tasks objectives.
11	**Resilience**	An ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.
12	**Victim**	A person adversely affected by an incident.
13	**Emergency Management Team**	An organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps.
14	**Resource**	A personnel and major items of equipment, supplies, and facilities available or potentially available for assignment to incident operations and for which status is maintained. Resources are described by kind and type and may be used in operational support or supervisory capacities at an incident or at an Emergency Operation Centre.
15	**DebrisRemoval**	An important element of recovery process after any disaster which generally occurs in two phases including initial debris clearance, an activities necessary to eliminate life and safety threats and debris removal activities, as a means to recovery.
16	**Effect**	An event that can produce other effects or a noticeable consequence of a disaster.
17	**Exposure**	A people, property, systems or other elements present in hazard zones that are thereby subject to potential losses.
18	**Economic Restoration**	A response and recovery action which actively support the recovery of business, industry and economic structure.
19	**Financial Assistance**	A provincial cost-sharing program with local government and private sector claimants based on provincial legislation provided to emergency affected persons, communities or organizations to assist their recovery from an emergency
21	**AidDistribution**	A process of distributing aid in types of food, medical, accommodation and utilities which are supplied by any local and foreign agencies or government to the victims of a disaster.

V1.1. The Community Resilience Model (CRM) [58]:
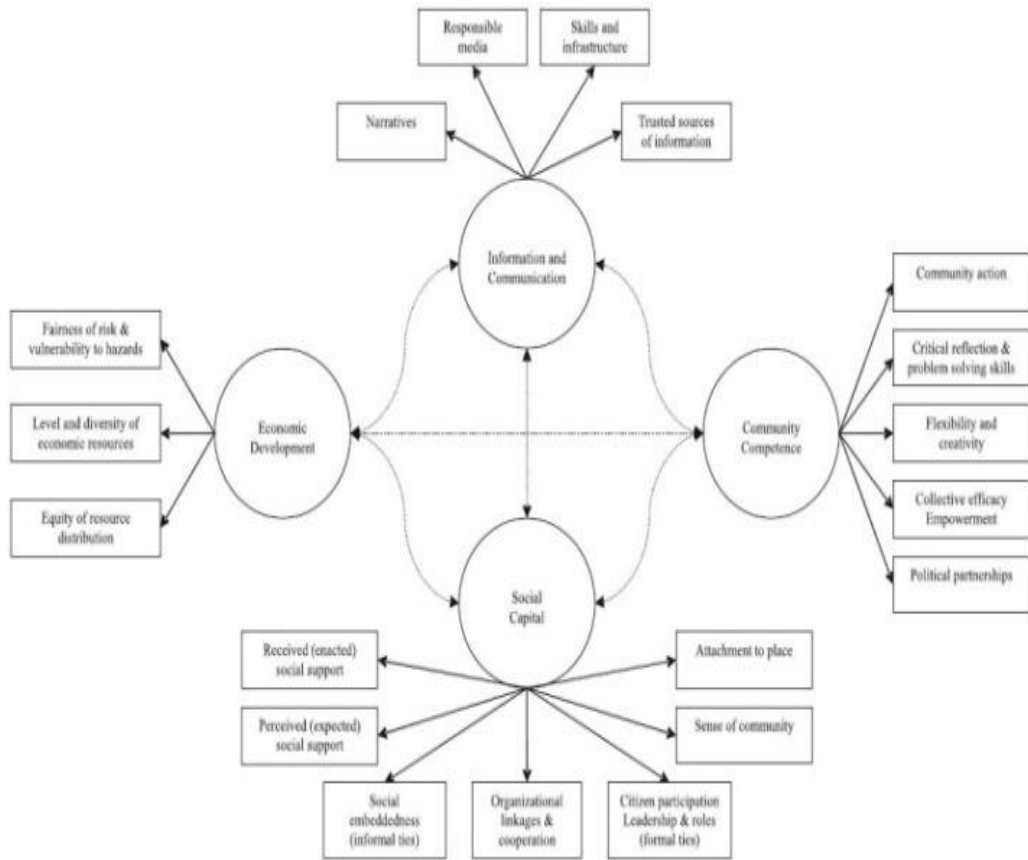
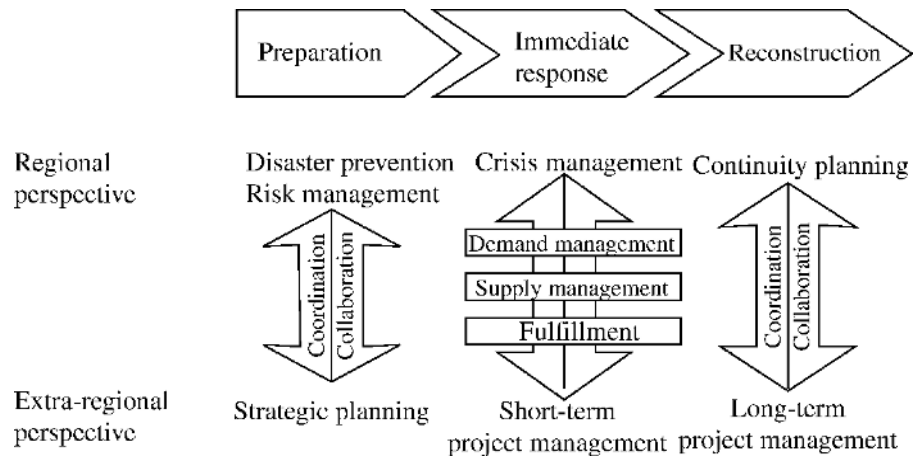V1.2. The Spatial Data Infrastructure (SDI) Conceptual Model*[59]*:
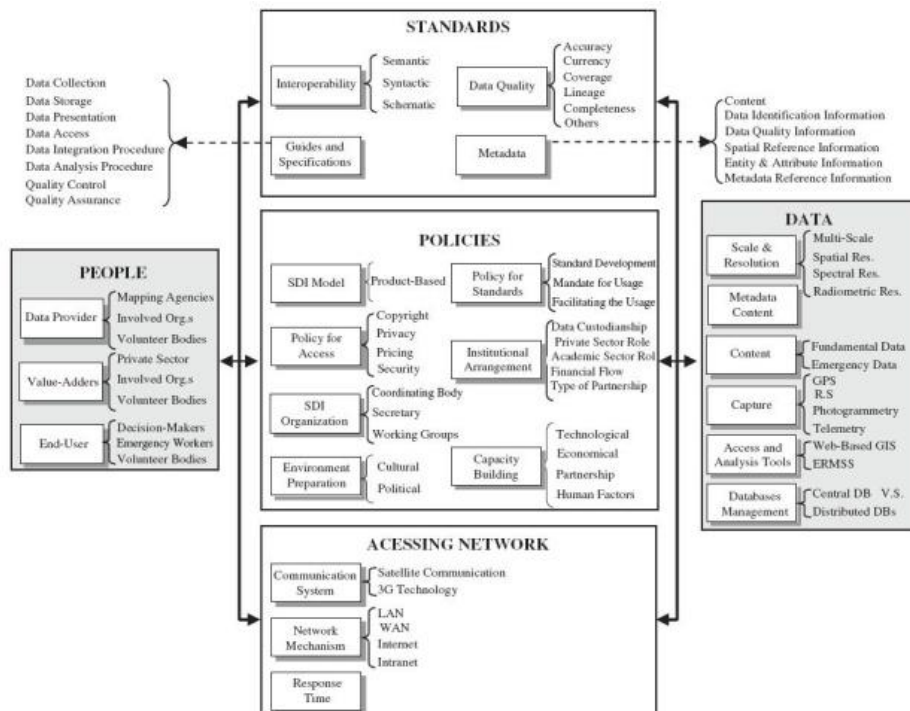
V1.3. The Framework for Modelling and Simulation for Emergency Response (iERF) [31]:
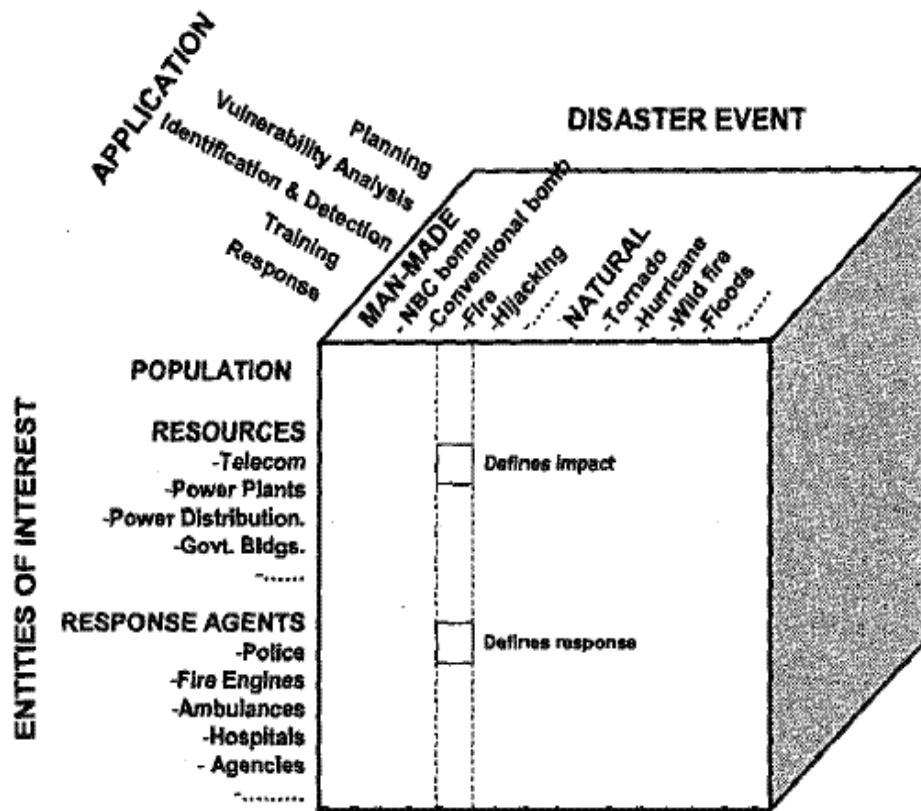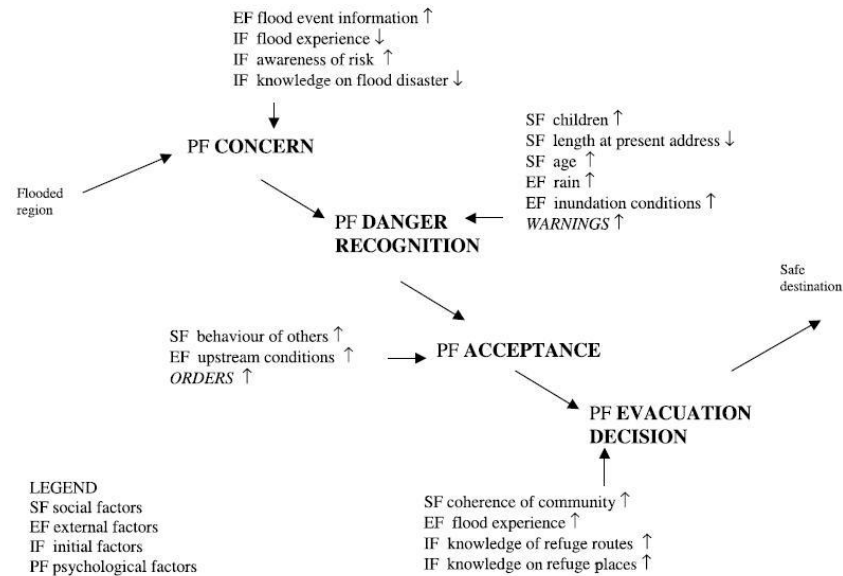

V1.4. The Strategic and Holistic Framework of Crisis and Disaster Management (SHFM) [60]:

V1.5. The Humanitarian Logistics in Disaster Relief Operation (HLDRO) *[43]*:

V1.6. Computer-Based Flood Emergency Planning (CFEP) *[42]*:

V1.7. The Disaster Operation Management (DOM) *[61]*:

Response
- Activating the emergency operations plan
- Activating the emergency operations center
- Evacuation of threatened populations
- Opening of shelters and provision of mass care
- Emergency rescue and medical care
- Fire fighting
- Urban search and rescue
- Emergency infrastructure protection and recovery of lifeline services
- Fatality management

Recovery
- Disaster debris cleanup
- Financial assistance to individuals and governments
- Rebuilding of roads and bridges and key facilities
- Sustained mass care for displaced human and animal populations
- Reburial of displaced human remains
- Full restoration of lifeline services
- Mental health and pastoral care

V1.8. The Integrated Community-based Disaster Management (ICDM) [62]:

V1.9. The Disaster Mitigation Model[63]:
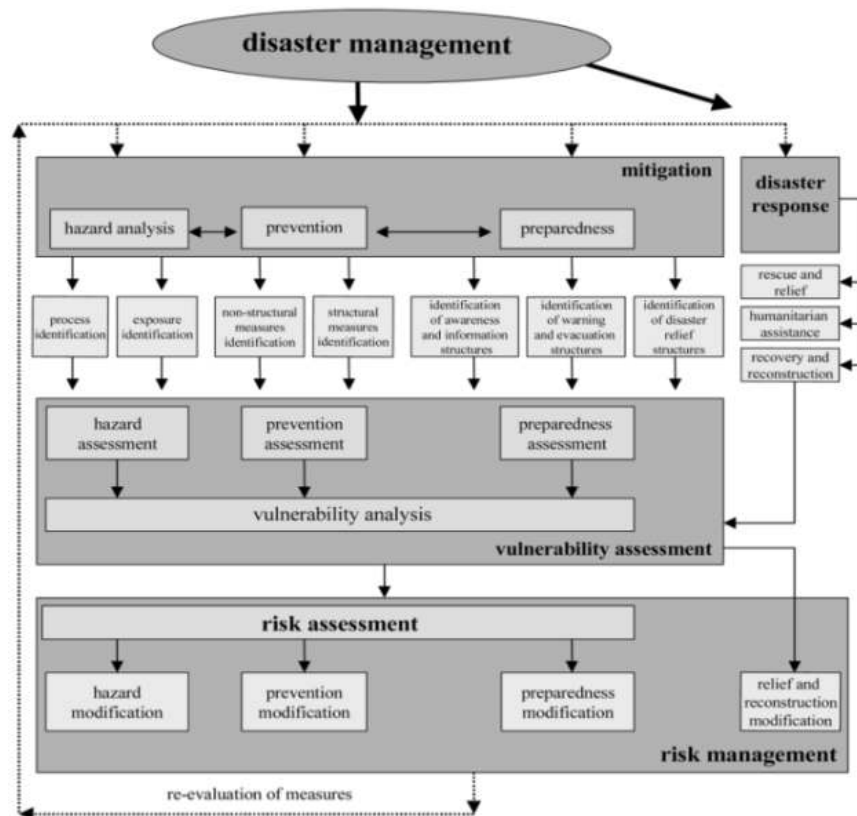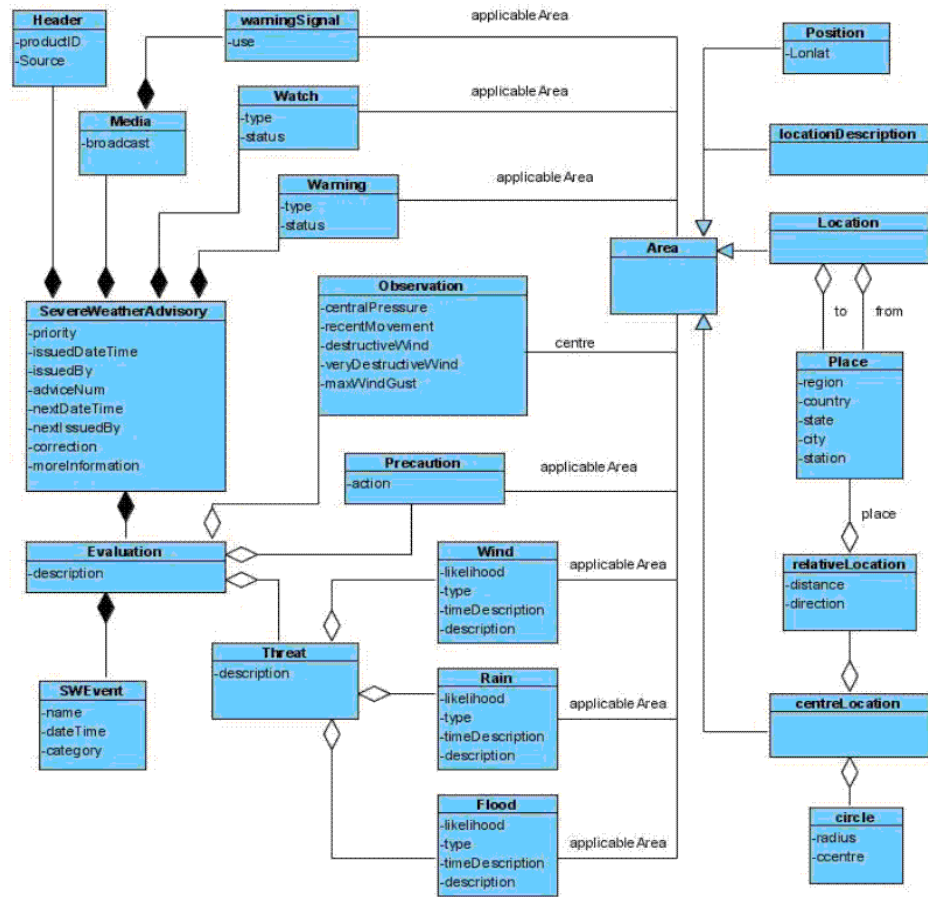
Appendix IV
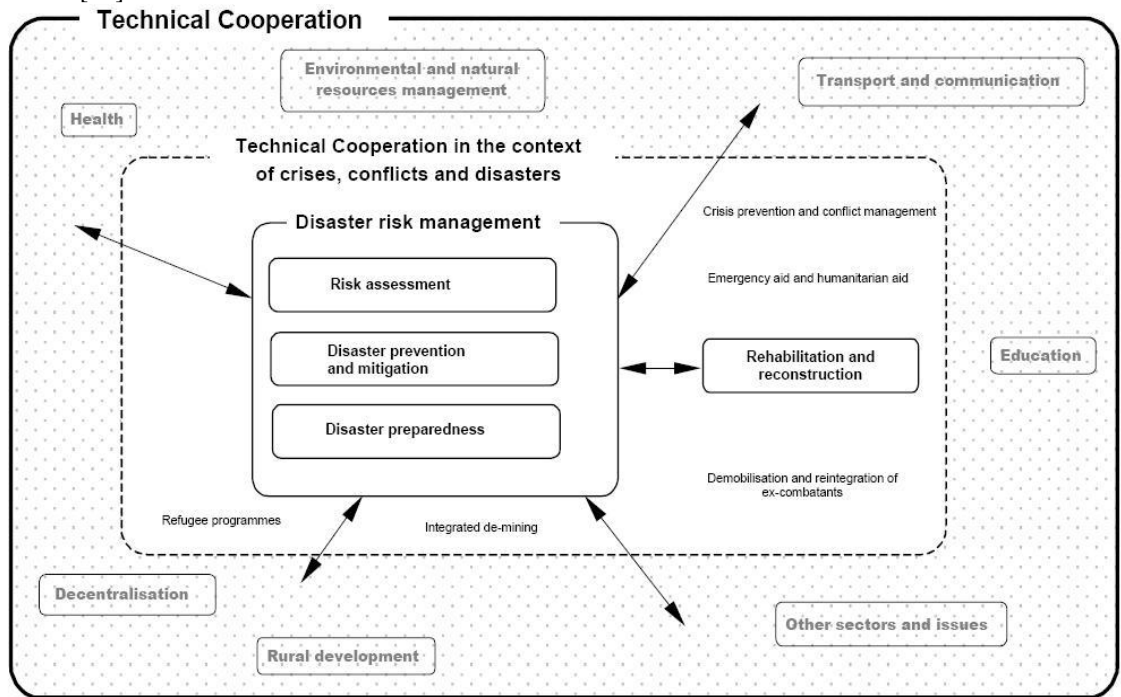# Overview of Models in Set V2

V2.1. The Traditional Model of Disaster Risk Management and Mitigation Management*[52]*:
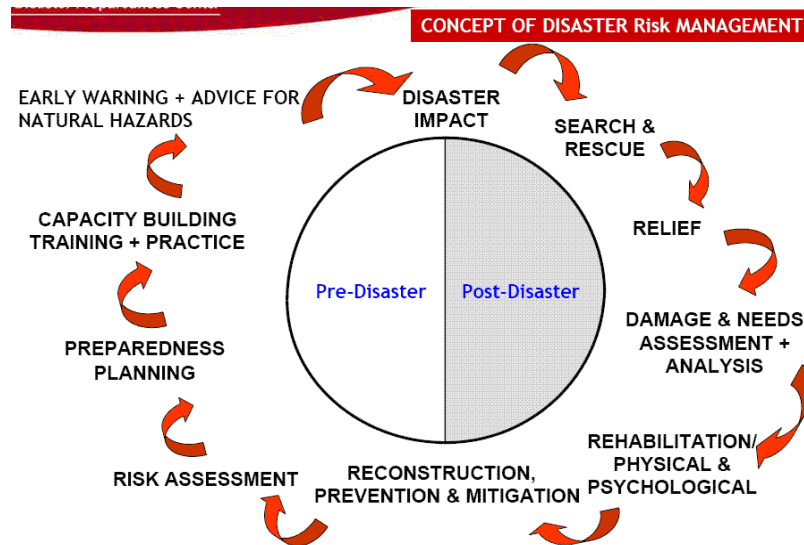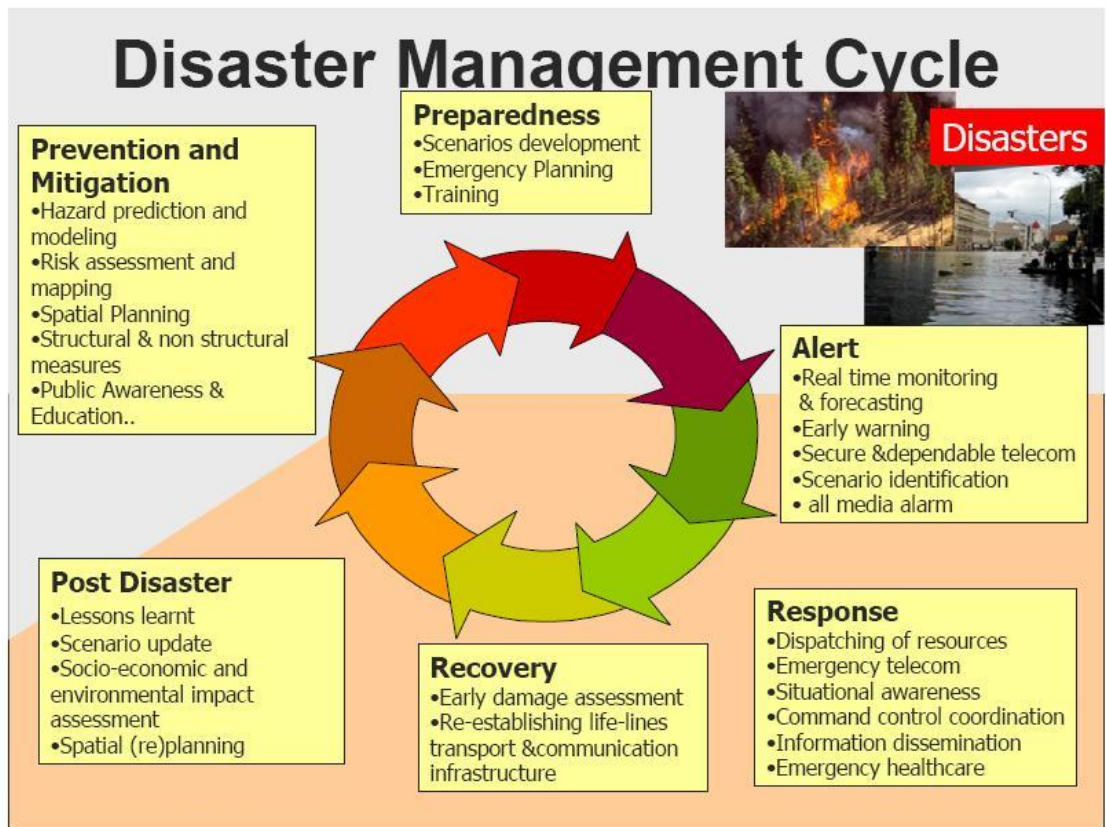
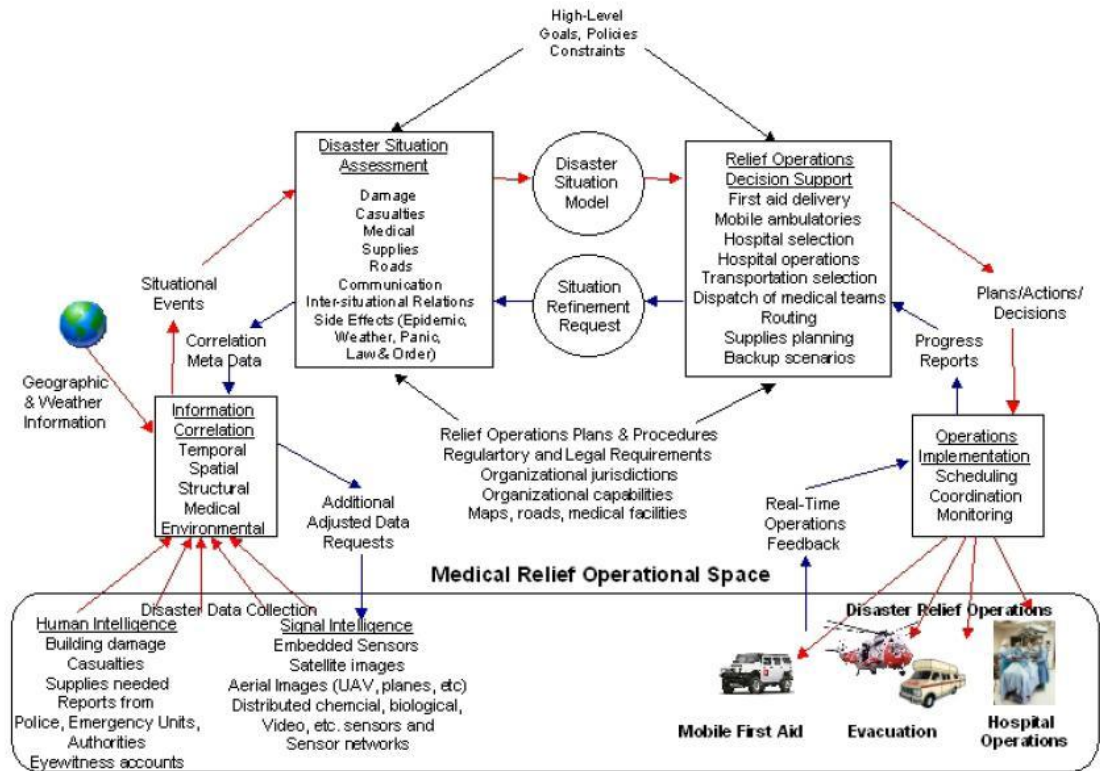

V2.2. The Damage Assessment Model (DAM) [64]:
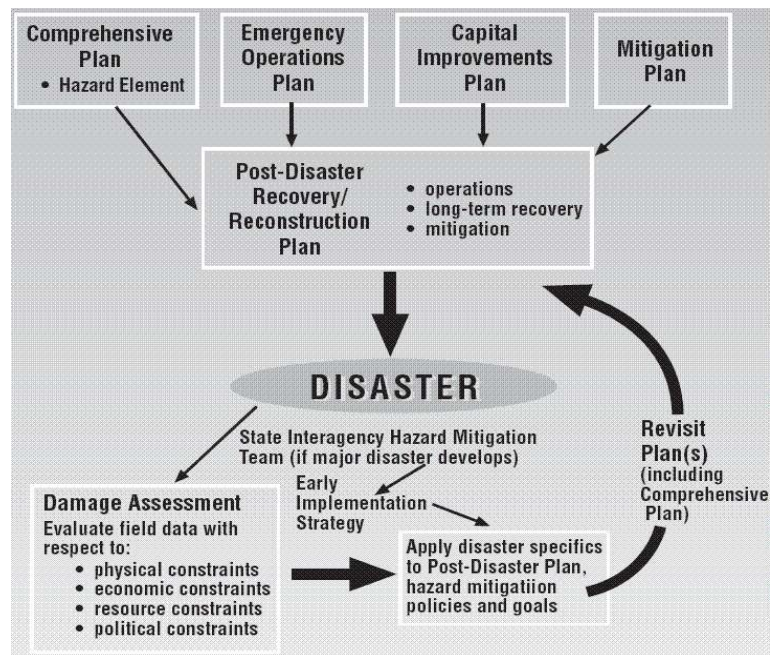
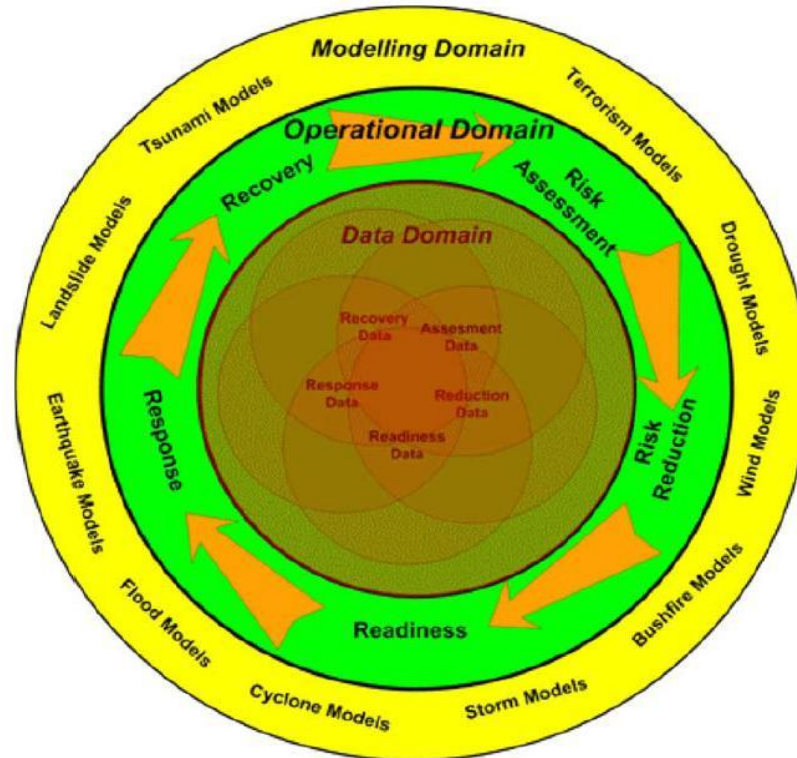V2.3. The Activity Areas in Disaster Risk Management in Technical Cooperation (TC) Context[65]:

V2.4. The Disaster Management Cycle (DMC) [66]:

V2.5. The Closed-Loop Disaster Medical Relief Operations Management using Disaster Situation Management*[67]*:
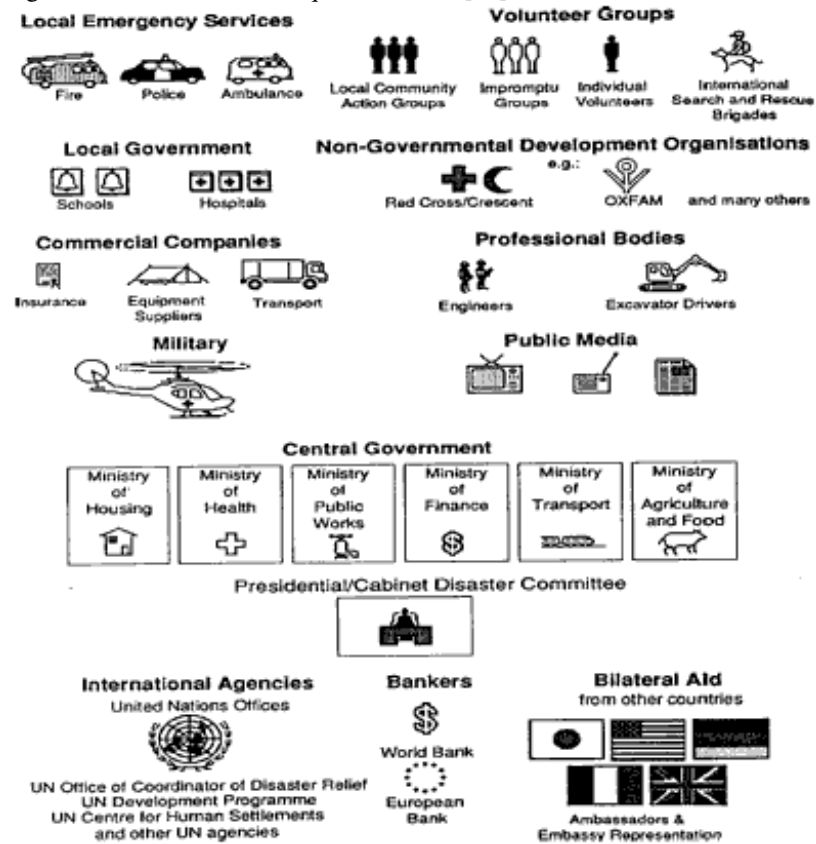

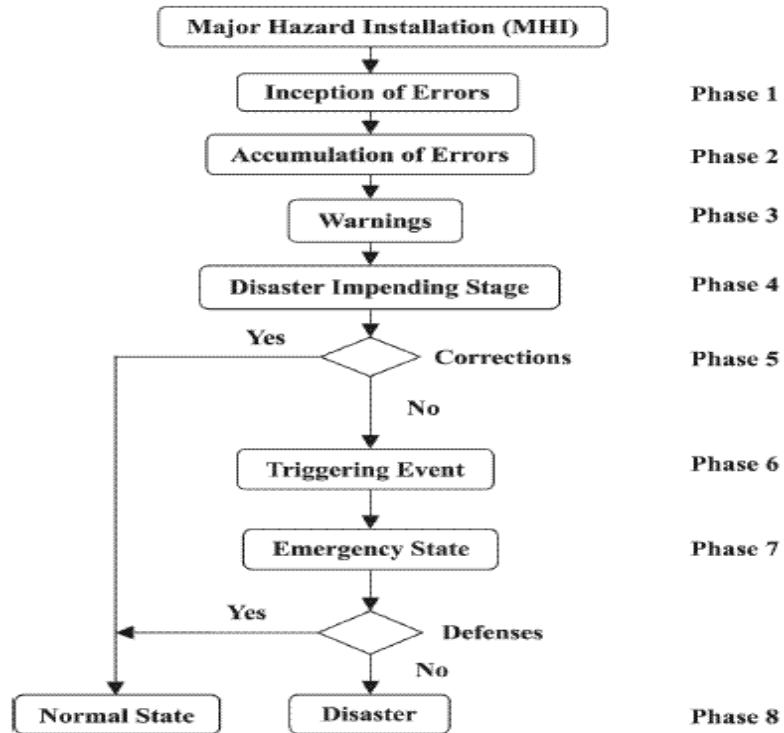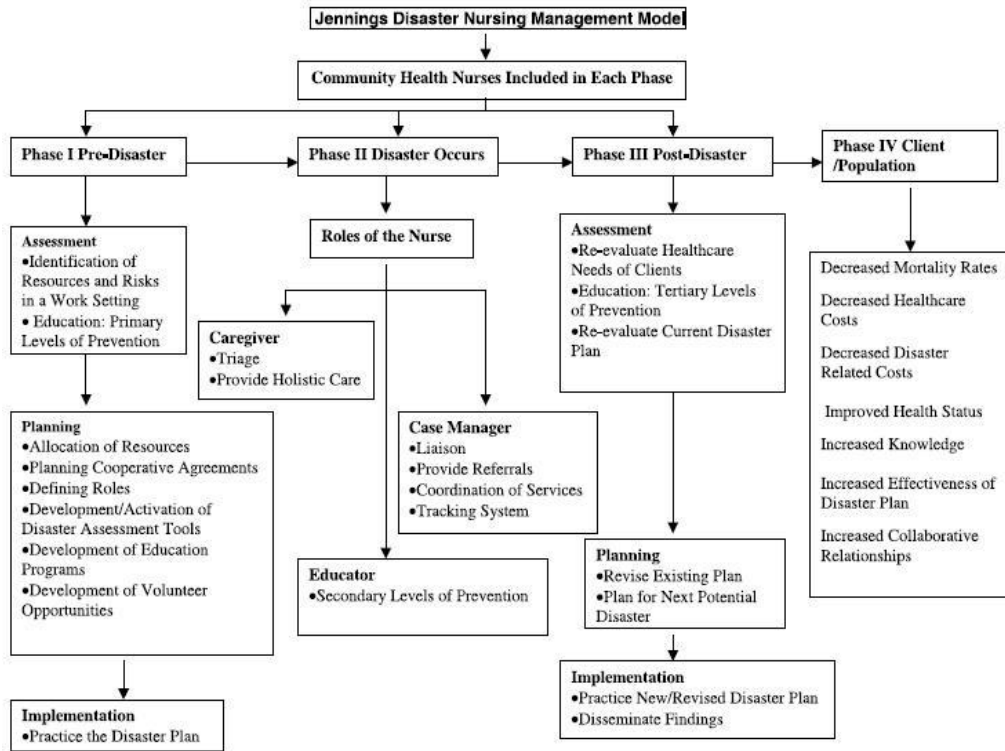V2(6). The Commonsense Knowledge Modelling Systems for Disaster Management[68]:

V2.7. The Organization Model in Earthquake Disaster[69]:

V2.8. The Technological Disaster Stages and Management (Ibrahim-Razi Model) [37]:

V2.9. The Jennings Disaster Nursing Management Model[70]:

V2.10. The Disaster Risk Management Cycle Diagram (DRMC) [71]: