A Comprehensive Conceptual Model for Disaster Management

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Existing Approaches to Disaster Management

Kelly (1998), states that, there are four main reasons why a disaster model can be useful. These are as follows:

1. A model can simplify complex events by helping to distinguish between critical elements. Its usefulness is more significant when responding to disasters with severe time constraints.
2. Comparing actual conditions with a theoretical model can lead to a better understanding of the current situation and can thus facilitate the planning process and the comprehensive completion of disaster management plans.
3. The availability of a disaster management model is an essential element in quantifying disaster events.
4. A documented disaster management model helps establish a common base of understanding for all involved. It also allows for better integration of the relief and recovery efforts.

Therefore, based on the above, it can be argued that a well defined and clear model is highly beneficial in the management of disasters because it facilitates the securing of support for disaster management efforts. Hence, disaster management needs a formal system, or a model, to manage and possibly reduce the negative consequences of a disaster.

Based on a survey of relevant literature, we have separated different disaster management models into the following main categories: logical, integrated, causes and others. Existing disaster management models fit into one of these categories, as shown in Figure 1. Logical models provide a simple definition of disaster stages and emphasise the basic events and actions which constitute a disaster. Integrated models characterise the phases of a disaster by the evolution of functions such as strategic planning and monitoring. In these models, modules are linked as events and actions. The cause category, which is not based on the idea of defining stages in a disaster, suggests some underlying causes of disasters. The last category, describes miscellaneous models.

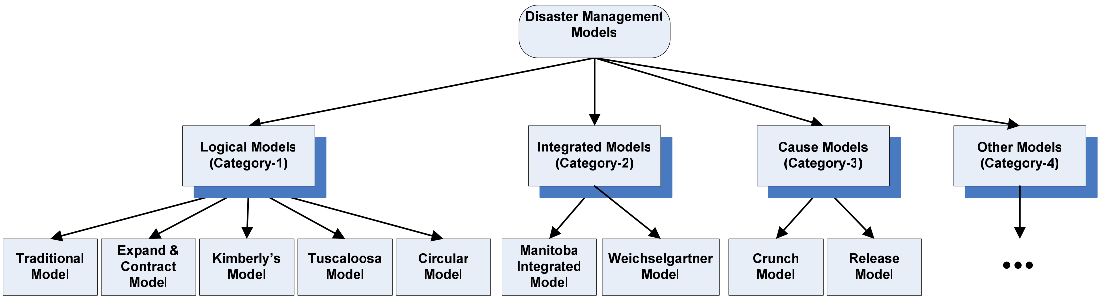

Figure 1: Categorization of Disaster Management Models

Therefore, we present various approaches studied in the past to explain the key elements of the disaster management domain as well as its operations and activities. Such approaches are discussed under the categorization highlighted in Figure 1.

The traditional process of disaster management consists of two phases (1) pre-disaster risk-reduction and (2) post-disaster recovery phase. The first consists of activities such as prevention, mitigation and preparedness while the second includes the activities of response, recovery and rehabilitation.

The important characteristic of expand and contract model is that it can be analysed as a continuous process. The different disaster management phases, rather than in a sequential manner, run parallel to each other, albeit with varying degrees of emphasis. These activities are expressed as the different strands (ADPC, 2000; Atmanand, 2003) and continue side by side, expanding or contracting as needed (DPLG-2, 1998). This model overcomes the limitations of the traditional model which is sequential in nature. This approach acknowledges that disaster management is a discipline which consists of various activities and actions that occur simultaneously

Kimberly (2003), defines mitigation, preparation, response and recovery as four phases of disaster management. This model portrays response as the biggest and most visible phase of disaster management. It places mitigation and preparation at the base, suggesting that they are both driving forces behind a successful response. The recovery phase has been placed at the top because it is what remains after the response. Moreover, it takes the largest amount of time and is the most costly. The limitation of this model is that it is very much focused on emergency management in hospitals and can not be significantly used in other applications. Since this model is restricted to hospital emergency management, its scope is limited

Tuscaloosa emergency management model (2003), which is an open-ended process. The four phases in the cycle begin and end with mitigation that is, the on-going attempt to limit the effects of a disaster

Kelly (1998), proposed the circular model for disaster management. It helps reduce the complexity of disasters and also handles the non-linear nature of disaster events. The model is more focused on practical disaster management needs than other disaster models. It lies in its ability to help in defining and elaborating the relationship between inputs and impacts rather than simply classifying disaster stages. The main characteristic of this model is its ability to learn from *actual disasters*.

An integrated disaster management model is a means of organizing related activities to ensure their effective implementation. Four main components can be identified:

1. Hazard assessment
2. Risk management
3. Mitigation
4. Preparedness.

The first task in an integrated disaster management model is hazard assessment which provides the information necessary for the next phase, risk management. This results in decisions about the balance of mitigation and preparedness actions needed to address the risks (Manitoba-Health-Disaster-Management, 2002). This model has altogether six independent elements such as a strategic plan, hazard assessment, risk management, mitigation, preparedness and monitoring and evaluation. Each element observes its own boundaries and involves its own set of activities and processes. These elements are dependent on each other in terms of providing support and can be further broken down into layers of sub-components. The advantage of this model is that it provides a balance between preparedness and flexibility in order to respond fluidly to the specific needs of disasters. Since this model provides the link between actions and events in disasters such links can be tight or loose. For example, it strongly links hazard and risk management activities but fails to provide a tight linkage between the four stages of disaster management which are important elements in a disaster management process.

The overall objectives of the Weichselgartner model (2001) are the assessment of possible damage and the planning of future actions to reduce this possible damage. It is argued that the assessment of vulnerability alone will not reduce natural hazards. Therefore, it is important that all measures taken are constantly reviewed and assessed. The model illustrates the process cycle and the integration of geographic placed-based concepts in disaster management

The crunch model provides the framework for understanding the causes of a disaster (ADPC, 2000; Bankoff, 2001; Heijmans, 2001; Cannon, 2004; Marcus, 2005). The progression of vulnerability of a community is revealed and the underlying causes that fail to satisfy the demands of the people are identified. The model then goes on to estimate the dynamic pressure and unsafe conditions

The pressure and release model (Blaikie et al., 1994; ADPC, 2000; Heijmans, 2001; Marcus, 2005) can be considered as the reverse of the crunch model. It indicates how the risk of disasters can be reduced by applying preventive and mitigation actions. It begins by addressing the underlying causes, and analysing the nature of hazards. This leads to safer conditions which help in order to prepare the community to deal disasters. The Indian Ocean tsunami and its impact on millions of people in the region demonstrates the high vulnerability of people in disaster situations when many existing predisposing factors are also in place (Blaikie et al., 2005).

Keller and Al-madhari (1996), proposed a model for the probabilistic prediction of disaster magnitude consequences and return period. As such it is particularly suitable for obtaining risk profiles.

Turner (1976), elaborated the sequence of events, which are the basis of development of a disaster. These stages are: (1) notionally normal starting points; (2) incubation period, (3) precipitation event; (4) onset; (5) rescue and salvage and (6) fully cultural readjustment.

Shrivastava (1992), proposed a model for industrial crisis through comparison of three crises: the Bhopal disaster, the Tylenol poisoning and the explosion of space shuttle challenger.

Larson and Enander (1997), proposed a theoretical two-dimensional model to investigate what people are prepared to do in the way of disaster preparedness and to examine how these assessments may lead to personal factors and attitude.

Mayers (1993), has also summarized disaster management process in four periods as follows: (i) normal operations; (ii) emergency response; (iii) interim process; and (iv) restoration.

Ibrahim-Razi et al.'s (2003b), model represents the technological disaster pre-condition stages. The model was discussed in detail by Shaluf et al. (2003), and Ibrahim et al. (2003a). The model is composed of eight phases: (1) inception of error; (2) accumulation of errors; (3) warning; (4) failure of correction; (5) disaster impending stages; (6) triggering events; (7) emergency stage and (8) disaster.

In summary, several models for disaster management have been proposed by researchers and agencies. The significance and usefulness of these different models have been discussed above, highlighting the instances and areas of applicability.

A Proposed Comprehensive Model for Disaster Management

Alexander (1997) argues that there is room for improvement in the approaches to disaster management based on the following three factors: (1) death tolls have not fallen dramatically in response to improved mitigation; (2) large-scale transfer of technology has not occurred and (3) disaster relief has not been adequately combined with mitigation and economic development. Therefore, this section proposes a comprehensive model for disaster management with improvements over existing models.

The models discussed in the previous section describe how the relationship between different phases of the disaster management process is mediated. It can be inferred from the study of these models that most revolve around the four major phases of disaster management: prevention, mitigation, response and recovery. Such models are not planned to cover all the aspects of the disaster management domain and have some limitations; for example, logical models (category-1) do not go beyond describing disaster stages and only provide conceptual frameworks for the very basic activities of a disaster. The expand-contract model of category-1 does not encapsulate hazard assessment and risk management activities. Similarly, the crunch and release model only identifies the underlying causes of a disaster and do not highlight other major activities of disaster management.

The integrated model (category-2) covers most of the activities of the disaster management domain but does not encapsulate the activities of response and recovery. In addition, it only states the top level actions of disaster management rather than providing the detailed activities involved in each phase.

In category-3, the models focus on vulnerable conditions that might affect disaster management by identifying the underlying pressure and root causes of a disaster. The discussion about conditions affecting the disaster management cycle is limited to vulnerability conditions. The models in this category do not consider conditions such as environmental factors that might change the severity of a disaster.

The analysis of the above-mentioned three categories reveals the following limitations:

- The design of most of the models revolves around the four main phases of disaster management: prevention, mitigation, response and recovery.
- There is no single model that encapsulates most of the major activities of disaster management within a single framework.
- The above-mentioned models do not consider environmental conditions that might affect the severity of a disaster. They only think of environment as another disaster category.
- Some models fail to present a comprehensive description of disaster management activities within a single model. Furthermore, the arrangement of activities (if any) is not in a logical sequence.
- The evaluation and analysis of information and data related to a current disaster are highly important and essential ingredients in the mitigation of future disasters. The existing models do not give effective consideration to evaluation and analysis.

The current models, in terms of the three different categories, lack all of the required features and functionalities that would enable them to manage a disaster in a comprehensive manner. A comprehensive disaster management model, which supports different stages and phases of a disaster management cycle, can fill in the gap which occurs in the current models. In addition, such a model should have the ability to handle complex and difficult disaster scenarios which are not addressed by the current models.

Generally, in major disasters, various resources, conditions and activities are involved; identifying and utilizing such resources, conditions and activities at a detailed level should be the goal of a disaster management model. Incorporating this level of activities and conditions affecting disasters, into existing models, would provide the basis for an effective, useful and practical disaster management model; one which would expand the attention to the full range of concerns about preparedness, mitigation, response and recovery.

Considering these limitations, and the insignificant highlighting of the conditions affecting disaster phases, we present, in Figure 2, a more comprehensive model which encapsulates all the required activities of disaster management.

The proposed comprehensive model is built upon linking the following: (1) hazard assessment and risk management activities; (2) risk management activities and disaster management actions. The distinctive feature that it takes into account is the arrangement of activities in a logical sequence. It is applicable and based on a series of easy-to-determine factors which are combined in a simple way. The result of this combination and linkage of steps is a comprehensive disaster management model. The model is simple and intelligible; no expert knowledge is needed for its comprehension. Therefore, any technological based infrastructure (such as cyberinfrastructure) can be linked to tackle disaster management problems. The model incorporates environmental conditions, which makes it possible to analyse and separate the environmental issues from a disaster.

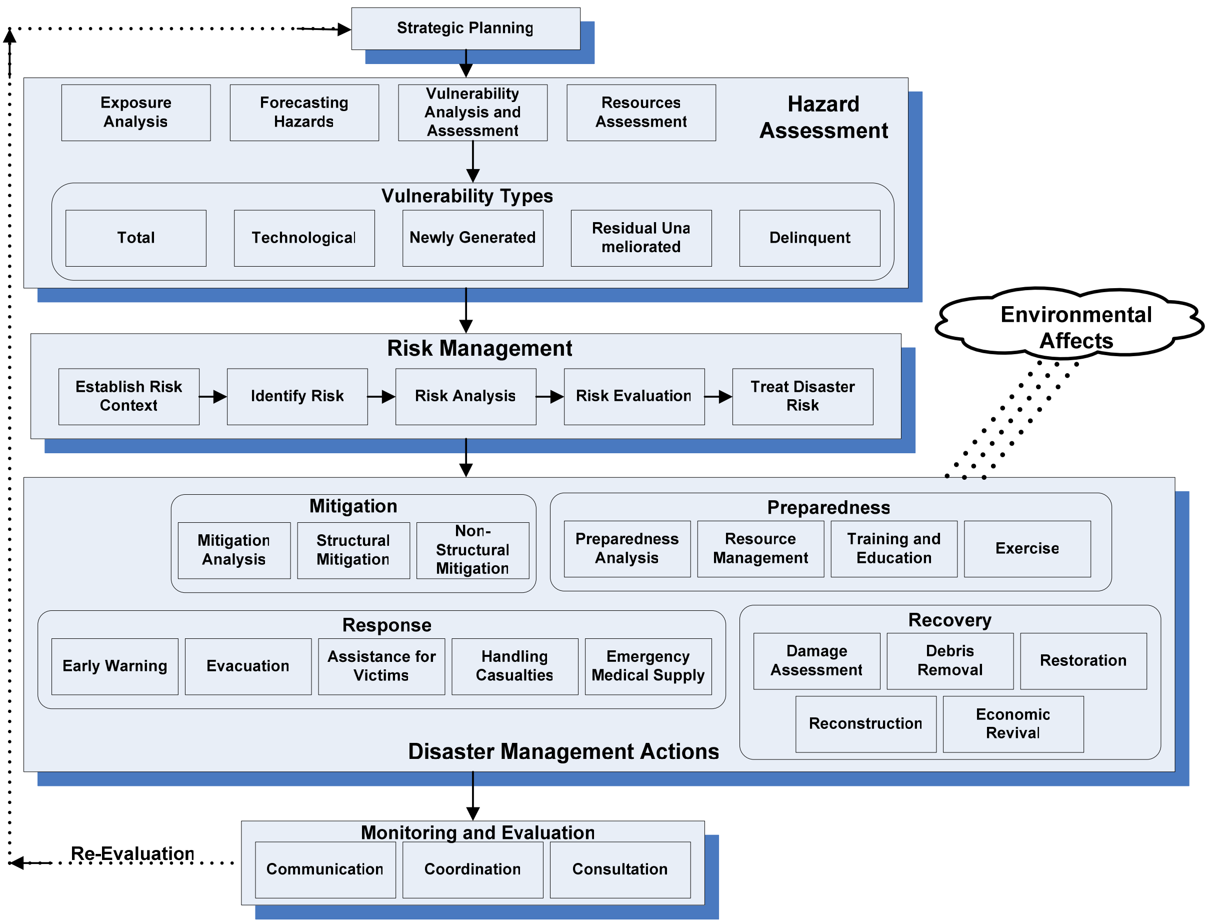

Figure 2: Proposed Comprehensive Model for Disaster Management

Earlier in this section, the limitations of existing disaster management models were highlighted. Based on these, we present the possible improvements which have been incorporated in the proposed comprehensive model (conceptual):

(1) The design of a comprehensive model does not revolve around four fundamental phases of disaster management. It has been segregated into six main components: strategic planning, hazard assessment, risk management, disaster management actions (four fundamental phases of disaster management), monitoring and evaluation and environmental effects.
(2) Within the comprehensive model these six main components are further decomposed into various activities which are required in carrying out disaster management operations.
(3) The disaster management actions are performed in a sequential manner in order to mitigate a disaster.
(4) All disaster management measures, and actions taken, are constantly reviewed and assessed within the context of varying environmental conditions.
(5) The results of, and assessments derived from the comprehensive model can be utilized as an input for a new evaluation which is obtained through the monitoring and evaluation module. Therefore, the evaluation of all measures, and feedback to the strategic planning module, is recommended.

(6) The model enables us to improve the forecasting of future events and their impacts, particularly those where the disaster management actions might be affected by changing environmental conditions (for example, climate change).
(7) The models discussed in the literature generally capture disaster management in a limited context, commonly revolving around mitigation, preparedness, response and recovery. But the proposed model extends this to include the changing effects of the environment in addition to other factors.
(8) The assessment of possible disaster events is a very important issue when mitigating disasters. This important issue is addressed with the incorporation of hazard assessment and risk management modules in the comprehensive model. The risk management module in the comprehensive model is derived from the Australia New Zealand Risk Management Standards (Salter, 1997; Standard-Australia, 1999).
(9) Alexander (1991), proposed an approach to vulnerability assessment based on simple conceptual equations. Based on that approach, overall vulnerability can be broken down into a series of components based on different aspects of the problem. Therefore, Alexander (1997), suggests five heuristic classifications of types of vulnerability based on their societal context. The comprehensive model has adopted such classifications of vulnerability and incorporated them in the hazard assessment module.

The above-mentioned improvements that have been incorporated in the comprehensive model suggest the following:

1. a large number of essential issues and activities are involved in the disaster management process
2. this results in a highly complex system.

The study of such activities and issues has raised inter-related problems associated with disaster management: The complexity and uncertain nature of the disaster management area is due to a large number of functions, features and activities.

Layered Relationship Derived from the Proposed Comprehensive Model

The analysis of the comprehensive model (Figure 2) shows that it can be observed as a two-layered framework. The first layer shows the relationship between hazard assessments and risk management, the second highlights the relationship between the risk management and the disaster management actions which are mitigation, preparedness, response and recovery. The layered relationship is shown in Figure 3.

In the literature, matrices have been used to represent different aspects of disaster management. For example, Kieft and Nur (2001), claimed that during disasters, the community's vulnerabilities are more pronounced than their capacities. To identify these, a capacity and vulnerability analysis matrix was drawn to examine various aspects.

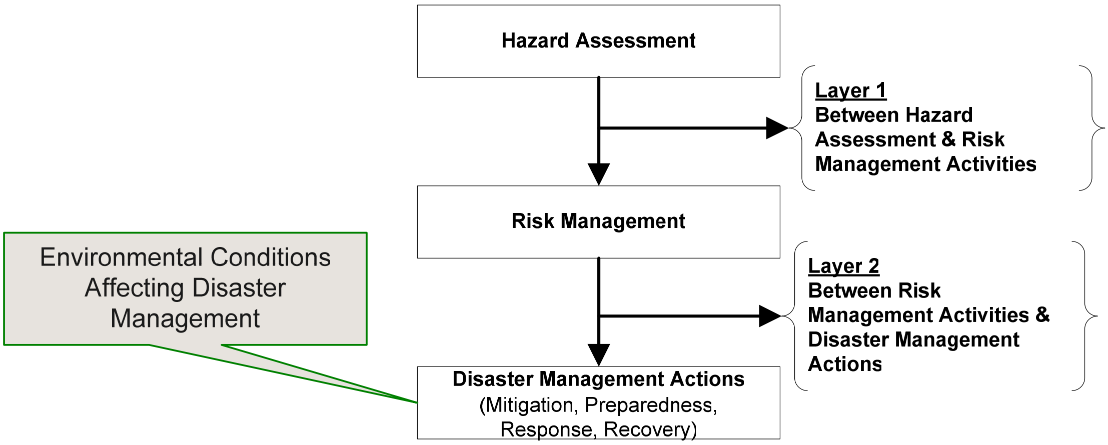

Figure 3: Layered Relationship Derived from Comprehensive Model

Yasemin and Davis (1993), also produced a matrix which gives a rough indication of which actors might participate in the five stages of a disaster recovery phase. Salter(1997), suggested that within the risk management framework, the identification and analysis of risk concentrates on the interaction between “source of risk” and “element of risk”. Therefore, Salter used a matrix approach to display such interactions within a disaster management context. Menoni (1996) also used a matrix-based approach to analyse the relationship between risk assessment and urban and regional planning. In our work we have used a similar approach where we perform an analysis of hazard assessment, risk management and disaster management actions. We have incorporated the layered relationship drawn from disaster management activities in two matrices (see Figure 4):

1. *Activity Matrix A:* Hazard Assessment and Risk Analysis
2. *Activity Matrix B:* Risk Analysis and Action (mitigation, preparedness, response and recovery)

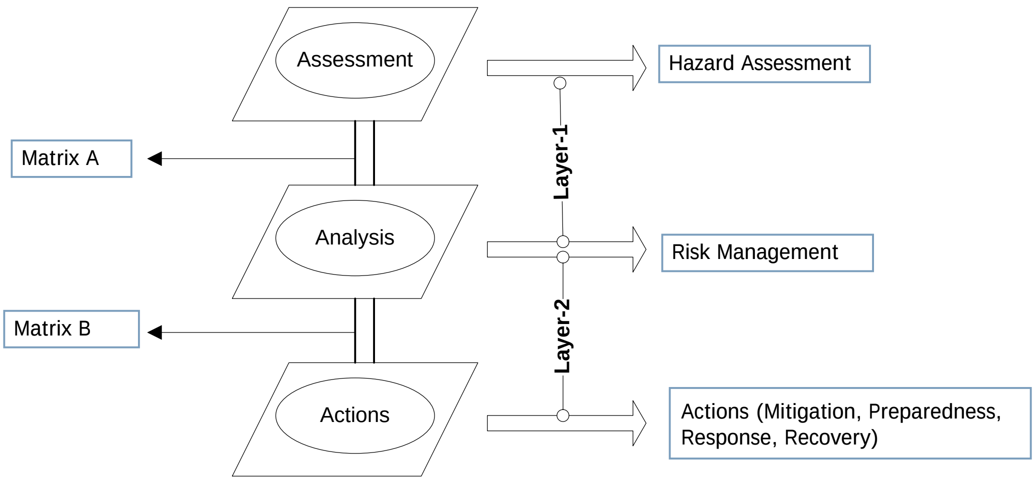

Figure 4: Layered Relationship and Matrices

The comprehensive model (Figure 2) shows that the hazard assessment phase consists of four fundamental activities: exposure analysis, hazard forecasting, vulnerability analysis, and resource assessment. Similarly, the risk management phase consists of five activities: establish risk context, identifying risk, risk analysis, risk evaluation and treat risk.

Table 1, matrix A, explains the relationship between activities of hazard assessment and risk management. *X* indicates the relationship between the activities. An analysis of matrix A indicates the following:

- *establish the risk context* is independent of *hazard forecasting* and *resource assessment* but related to *vulnerability analysis*
- the *identification* and *analysis of risk* activities may be involved in *hazard forecasting* and *vulnerability analysis* but independent while carrying out the *resource assessment* activity
- the *evaluating risk* activity is useful in *hazard forecasting* but independent of *vulnerability analysis* and *resource assessment* activities
- the *treat risk* activity of risk management can be useful while carrying out *resource assessment* activity.

Table 1: Activity Matrix A for Hazard Assessment and Risk Analysis

Risk Management → **Hazard Assessment ↓**	**Risk Context**	**Identify Risk**	**Analyse Risk**	**Evaluate Risk**	**Treat Risk**
Exposure Analysis					
Hazard Forecasting		X	X	X	
Vulnerability Analysis	X	X	X		
Resource Assessment					X

Similarly, Table 2, matrix B, establishes the relationship between risk management and disaster management action activities. The following are the implications of matrix B:

- *establish risk context* is only required in the mitigation phase of the disaster management
- *identification, analysis* and *evaluation of risk* activities are involved in mitigation and preparedness phases of the disaster management lifecycle and do not contribute in the response and recovery phases
- *treat risk* can be related to the response phase of disaster management lifecycle.

Table 2: Activity Matrix B for Risk Analysis and Actions

Risk Management → **Actions ↓**	**Risk Context**	**Identify Risk**	**Analyse Risk**	**Evaluate Risk**	**Treat Risk**
Mitigation	**X**	**X**	**X**	**X**	
Preparedness		**X**	**X**	**X**	
Response					**X**
Recovery					

Similarly, Figure 5(cube) illustrates the level of representation that can be developed to examine the following constant relationships:

- between hazard assessment and risk management
- between risk management and disaster management actions (mitigation, preparedness, response and recovery).

The values within the cells of the cube may vary from one disaster scenario to another but the process of mapping, which we have formalised, remains the same. The implication of this cube is that there is a standard relationship among events such as hazard assessment, risk management and disaster management actions.

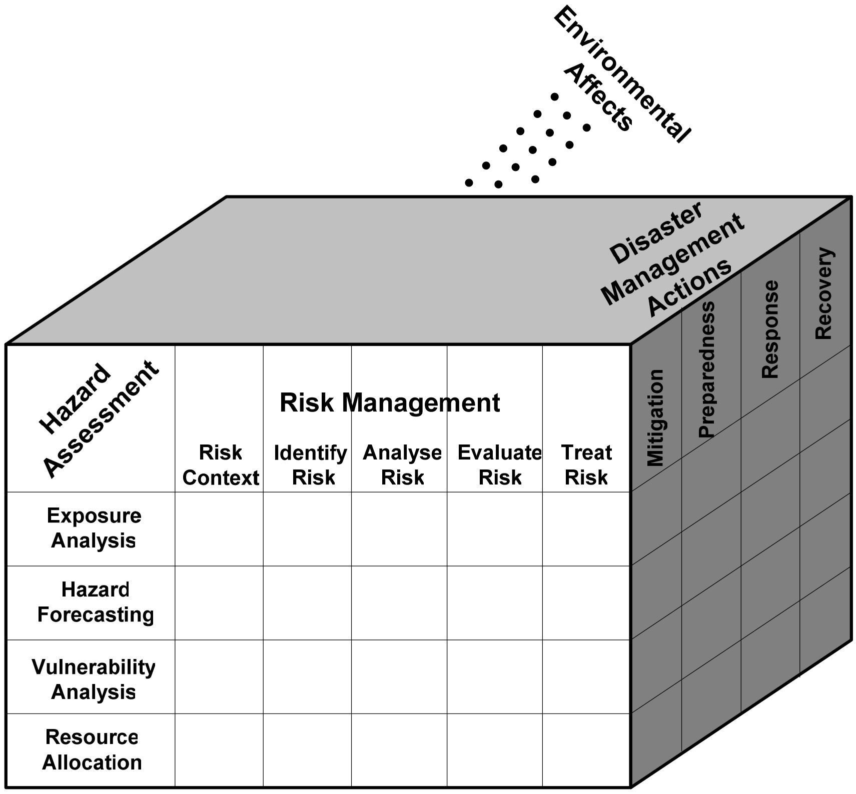

Figure 5: A Cube Representing the Relationship between Hazard Assessment, Risk Management and Disaster Management Actions

Problems Related to Disaster Management

The comprehensive model suggests that a large number of activities are involved in mitigating disasters. The involvement of this large number of activities raises the problem of complexity in disaster management. This section further elaborates on the issue of complexity that evolves from the management of such activities and highlights the characteristics of a complex environment.

The characteristics which make disaster management a complex domain are as follows:

- A large number of activities involved with varying features and functionality
- Changing environmental conditions
- Highly interdisciplinary and its changing nature
- A global perspective
- Dynamic decision support needs
- Data scattered at various sources
- The complexity of the system
- Uncertainty involved in decision-making

- A huge volume of diverse data.

Because of the diversity and above-mentioned characteristics of the disaster management domain (which can be viewed by analysing the activities elaborated in Figure 2), it is impracticable to develop an integrated disaster management system to cope with all these activities. Another important question that has received attention in the past years in disaster management is how to use the distributed data and share the distributed resources in disaster management. In disaster management, it is a well established fact that a high-level of coordination is required. The flow of information is immense, and such information must be communicated between organizations and agencies in the event of a disaster. Hence, the need arises for an integrated communication platform. According to McEntire(2002) and Auf der Heide (1989), social and behavioural research indicates that coordination is a major challenge among individuals, groups and agencies that respond to disasters. Therefore, the ability to communicate, coordinate and work effectively as a team can be a major factor in the success of any emergency plan. In response to these issues, we highlight the main problems associated with the development of disaster management systems. These are:

1. establishing techniques for dynamic monitoring of disasters
2. failure in maintaining communication links
3. the slow access to data which makes for poor updating of disaster-related information
4. difficulties in disaster-related data collection and integration
5. communication and collaboration among agencies
6. designing techniques for automated data processing from distributed sources
7. designing and developing decision support system to help emergency managers achieve effective decision-making for different disaster management activities such as mitigation, preparedness, response and relief
8. multiple models are required for decision-making
9. varying environmental affects which can significantly change the severity of a disaster.

Figure 6 shows problems associated with disaster management. As mentioned earlier, such problems arise due to the complexity involved in managing a large number of activities.

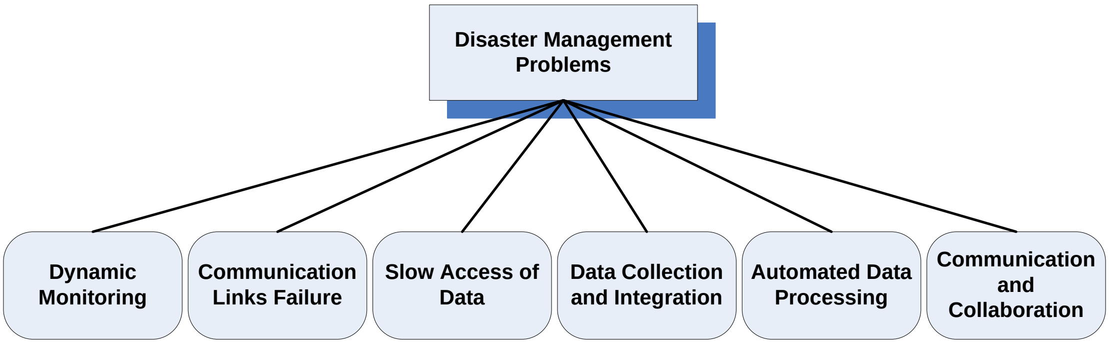

Figure 6: The overall Complexity of the Disaster Management Domain

The problems, which include dynamic monitoring, failure of communication links, slow access of data, data collection and integration, automated data processing and communication and collaboration among different agencies, can be solved with the adaptation of a cyberinfrastructure. A proposed model for cyberinfrastructure is provided in the next section.

Cyberinfrastructure as a Possible Solution

Disaster management is a challenging and complex area with dynamic needs and an adaptive nature (Schneid, 2001). Cyberinfrastructure can potentially contribute towards meeting those needs and challenges because of characteristics attributed to the disaster management area such as a global perspective, dynamic decision support needs, the complex nature and huge volume of data scattered at multiple locations. This infrastructure helps to overcome the existing problems (Figure 6). With the implementation of this infrastructure we can solve the following problems: dynamic and the global monitoring of disasters, collection and integration of scattered data, communication and collaboration, global view of environmental changes and sharing decision-making for disaster management.

It is fact that there have been, and possibly will be, more problems encountered on the way to a new information forum. Quarantelli (1997) has insightfully investigated ten issues which may be problematic with the advent of these new technologies. In response to these problems, Fischer (1998) outlined several examples of how the new information technologies are being used, as well as how they may be used in the future, in a manner which may assuage several, though not all, of Quarantelli concerns.

"Cyberinfrastructure refers to the distributed computer, information and communication technologies that provide the platform on which to build the new types of scientific and engineering knowledge environments which will enable research to be conducted in new ways and with increased efficiency" (Hunter et al., 2004). The growing use of information, data, technology and sophisticated instruments is leading to the emerging concept of cyberinfrastructure, the objective of which is to provide an integrated, high-end system of computing, data facilities, connectivity, software, services and instruments that would enable all scientists and engineers to work in new ways on advanced research issues that would not otherwise be solvable (Blatecky, 2003). The main components of a cyberinfrastructure are:

- Communicational infrastructure
- Knowledge management systems, database systems and digital libraries
- Organizational structure and agencies involved
- Services and expertise
- Softwares, collaborative tools, equipments, advanced applications, algorithms and models
- Computational, physical, technological and human resources.

The recent threats of man-made disasters such as terrorism and the current problems associated with disaster management, for instance global monitoring, communication, collaboration, and dynamic environmental changes, have reaffirmed the role of an emerging cyberinfrastructure to respond to these unexpected events and problems. The idea of the application of cyberinfrastructures to disaster management is relatively new and very limited research has been carried out in this area.

Nevertheless, it is suggested in the research community that cyberinfrastructure might be used to support the unique needs of dealing with disasters and their disruptive consequences (NSF, 2004). It is revealed that four applications of cyberinfrastructure address the needs critical to the disaster management domain:

1. Ubiquitous vision and sensing
2. Syndromic surveillance
3. Information integration, sharing and visualisation
4. Enabling the ecology of virtual organizations.

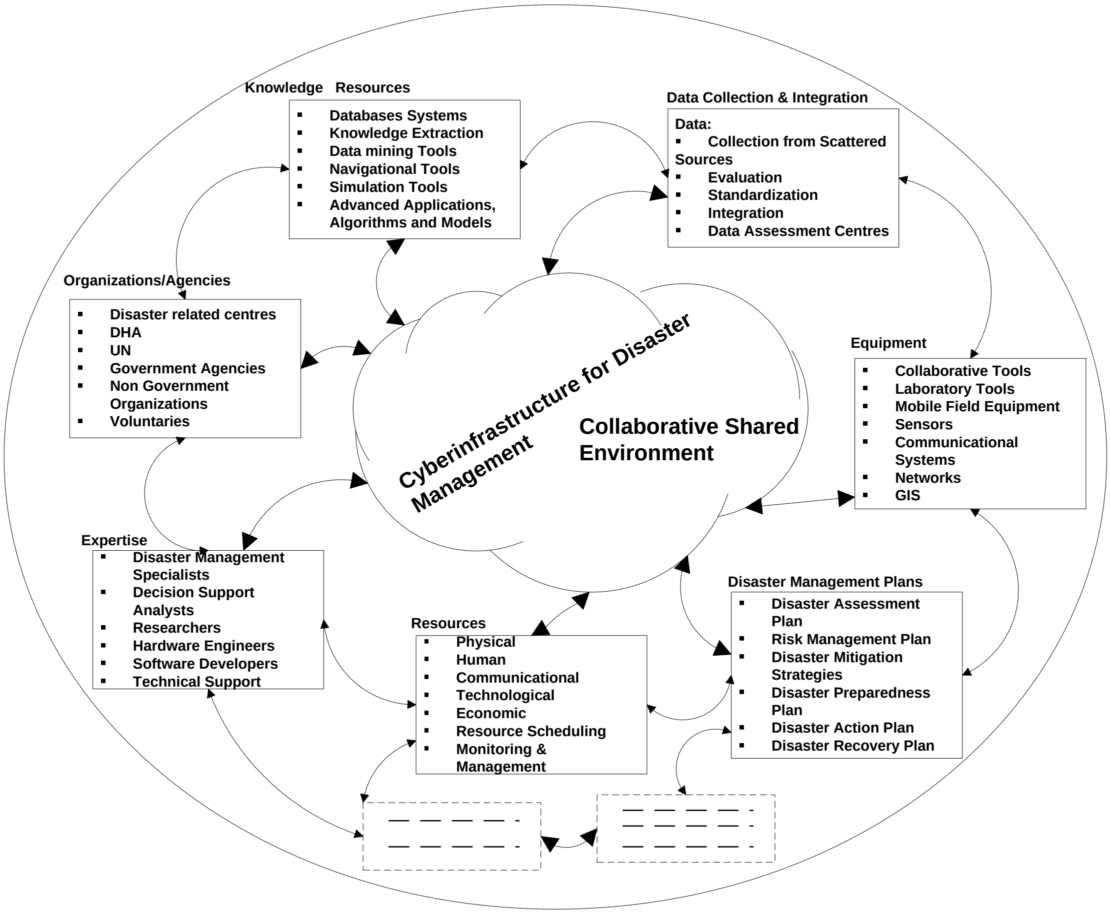

Figure 7: Cyberinfrastructure for Disaster Management

The proposed model for cyberinfrastructure is an attempt to support these application areas and to provide appropriate solutions to the current problems in the disaster management field. The model for cyberinfrastructure, (Figure 7), which focuses on the use of information sharing, integration and decision-making for agencies concerned with national security and disaster responses. It also assists the national security and disaster response agencies to develop consolidated decision-making, coordination and integrated information to adequately serve disaster needs. The cyberinfrastructure model also explains the wide variety of information sources, organizations, resources, infrastructure and tools that become available due to its existence. It is now possible to make use of these when designing systems for disaster management. Making use of such information can provide a more global picture of the situation, which will result in the better management of disasters. This is especially relevant since the outcomes of man-made disasters (for example terrorism) can in some instances have similar components to natural disasters (for example a terrorist bomb blast may lead to fire spreading into a densely populated area). Therefore, the same or similar disaster management techniques may be relevant and useful. We outline the main advantages of making use of a cyberinfrastructure for disaster management as follows:

1. It makes use of more complete, distributed information and other resources in managing traditional disasters.
2. As globalization and advancements in technology have contributed to an increase in certain disasters (especially man-made such as terrorism) the same new technology can be used to counteract these disasters.
3. Cyberinfrastructure for disaster management systems facilitates the availability of relevant data for post-disaster lesson-learned analysis and for training purposes.
4. Cyberinfrastructure fulfils the need for coordination and communication and provides efficient, reliable and secure exchange and processing of desired information and data.

The infrastructure not only bridges the gap between traditional disaster management systems and emergent disaster needs but also helps to solve the problems encountered in the management of disasters. The empty boxes, as shown in Figure 7, highlight the fact that the infrastructure is still not complete and new components can be incorporated as needed.

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