International Journal of Information Technology & Decision Making
Vol. 7, No. 1 (2008) 115–145

CATEGORIZATION OF DISASTER DECISION SUPPORT NEEDS FOR THE DEVELOPMENT OF AN INTEGRATED MODEL FOR DMDSS

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The wide variety of disasters and the large number of activities involved have resulted in the demand for separate Decision Support System (DSS) models to manage different requirements. The modular approach to model management is to provide a framework in which to focus multidisciplinary research and model integration. A broader view of our approach is to provide the flexibility to organize and adapt a tailored DSS model (or existing modular subroutines) according to the dynamic needs of a disaster. For this purpose, the existing modular subroutines of DSS models are selected and integrated to produce a dynamic integrated model focussed on a given disaster scenario. In order to facilitate the effective integration of these subroutines, it is necessary to select the appropriate modular subroutine beforehand. Therefore, subroutine selection is an important preliminary step towards model integration in developing Disaster Management Decision Support Systems (DMDSS). The ability to identify a modular subroutine for a problem is an important feature before performing model integration. Generally, decision support needs are combined, and encapsulate different requirements of decision-making in the disaster management area. Categorization of decision support needs can provide the basis for such model selection to facilitate effective and efficient decision-making in disaster management. Therefore, our focus in this paper is on developing a methodology to help identify subroutines from existing DSS models developed for disaster management on the basis of needs categorization. The problem of the formulation and execution of such modular subroutines are not addressed here. Since the focus is on the selection of the modular subroutines from the existing DMDSS models on basis of a proposed *needs classification scheme*.

Keywords: Decision support systems; disaster management systems; model selection; model management.

1. Introduction

The multidisciplinary nature and increasing complexity of the disaster management area have resulted in the increased use of Decision Support Systems (DSS). The need for decision-making in disaster management often requires a decision support system to fulfil the decision needs. Disaster Management Decision Support Systems (DMDSS) are dedicated to support decision-making in disaster management and are considered to be complex applications possibly integrating advanced computing techniques and requiring state-of-the-art research and development efforts.

The wide variety of disasters and the large number of activities have resulted in the demand for separate models to manage different requirements. Therefore, the need aroused for the specific design and development of DSS models to manage and to fulfil particular decision support. Model integration is a method that can help to address this need. It has been explored as a solution to reduce the complexity and inefficiency in dealing with several DSS models. However, with the availability of advanced DSS technologies, the advantages of such model integration have become even more important.

Literature reveals that in model integration the existing DSS models are initially decomposed into modular subroutines or modules such that each subroutine is loosely coupled and functionally independent. This has been called the modular approach to model management. Past researchers have applied this approach to solve the problem of multiple models and they have found it a promising technique for modelling complex decision support systems.

In this paper, this approach is used to provide a framework with which to use model integration for building a DMDSS. The broader view of our approach is to provide the flexibility to organize and adapt a tailored DSS model (or existing modular subroutines) according to the dynamic needs of a disaster. For this purpose, the existing modular subroutines of DSS models are selected and integrated to produce an integrated model focussed on a given disaster scenario. In order to facilitate the effective integration of these subroutines, it is necessary to select the appropriate modular subroutine, beforehand. Therefore, subroutine selection is an important preliminary step towards model integration in developing the DMDSS.

The ability to identify a modular subroutine for a problem is an important feature before model integration is performed. Therefore, this paper describes the technique used to identify suitable modular subroutines. The problem of formulation and execution of such modular subroutines is not addressed here; the focus is on the selection of subroutines from the existing DMDSS models on the basis of a proposed needs classification scheme.

The organization of this paper is as follows. Section 2 presents an overview of decision support systems. Section 3 defines a decision support system specific to disaster management (DMDSS). Section 4 identifies the problems associated in developing a DMDSS. Section 5 outlines our approach towards the development of a DMDSS and model integration. Section 6 presents an overview of modular subroutine selection. Section 7 describes the selection process. Section 8 presents the concept of decision support needs. Section 9 proposes the needs classification scheme for modular subroutine selection. Section 10 illustrates an example to support the needs classification scheme. Sections 11 and 12 describe the experimental results and conclusions, respectively.

2. Decision Support Systems: An Overview

Decision-making is one of the most fundamental tasks that a manager has to perform.[1] In disasters, bad decision-making has negative consequences. Therefore, the need for decision-making skills increases significantly in disastrous situations.[2] According to Kersten *et al.*[3] the requirements of the managers and decision-makers can be fulfilled with different types of information systems such as management information systems, database management systems and on-line analytic processing (these are a few examples of systems that provide information used in decision-making). It has been suggested that decision support systems must address some or even all of the key requirements.

Decision support systems are interactive computer based systems used to help and assist decision-makers in finding solutions to their un-structured and semi-structured decision-making problems.[4] Little[5] is one of the pioneers who started work on computer-based decision support systems and suggested that:

> *DSS are a model-based set of procedures for processing data and judgments to assist a manager in his/her decision.*

According to Bhagrava *et al.*,[6] DSS are computer systems that facilitate the user to apply analytical and scientific methods to a decision-making process. Their work is based on models and algorithms from multiple disciplines. Beulens and Nunen[7] reiterate that:

> *A DSS enables managers to use data and models related to an entity (object) of interest to solve semi-structured and un-structured problems with which they are faced.*

This view of DSS allows incorporation of data and model concepts in a DSS. This view is also supported by Emery[8] and Bell.[9] According to them:

> *Main feature of DSS rely in the model component. Formal quantitative models such as statistical, simulation, logic and optimization models are used to represent the decision model and their solutions.*

The above-mentioned study has clearly identified two important components of a decision support system as data management and model management. Sprague and Carlson[10] also categorized the technical capabilities of a DSS into the three subsystems such as Dialog Generation and Management System (DGMS), the Database Management System (DBMS) and the Model Management System (MMS).

With the advancement of computer technologies and the availability of visual programming environments the interface component (DGMS) of DSS has improved significantly. Similarly, with the advancement of database technologies the DBMS component has also been improved. However, the model management is still the area with growing emphasis, and research indicates interest in further development and research contributions in this area. According to Mentzas,[11] a typical model management system should support the following tasks: model formulation, model representation, model processing, model selection and model integration. Within the model management area, this work is focused on model selection, integration and representation.

3. A Disaster Management Decision Support System (DMDSS)

From the view point and definitions presented in the previous section, we can determine the specific characteristics required for a decision support system for disaster management. According to Geoffrion,[12] a typical decision support system must exhibit certain characteristics:

- designed to solve ill or semi-structured problems, especially where goals are not precisely defined,
- powerful and friendly user-interface,
- enable model integration and composition in a flexible manner,
- may be used to generate other alternative solutions,
- are adaptive and provide support for multi-criteria decision-making,
- enable decision-making in an interactive and complex environment or domain.

Disaster management is an area which posses these characteristics. Therefore, the need for a decision support system to manage disasters arises. Such need is also justified from the fact that a large number of people and property are affected by these disasters every year. In the last two decades, additional man-made disasters have emerged on top of existing ones, mainly due to globalization, inter-connected networks and the vast development in technology. The recent threats of these disasters have reaffirmed the urgency and importance of loss assessment and the need for decision support tools.

Decision-making is required in almost all activities of disaster management. For example, consider a typical disaster scenario in which comprehensive disaster forecasting, monitoring, data acquisition, evacuation and damage assessment activities are involved. In order to provide effective decision-making for these activities, we need to establish a decision support system.

However, due to the diversity in the disaster management domain, it becomes necessary to formulate decision support system models for each disaster category such as flood, earthquake, fire or drought or various issues and activities within a disaster; for example, evacuation planning, assessment of damages, risk assessment and predictions. A more practical alternative is to develop a decision support model which can easily adapt to different disaster scenarios. The decision support for disaster management requires focusing on many different aspects and issues; it is, therefore, a good candidate for applications area requiring an integrated model for decision support. In such applications, the need for model selection and subsequent model integration arise, dynamically.

The aim of a DMDSS is to help emergency managers carry out operations and functions, effectively, in order to make decisions in disasters. On the basis of a study of the disaster management domain, we have formulated three main functions:

I. identify the disaster events and determine their characteristics
II. use such characteristics (from I) to identify the needs for managing such needs
III. integrate existing decision-making models (based on the identified needs in (II)) for new disaster scenarios

On the basis of the above-mentioned functions, we propose the following definition of a Disaster Management Decision Support System (DMDSS):

> *As an extension of the DSS, the Disaster Management Decision Support System (DMDSS) is a computer-based system, that helps the decision-makers in the use of data and provides the model to find solutions for identification of events, decision needs, selection of modules, integrating models, and traditional disaster management problems based on a disaster scenario.*

4. Problems in Developing DMDSS

In this section, we describe the difficulties encountered in developing DMDSS and in the later sections we suggest a possible solution for the development of such systems. It is evident from the literature that a large number of DSS has been developed and in use for disaster management shown in Table 1.

Table 1. Description of DMDSS based on specific needs.

DSS Developed for DM	Description	Based on DSS Needs
A simulation model for emergency evacuation.[13]	The development of a prototype spatial DSS for use by emergency planners in developing contingency plans for evacuations from disaster areas.	Evacuation planning in response phase of disaster management.
DSS for hillside safety monitoring.[14]	Describing the development of DSS for safety monitoring of hillsides.	Monitoring.
Towards intelligent decision support systems for emergency managers: the IDA approach.[15]	The objective was to develop and verify agent based system for knowledge management and planning in emergency domain.	Suggesting a plan for every new significant event in the emergency scenario.
Web based decision support tool in order to response to strong earth-quakes.[16]	Provides a web based decision support tool "WaveLet" for expected damage and loss assessment, also identification of response measures to earthquakes.	Damage assessment and identification of effective response measures.
The Muse system.[17]	Provides environmental emergency response team with a DSS that would allow them to improve their efficiency.	To determine and put into action restoration methods in the event of a hydrocarbon spills.

Table 1. (*Continued*)

DSS Developed for DM	Description	Based on DSS Needs
Earth observation and case-based systems for flood risk management.[18]	It treats two case studies of Earth Observation data integration into geo-information system as an aid in risk management.	Flood risk management.
Design and evaluation of multi-agent systems for rescue operations.[19]	Describe the development of a multi-agent system based on RoboCup Rescue simulator to allow monitoring and decision support needed in rescue.	Searching and rescue of victims in large-scale disasters.
A study of forest fire danger prediction system in Japan.[20]	Developed a system to predict forest fire danger.	Forecasting forest fire.
Decision support system of flood disaster for property insurance.[21]	Developed a DSS of flood disaster for property insurance.	Property insurance needs in disaster recovery and rehabilitation phase.
Federal Emergency Management Information System (FEMIS).[22]	Developing a single architecture to support all phases of emergency response of disaster and enhance existing capabilities from FEMA's toolbox.	Complete DSS needs in response phase of hazards.
BEHAVE: fire behavior prediction and fuel modelling system.[23]	System developed for the prediction of fire behavior and fuel modelling.	Fire prediction.
Fire behavior-modelling concepts for fire management systems.[24]	Describe fire behavior modelling concepts.	Fire management needs.
Providing decision support for evacuation planning: a challenge in integrating technologies.[25]	Identifies and analyze the challenge issues faced in linking two technologies: simulation modelling and GIS, to design evacuation planning.	Evacuation planning.
Decision support system in oil spill cases.[26]	Proposed a DSS to assist managers to choose most suitable method for combining oil spills, according to costal area sensitivity.	DSS needs in marine coastal environments.
An integrated emergency management decision support system for hurricane emergencies.[27]	Developed a DSS for hurricane emergencies to support decision making in evacuation planning and modelling.	Evacuation planning, modelling and estimation of evacuation time for hurricane emergencies.
Regional Evacuation Modelling System (REMS).[28]	REMS help decision makers in establishing the selection of shelters and are capable of making the optimal allocation of the evacuating population to their nearest shelters.	Shelter selection and evacuation planning.

Decision Support Systems in general[29,30] and above-mentioned systems in particular, have limited scope and possess certain limitations. Therefore, a DMDSS with capabilities beyond those offered by the existing systems is required. These systems have been developed in the past by various developers and targeted to meet specific needs of disaster management. Some are designed for research purposes and others have been developed for a specific category of disaster with specified needs. However, most of the work is committed to fulfil specific needs of disaster management.

There are many other features and characteristics, apart from specific needs, associated with each of the decision support system for disaster management, such as implementation and operational issues. On the basis of the study and within the perspective of disaster management issues, we propose seven characteristics to evaluate the existing DMDSS. These are summarized in Fig. 1. Such characteristics are explained as follows:

(i) disaster phase: under which category of disaster phase the system falls (disaster phases have been discussed in the previous chapter),
(ii) the type of technology used,
(iii) is the system implemented or not,
(iv) the type of data used,
(v) is the system operational,
(vi) is the system generalized or specific to a disaster,
(vii) limitations of the system.

Figure 1 presents a number of known DMDSS analyzed according to the proposed characteristics.

Figure 1 provides the summary of evaluation of past systems based on our proposed parameters. It must be noted that this is not a complete list of the features and characteristics of developed systems. Based on the analysis of the previously developed DMDSS, we can raise the following problems associated with the existing DMDSS:

1. Table 1 and Fig. 1 illustrate that, over the past two decades, a large number of decision support systems have been produced by various developers on the basis of specific needs in specific disaster types. The problem in developing DMDSS is that a DSS developed on the basis of specific needs cannot be adapted to handle the various activities of a disaster with different characteristics. Furthermore, these systems cannot be readily modified with the changing needs of disaster management because they are developed to fulfil the specific and targeted needs of decision-making in a particular disaster.
2. The traditional DMDSS do not consider common and environmental factors across diverse disasters for effective decision-making in a new disaster situation.
3. In the disaster management domain, a large number of DSS models are available. Such models do not handle mutually exclusive problems and as such much

System	Disaster Phase	Technology	Implementation	Data Used	Operational	Generalization	Limitations
Emergency Evacuation	Response	ARC/INFO	Prototype Developed	Details Not Provided	No	Specific to Road Networks UK	Need to incorporate more route finding techniques within simulations
Hillside Safety	Pre-Disaster & Response	Fuzzy Set Theory GIS	Developed Complete System	Validated with Data	Yes	In Practice in Taiwan	Model cannot be generalized to other categories of monitoring
IDA Approach	Response	Agent-Based	Prototype Developed	Validated with Test Case	No	Yes	Personoid model need to be extended to add more models
WaveLet	Recovery	Combining Two Developed Systems	Developed Complete System	Yes	Yes	Specific to Loss Estimation of Earthquakes	Not Distributed System
Muse	Recovery & Restoration	Backward Chaining Rule-Based	Developed Complete System	Details Not Provided	Yes	Specific to Hydrocarbon Spills	Domain dependent- Only designed for hydrocarbon spill
Earth Observation	Pre-Disaster	Case-Based Approach	Developed Complete System	Optical & Radar Data Used	Yes	Too specific	Simple assumptions of causes and effects are used to quantify the flood situation
RoboCup Rescue	Recovery	Multi-Agent System	Conceptual Level	Optical & Radar Data Used	Simulation Performed	Not specific to a Particular Disaster	Effective for prototype implementation and not validated with real-time scenario
Forest Fire Danger Prediction	Pre-Disaster	Simulations	Simulation Models Implemented	Weather & Population	Yes	Specific to Fire Prediction in Japan	Simulation Model cannot be generalized to other categories of disasters
Flood Disaster Property Insurance	Post-Disaster	GIS/RS/GPS	Yes	Yes	Yes	Predicating only Insurance Claims	It covers only one aspect of recovery phase cannot generalized
FEMA's DSS	Response	GIS & RDBMS	Conceptual Level	No	No	Generalised for any Disaster Recovery	Only design is provided at abstract level
BEHAVE	Pre-Disaster	Simulations	Yes	Yes	Yes	Generalised to Fire Prediction	Model cannot be generalized to other categories of disasters
Oil Spill DSS	Post-Disaster	GIS	No	No	No	Specific to Oil Spills	Conceptual level design without implementation
Hurricane DSS	Response	Integrated	No	No	No	Specific to Hurricane	Conceptual level design without implementation
RAMFLOOD	Pre-Disaster	ANN	Yes	Yes	Yes	Specific to Floods	Only for Flood Management

Fig. 1. Evaluation of developed DSS for disasters based on proposed parameters.

overlap appears in their functionality. Table 1 shows that most of the DMDSS overlaps the functionality, for example, the simulation model for emergency evacuation, providing decision support for evacuation planning, an integrated emergency model DSS for hurricane emergencies, and regional evacuation modelling systems are all designed for the same functionality (evacuation). Such overlapping of functionality justifies the need for integrating DSS in disaster management.

4. Since one disaster may trigger another (for example, a volcanic eruption may lead to forest fires), with the requirement of diverse DSS needs, it is quite possible that a number of different models may need to be used simultaneously.
5. There can be certain situations in which user needs can be fulfilled by executing one or more subroutines or modules. Therefore, when a new situation comes along, subroutines can be reused to provide the solution for a new problem.

For example, the evacuation planning system[13] can be decomposed into modular subroutines; the decision support need in flood management "timely distribution of flood emergency information" can be fulfilled by execution of a few of the subroutine of evacuation DSS system instead of developing the complete DSS model from scratch. The existing DMDSS lacks such functionality.

5. Our Approach Towards the Development of DMDSS and Model Integration

As stated above, the decision support in disaster management involves a large number of models and therefore a decision-maker is faced with the following questions[31]:

1. If the value of a particular variable or parameter is required, is this information already available in the existing modules, possibly as the result of a previous analysis?
2. If the information is not available, are the existing DSS modules sufficient to obtain this information? What other modules are required?
3. If there are modules sufficient for this purpose, are there also alternative combinations of modules that can be used?
4. When two or more combinations can be used, what other useful information is generated?
5. Are there any modules that appear in every combination and are therefore essential to the calculation of the desired result?
6. Given certain available information, what is the set of all other information that can be obtained by applying the modules in the DSS to this information?

A possible answer to these questions, and the associated problems in existing DMDSS (discussed in Sec. 4), is model integration. Model integration is a way of creating decision models from existing ones and is a reusable approach for creating models.[32] There has been significant work done in the field of model integration and composition (summarized in Table 2).

The current work is in contrast to the existing standard model integration techniques. These techniques are conceptual and have been implemented within different domains. The work articulated in this thesis towards model integration is domain and disaster situation dependent. It demonstrates that the proposed integration technique can only be applied to integrate modular subroutines in disaster management. The benefits of the proposed integration technique are identified when applied to disaster management applications where dynamic decision-making is required.

In order to further elaborate the technique, and produce an integrated model for decision support need in disaster management, we propose the process as shown in Fig. 2. The need for this proposal arises out of the subjective nature of the disaster management domain and the wide range of contexts and disciplines involved in

Table 2. Summary of model integration and composition approaches.

Authors	Integration/Composition Approaches Used	Summary
Basu and Blanning[33]	Meta-graph	Implementation issues not addressed, integration based on specific user problems.
Blanning[34]	Relation (ER approach)	Theoretical concept, only provide a model representation in ER framework.
Jeusfeld and Bui[35]	Script-based	No implementation details and scripts are required to model every different situation.
Dolk and Kottermann[36]	Suggested MML to support integration	Survey main aspects of model integration, identified limitation of relation theory to build theory of models.
Tian *et al.*[37]	Extended structure modelling	Integration of dynamic models based on extended structured modelling paradigm is shown using examples and formal notations without implementation details.
Geoffrion[38]	Structured modelling	Model representation framework and using genus graphs for model integration.
Tsai[39]	SML	Defined schema operations for model integration.
Gagliardi and Spera[40]	Structured modelling	Defined automated procedures, which can be used to replace genera and modify definitional dependencies among models.
Muhanna and Pick[41]	Graphical	Implementation does not support model automation.
Holocher *et al.*[42]	Knowledge-based	Approach only caters for structured models.
Chari[43]	Knowledge-based	Implemented the approach and handle integrated partial solutions.
Muhanna[44]	Object-oriented	Proposed conceptual framework.

disasters; therefore, a general and traditional approach towards DSS development is not satisfactory.

In order to address the problems articulated in the previous section within the context of DMDSS and the questions posted above, we argue that a dynamic integrated model (based on a disaster scenario) for disaster management can significantly help in answering questions and providing solution. Such an integrated model is the outcome of the DMDSS development process shown in Fig. 2. To achieve a dynamic integrated model, selection of modular subroutines of existing DSS models for disaster management is suggested. Such an approach provides reusability of existing well established subroutines and also the proposed model could be used as an integrating "layer" where multiple DSS models already exist. This approach can be considered as a preliminary step before model integration. Therefore, there are

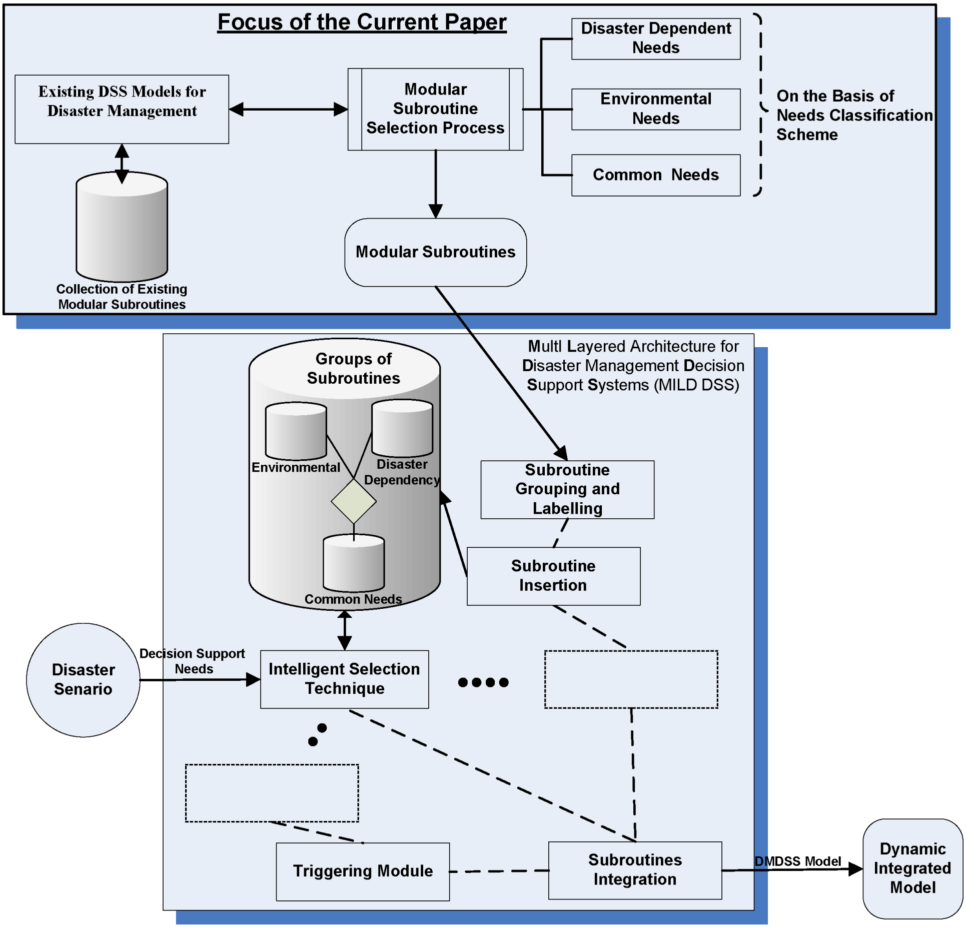

Fig. 2. Development process of a DMDSS model.

two main components of the DMDSS process:

1. Modular Subroutine Selection (focus of the current paper),
2. **M**ult**I** **L**ayered Architecture of **D**isaster Management **D**ecision **S**upport **S**ystems — MILD DSS (Beyond the scope of this paper).

As shown in Fig. 2, DMDSS development process starts with studying and analyzing existing DSS models developed for disaster management. Modular subroutines are selected from the existing DMDSS model on the basis of a proposed selection criterion (discussed in Section 9) and stored in a knowledge base which should be viewed as a collection of loosely coupled subroutines. It is designed to be adaptable and amenable to changes. In response to a new disaster scenario, MILD DSS can be accessed and used to provide the dynamic integrated DMDSS model.

6. Modular Subroutine Selection

The modular subroutine selection process tries to determine what subroutines are available for use in the development of a dynamic integrated model and automatically selects the subroutines based on a proposed needs classification scheme. We are using the term modular for the subroutines because only those subroutines will be selected which are capable of independent execution. The advantage of using this approach is that it enables the reuse of debugged and validated subroutines. To facilitate subroutine selection, we highlight and address three important issues:

1. **Organizational issue:** this addresses the question of how selected modular subroutines should be organized in order to facilitate a dynamic integrated model development. For example, should subroutines be grouped by a given criteria? In order to support this issue, the modular subroutines will be grouped in three categories: disaster-dependent, environmental and commonality of decision support needs.
2. **Selection criteria issue:** questions that need to be answered with respect to this issue relate to the identification of the criteria that play a role in subroutine selection. Is it the validation underlying the model? Is it the problem solving ability of the model? Is it the modularity of the model? We have proposed a decision support needs classification scheme for the selection of modular subroutines to deal with this issue.
3. **Storage and retrieval issue:** there are two questions related to this issue. First, how should the storage is designed to accommodate new subroutines and knowledge? A knowledge base was designed to answer this question. It contains information about the subroutines, the algorithms or equations that compute them, typical problems for which they are used, a brief description and the label. Second, what is the usage of this selection of subroutines? These subroutines are retrieved on the basis of given disaster scenario in order to achieve a dynamic integrated model for disaster management.

Previous researchers in model management have developed different model selection techniques. For example, Elam[45] was among the first to propose an approach to the model selection problem. She used entity relationship constructs to address the problem. Marsden *et al.*,[46] on the other hand suggest that model selection decisions must be viewed as a two step process:

1. determine which models are potentially useful for solving the problems in the scope of the desired DSS,
2. determine which models are cost-effective to include in the scope of the DSS.

In addition, Basu and Blanning[31] emphasize the use of metagraphs in addressing issues in the identification of relevant modules for specific problem instance and also the selection of a module while Mili and Szoke[47] developed a documentation framework for the selection of a model and the evaluation and comparison of model for a given problem.

Banerjee and Basu[48] have also performed extensive work on model type selection in an integrated DSS environment. They have proposed a classification scheme which organizes different models in four levels of abstraction: environmental, structural, instance and solver levels. They select the model to solve a particular problem, and the criterion for selection is the structure of the model.

Nevertheless, previous research on model selection has been very limited because of the complex nature of this discipline. Previous researchers have proposed different model selection schemes for identifying, selecting and structuring the important characteristics of decision models as they relate to problems. They have also argued that selection of a model depends not only on problem description but also on the resources available to solve the problem.[49] The current work contrasts with the previous work done in the field of model selection in that we focus on the problem of determining precisely what modular subroutines are useful and match with our proposed needs classification scheme.

Our proposed modular subroutine selection scheme is not related to a particular problem but it is used to select different modular subroutines from the previously developed DSS model in order to formulate different groups of subroutines in the knowledge base. In doing so, we are developing three different groups of subroutines in the knowledge base. We illustrate that our proposed needs classification scheme can be used as basis for modular subroutine selection processes. Moreover, dynamic decision support needs in a given scenario can be fulfilled with this labelled and grouped structure of modular subroutines. Finally, we are not looking for the best subroutine to solve a specific problem, but facilitating a labelling of the modular subroutine to create different groups of subroutines in the knowledge base which can then be used more widely.

7. Modular Subroutine Selection Process

Figure 3 shows the process of selecting the modular subroutines collected from the existing DMDSS models.

Figure 3 illustrates that existing DSS models are initially decomposed into modular subroutines (produced as result of modular approach to model management) such that each subroutine is loosely coupled and functionally independent. For example, DSS Model-1 is decomposed into Modular Subroutine-1.1, Modular Subroutine-1.2, Modular Subroutine-1.3, and so on. Similarly, DSS Model-2 is decomposed. The process of subroutine selection collects different subroutines from different DSS models and creates the groups of subroutines in the knowledge base.

Previously, we have emphasized that disaster management is a complex and dynamic area which involves multiple categories, or issues of disasters, that require intelligent and sophisticated decision support. The availability of large volume of scattered information, highly critical applications, and challenging preferences

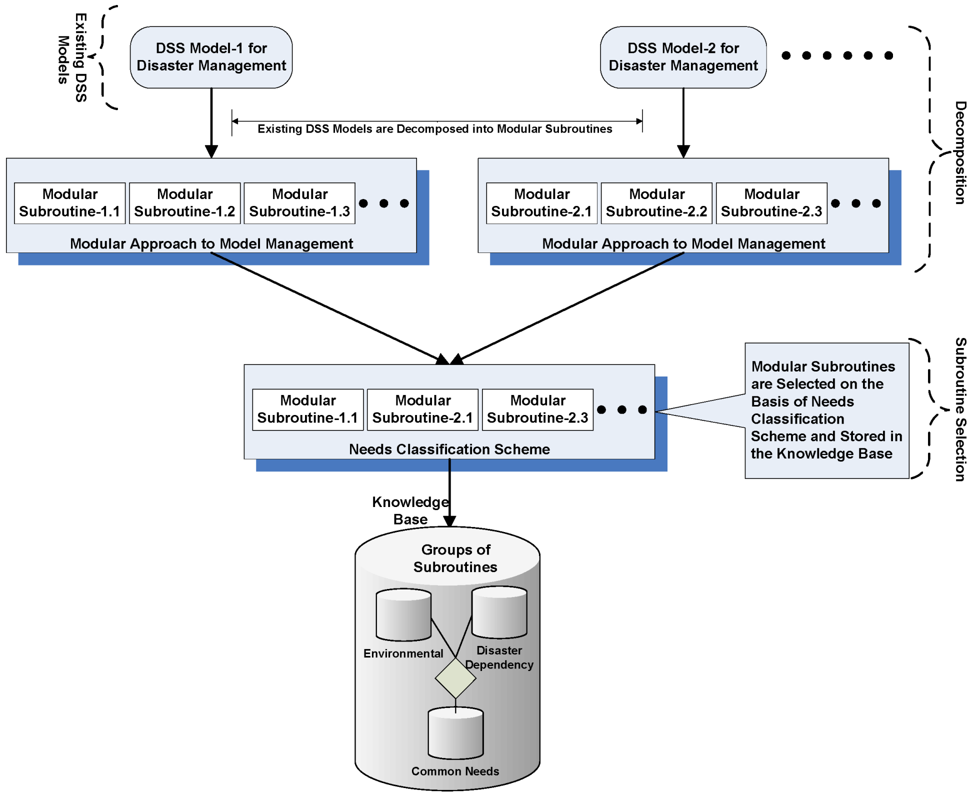

Fig. 3. Modular subroutine selection process.

hamper appropriation of a superior outcome. It is therefore desirable to develop a dynamic integrated model that deals with such challenging issues and provides an efficient means of decision-making. The design of such a system has clearly shown the most promise, and brings to bear a variety of technical and theoretical aspects such as modularity, model reusability, object-oriented approach to model decomposition and model integration. We are suggesting the selection of modular subroutines on the basis of a proposed needs classification scheme (see Sec. 9) as a possible solution in the development of an integrated DSS model for disaster management. Such an approach can be considered as a preliminary step before the formulation of a dynamic integrated model.

8. Decision Support Needs in Disaster Management

It is important to present the concept of decision support needs in the disaster management domain prior to the discussion of a needs classification scheme. This section elaborates on the decision support needs and categorises those needs into environmental, common and disaster dependent groups.

Needs assessment in disaster management is a study in which facts are collected to provide effective decision-making. The primary focus is on the identification of needs to help in decision-making. The process of decision-making in disaster management is based on identifying the decision support needs which must be understood before the process of implementing DMDSS for the following reasons:

(i) it is impractical to make effective decisions without understanding the decision support needs,
(ii) in order to obtain the modular subroutines of existing DMDSS we need to understand the decision support needs because these needs are the basis of our subroutine selection criteria.

The proper way to move towards the development of DMDSS is to define needs as decisions. Therefore, the needs become our target goals. Although needs in a disaster management area are extensive, and a complete list of needs has to be developed for a complete DSS, we only focus on the primitive and the major decision support needs. However, it is useful to show here the approach applied to derive decision support needs, as shown in Fig. 4. The process to define needs uses the following approaches:

1. Needs follow from facts and information related to the disaster management domain, therefore, they can be derived from four different sources: environmental conditions, information resources related to disasters, disaster related data and past knowledge of DSS (see Fig. 4).

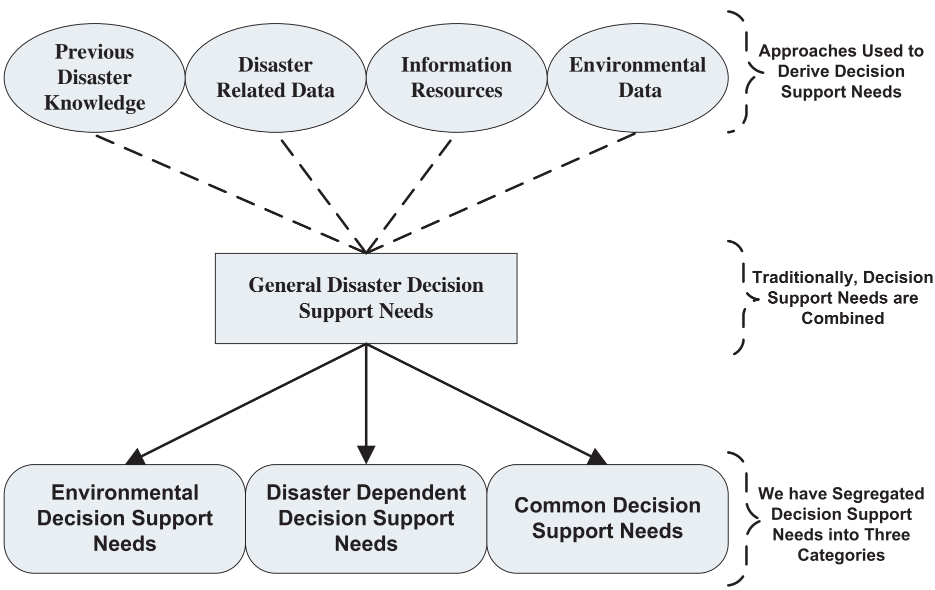

Fig. 4. Identification of decision support needs.

2. Decision support systems already developed on the basis of certain needs are used to construct decision support needs (see Table 1), the list of which is primarily based on working back from the outcomes of previous disasters.

Traditionally, decision support needs are combined, and encapsulate different requirements of decision-making in the disaster management area. In this context, we suggest three categories of decision support needs:

1. Environmental,
2. Disaster dependency, and
3. Common.

There may be a disaster situation, where a combination of these three categories arises, for example, *environmental-disaster dependent*, *environmental-common*, and *disaster dependent-common*. We are not categorizing such overlapping as a separate category; rather it is included in the above-mentioned three categories.

Therefore, based on the above-mentioned categories, we identify the decision support needs in disaster management. The major (not exhaustive) decision support needs in disaster management are categorized in Table 3.

Table 3. Categorized decision support needs in disaster management.

Environmental	Disaster Dependent	Common Needs
Vulnerability and hazard assessment under different environmental conditions	Identification of disaster events	Integration of disaster-related data
Analysis of disaster impacts according to different geographical locations	Forecasting of disasters	Communication between agencies and authorities
Needs for effective response actions and measure according to different environmental conditions	Effective selection of mitigation measures and actions	Education and training of different disaster agencies
Need of rehabilitation measures based on different environmental conditions	Support the development of disaster preparedness and mitigation plans	Collaboration between agencies and authorities
Environmental impacts assessment	Risk assessment and management	Dissemination of disaster information
	Thorough assessment of disaster monitoring	Evacuation planning
	Cost estimation based on specific disaster	Measures to rescue victims
	Analysis and evaluation of data for a specific disaster category debris removal	Calculate physical damage to a structure and infrastructure

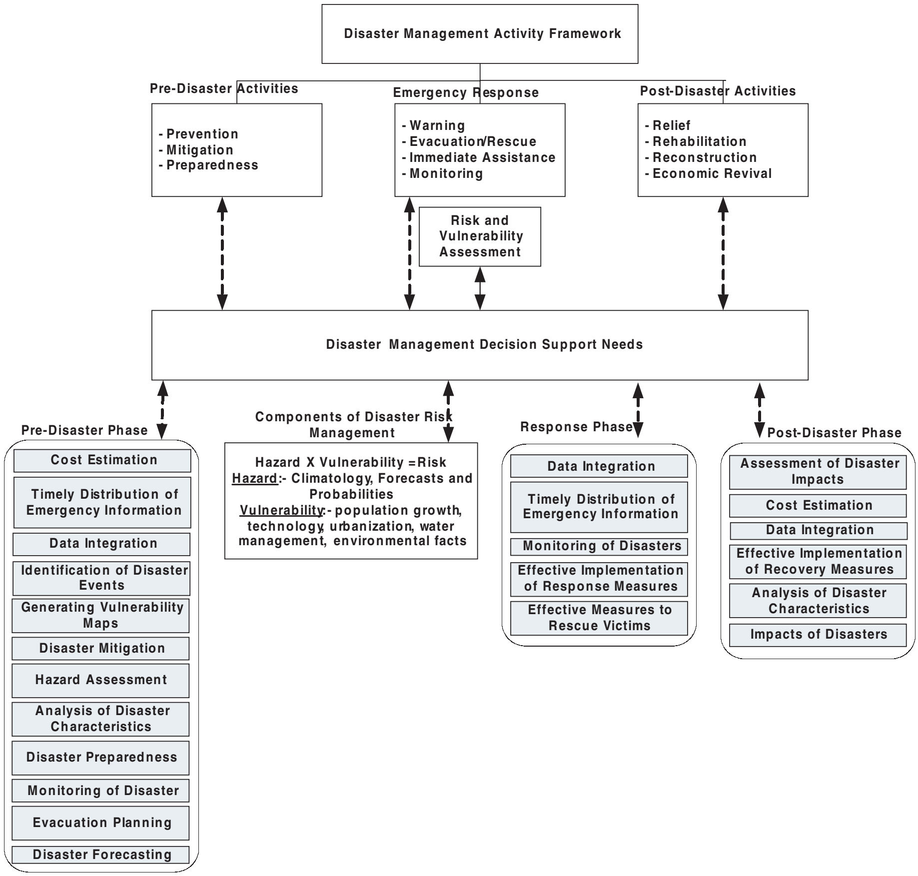

Fig. 5. Disaster management activity framework mapped to disaster management decision support needs.

To elaborate on the relationship between the needs identified with the traditional disaster management activities such as preparedness, mitigation, response and recovery, we have produced the mapping as shown in Fig. 5. The purpose is to demonstrate how decision support needs for each phase of a disaster can be grouped within the activities of disaster management. In general, disaster management activities can be categorized into three phases such as pre-disaster, emergency response and post-disaster. Each activity has its own decision support needs and requirements. In Fig. 5, we have separated the activities of disaster management into three phases and mapped decision support needs against each phase. However, this mapping has raised the important issue that certain activities are common in two or more phases. For example, the cost-estimation decision support need requires decision-making in the pre- and post-disaster phases, not during the emergency response phase. Similarly, the data integration decision support need requires decision-making in all three phases of disaster management.

To highlight the significance of the decision support needs, a scenario could be utilized. This approach allows us to derive the decision support needs from a given situation. The needs generated from various scenarios form a basis for the development of DMDSS. Moreover, scenarios for the hypothetical construction of future events are useful in elaborating decision support needs. Therefore, the following scenario can help to both derive and understand the decision support needs and how to categorize such needs.

A Disaster Scenario: Kocaeli Earthquake. Adapted from Aleskerov *et al.*[50]

The Kocaeli earthquake on 17 August 1999 and the Düzce earthquake on 12 November 1999 claimed the lives of more than 18,000 people, destroyed 16,400 buildings and caused massive disruption to the economy of Western Turkey (Erdik, 2001). The price of inadequate preparedness was the loss of thousands of lives, the displacement of thousands of people from their homes, and more than USD 20 billion.[51]

The threat of a devastating earthquake has pointed out the urgent need to develop a comprehensive disaster management system for Istanbul. Therefore, many aspects of a disaster management system needed to be finalized, such as the relocation of residential areas, structural retrofitting, administrative restructuring and supporting financial or insurance tools. Such measures require contributions from various fields of expertise and may take considerable time to draw up and implement, thus requiring long-term planning. Disaster preparedness has been stressed in countries with less-developed disaster management systems following a major disaster. The tendency within these nations is to deal with the disaster after it occurs. The decision to focus more on the pre-disaster stages is itself a fundamental change in disaster management in these contexts. One of the main issues in developing such a system is the estimation of casualties and their distribution across the territory. This is part of disaster management risk assessment. The expected number of fatalities and injuries is a function of the expected damage to buildings exposed to the earthquake. Thus, in a particular earthquake situation, the vulnerability of buildings becomes the most important variable in determining the extent of casualties. However, such estimations may be highly unreliable due to the impossibility of precisely assessing the earthquake parameters (time, place and magnitude, for instance) beforehand. The difficulty in obtaining reliable estimates is increased by incomplete knowledge of how parameters such as local soil conditions, construction type, structural systems and construction quality interact. It has been suggested in studies conducted after large-scale disasters, such as the earthquake in Gujarat, India, on 26 January 2001 that information, communication and loss estimation are of great importance in the post-disaster period.[52] Indeed, in order to respond effectively to disasters, it is necessary to have both exact and reliable information on the situation and well-trained personnel at all levels of management (from administration and search-and-rescue to technical support groups). When an earthquake strikes, it is extremely difficult to obtain immediate and reliable information due to communication problems.

Table 4. Categories decision support needs based on the Kocaeli earthquake.

Environmental	Disaster Dependent	Common Needs
Determining the extent of casualties. (It varies with the vulnerability of buildings from one location to another.)	Evaluates human losses and injuries at both the district and sub-district level of the city of Istanbul.	Effective preparedness implementation for earthquake victims.
Analysis of earthquake impacts according to different geographical locations.	Forecasting of earthquake events.	Suitable plans for relocation of residential areas.
	Evaluate the possible earthquake impacts.	Execution of effective structural and non-structural mitigation measures for earthquake.
	Cost estimation based for earthquake in Istanbul.	Earthquake risk assessment.
	Evaluates the need for temporary shelters.	Dissemination of disaster information.
		Estimation of casualties and their distribution across the territory.
		Communication between agencies and authorities.
		Education and training of different personnel at all levels of management.

During earthquake preparedness and mitigation efforts, risk assessment to estimate building damage and human casualties needs to precede other planning activities. Therefore, a DMDSS is required for this very purpose. The DMDSS evaluates human losses and injuries as well as the need for temporary shelter at both the district and sub-district levels of the city of Istanbul. It also needs to be designed to evaluate the possible earthquake impact depending on the level of damage sustained by buildings and also estimate human losses and injuries. Finally, the DMDSS should also be extended to include a model for the need for shelters.

Based on the above-mentioned scenario, we derive the decision support needs as shown in Table 4. These needs are categorized according to our proposed three categories.

9. Needs Classification Scheme

A central issue involved in the model management area is to determine the criteria for model selection. There are no general rules that apply to model selection, but we propose a needs classification scheme for modular subroutine selection within the disaster management. Our proposed scheme has the following criteria:

1. A DMDSS modular subroutine should be selected on the basis of the disaster dependent needs.
2. A DMDSS modular subroutine should be decomposed on the basis of the environmental needs.
3. A DMDSS modular subroutine should be decomposed on the basis of the commonalities among decision support needs.
4. Modifying one subroutine should not necessitate changing other subroutines.
5. Subroutines should have input and output parameters.

The basis for modular subroutine selection is the disaster decision support needs. Therefore, a modular subroutine can be selected on the basis of the three main categories of decision support needs. In order to provide support for modular subroutine selection, the following observations can be made:

- the subjective nature of the model and modular subroutines must be understood and the emphasis must be on what the model is capable of doing,
- the context in which the modular subroutine has been used must be known as well as its dependent subroutines,
- different types of information are associated with each model.

A major motivation for this classification scheme is that it perceives the model at a higher level of abstraction and progressively segregates the subroutines in three different levels. Such classification facilitates modular subroutine selection. The above framework provide a degree of flexibility to modular subroutine selection procedure because we organize the selected groups of subroutines based on the classification scheme in such a way that it establishes an efficient search procedure for later use.

There are three main tasks associated with subroutine selection: firstly, we have to decide which subroutines are disasters dependent; secondly, we must make the decision to separately identify environment depended subroutines and finally, we must determine which subroutines are based on commonality of decision support needs. As shown in Fig. 6, we can highlight that, with the proposed needs classification scheme, a DMDSS model is decomposed into subroutines A, B and C.

Initially, in traditional decision support systems, the traditional, environmental and common needs are combined. By separating these needs, as shown in Fig. 6, we are trying to segregate traditional, environmental and common needs. The needs classification scheme has several advantages:

- The needs classification scheme makes it easier to organize groups of subroutines in the knowledge base. This would help in establishing an efficient search procedure to develop an integrated model.
- The needs classification scheme is a convenient and comprehensive means for representing modular subroutines. For example, a needs classification scheme

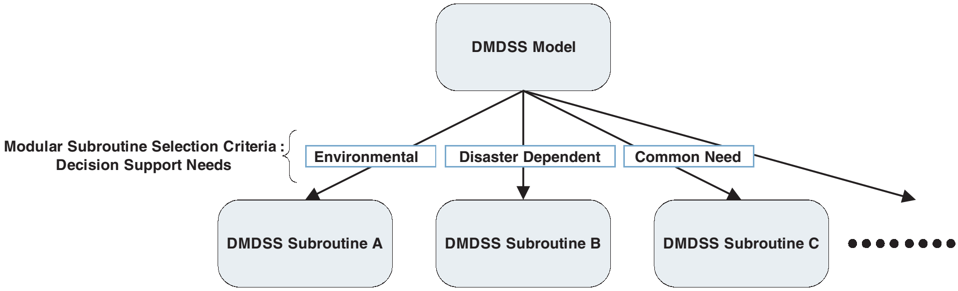

Fig. 6. Needs classification scheme.

may not be available for a given subroutine; in such circumstances, we assume it at be an overlap category such as environment-common.

- The need classification scheme provides a uniform semantics of labelling and categorizing a wide variety of modular subroutines in disaster management.
- Another advantage of the needs classification scheme is that it analyses the characteristics and the parameters of modular subroutines and identifies its category in order to store it in the relevant group in the knowledge base.

10. An Example Application

An example application that demonstrates the use of selection of modular subroutines in DMDSS is presented in this section. This example considers the organization of three different DMDSS models; other scenarios can also be generated.[53] The primary purpose of the example is to illustrate the major idea in our modular subroutine selection approach; consequently, we have not included the entire DMDSS model in Fig. 7. It is restricted to three main DMDSS models: Epidemic-type Aftershock Sequence (ETAS)[54]; Fire Spreading Simulation[55] and Post-Disaster (Earthquake) Transportation System.[56] The reason for placing such a limitation is to illustrate the classification scheme without the loss of generality of the framework. The complete description and labelling of these models (modular subroutines) are presented in Table 5.

We illustrate the salient feature of this needs classification scheme with reference to Fig. 7. The three DMDSS models Epidemic-type Aftershock Sequence (ETAS) — Model 1, Fire Spreading Simulation — Model 2 and Post-Disaster (Earthquake) Transportation System — Model 3, have initially decomposed into modular subroutines as shown in Fig. 7. Initially, all the modular subroutines are labelled CDE (C = Common, D = Disaster Dependent and E = Environmental). This indicates that this labelling occurs prior to the needs classification scheme.

One of the distinguishing criteria of the needs classification scheme is the selection of the modular subroutines on the basis of commonality of decision support needs. The common need is the criteria which works best for cases where decision

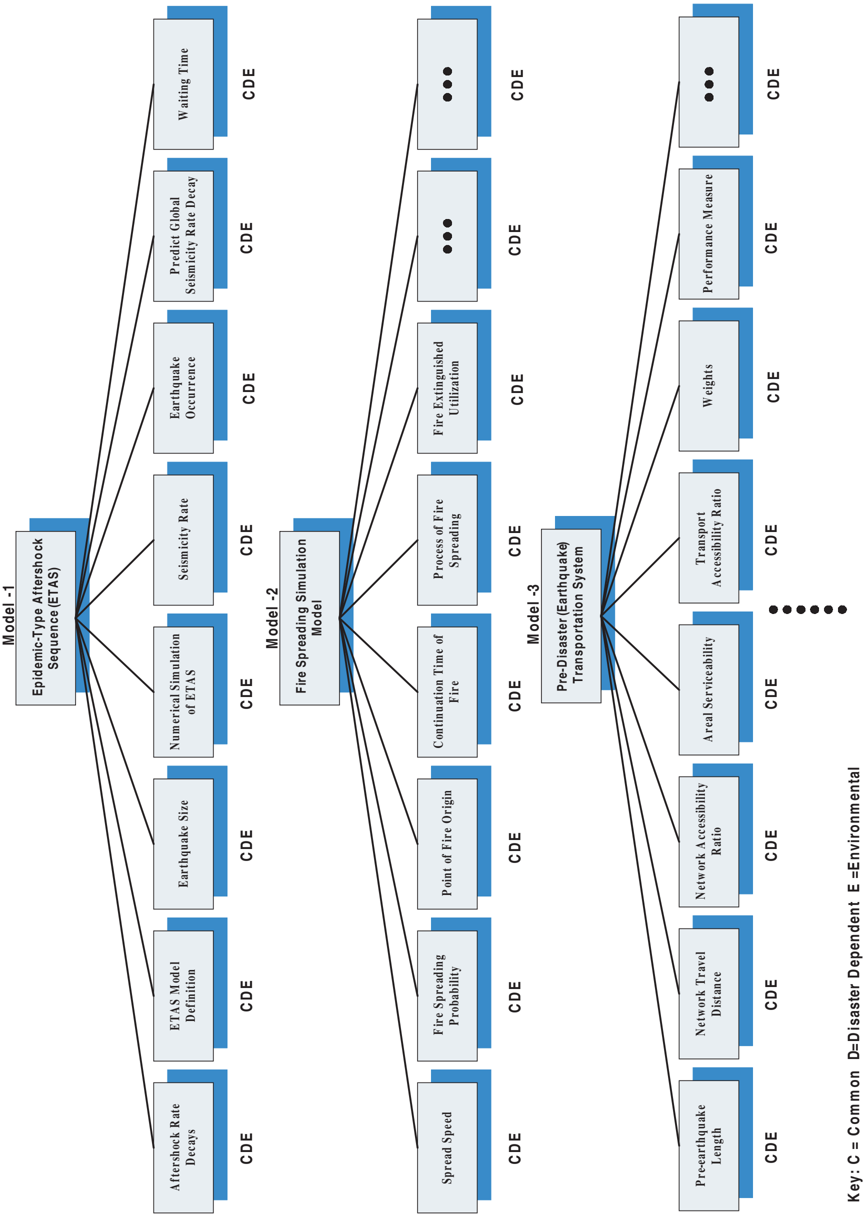

Fig. 7. Existing decomposed modular subroutine of DMDSS models.

Table 5. Description and labelling of the modular subroutines.

Models	Subroutine Name	Subroutine	Labelling
Epidemic-type aftershock sequence (ETAS)	Aftershock rate decays	$t^* = c\left(\frac{n\Gamma(1-\theta)}{\|1-n\|}\right)^{1/\theta}$	Common
	ETAS model definition	$\phi_{m_i}(t-t_i, \vec{r}-\vec{r}_i) = \rho(m_i)\Psi(t-t_i)\Phi(\vec{r}-\vec{r}_i)$	Disaster dependent
	Earthquake size	$P(m) = b\ln(10)10^{-b(m-m_0)}$	Environment
	Numerical simulation of ETAS	$\lambda(t) = \sum_{t_i \leq t} K10^{\alpha(m_i-m_0)} \frac{\theta c^\theta}{(t-t_i+c)^{1+\theta}}$	Disaster dependent
	Seismicity rate	$N_m(t,\vec{r}) = S(t,\vec{r},m) + \int d\vec{r}' \int_{m_0}^{\infty} dm' \times \int_0^t d\tau \phi_{m' \to m}(t-\tau, \vec{r}-\vec{r}')N_{m'}(\tau, \vec{r}')$	Common
	Earthquake occurrence	$S(t,\vec{r},m) = \delta(t)\delta(m-M)\delta(\vec{r})$	Environment
	Predict global seismicity rate decay	$N(t,\vec{r}) = \frac{c'^{-\theta}}{2Dt^{1-(\theta/2)}} \sum_{k=0}^{\infty} \frac{(-1)^k z^k}{k!\Gamma[(1-k)\theta/2]}$	Common
	Waiting time	$\Psi(t) = \lambda e^{-\lambda t}$	Common
Fire spreading simulation	Spread speed	$D = 1.15(5+0.5\nu)$	Common
	Fire spreading probability	$F_{ij} = \alpha \cdot (S_{ij} \cdot P_{ij}) \cdot W_{ij}^B \cdot p(t_{ckl})$	Environment
	Point of fire origin	$t_x = (3+3a/8+8d/D)/(1+0.1\nu)$	Disaster dependent
	Continuation time of fire	$t_y = (w/5.5)/(A_w\sqrt{H}/A_f)$	Disaster dependent
	Process of fire spreading	If $n_{ij}(t) = 1$ and $F_{ij} > ran$ then $n_{ij}(t+1) = 2$	Environment
	Fire extinguished utilization	$C_B = \{V_w/(C_w \cdot t_f)\} \cdot R_w$	Common
Post-disaster (Earthquake) transportation system	Pre-earthquake length	$L(t) = \frac{x(t)}{\bar{x}}$	Environment
	Network travel distance	$D(t) = \frac{f-A(t)}{f-1}$	Disaster dependent
	Network accessibility ratio	$A(t) = \frac{\sum_i \sum_j d_i j(t)}{\sum_i \sum_j \bar{d}_{i,j}}$	Common
	Areal serviceability	$D_s(t) = \frac{f-A_s(t)}{f-1}$	Environment
	Transport accessibility ratio	$A_s(t) \frac{1}{n_s} \sum_{i \in N_i} A_i(t)$	Environment
	Weights	$w_{ij} \frac{1}{n_r - \delta_r} \cdot \frac{\nu_{sr}}{\sum_p \nu_{sp}}$	Environment
	Performance measure	$Z' = Z + r_j \cdot (\bar{Z} - Z)$	Common

support needs are common for a given new disaster scenario. The modular subroutines selected from all three models of Fig. 7 are shown in part A, of Fig. 8.

As Fig. 8 illustrates, the modular subroutine "Spread Speed", fulfils the decision support needs to show the appearance of fire spreading. It can be used in the development of another DMDSS because it serves the common needs. It is labelled as C2.5, which indicates common subroutine 5 of model 2.

Suppose the user is interested in solving a transportation problem in a post-disaster earthquake scenario, and the decision support need is to calculate the transport accessibility ration. The nature of this decision support need indicates that this ratio may vary from one location to another; therefore, this subroutine has been placed in the environmental level of the needs classification scheme which is shown in the part B of Fig. 8.

The last criterion of modular subroutine selection of the classification scheme is based on disaster dependent needs. Some subroutines are very specific to a particular disaster and provide solutions to specific decision support needs. For example, the subroutine "Numeric Simulation of ETAS" calculated the simulation for a particular earthquake disaster and can only be used for a specific disaster category. Such type of subroutines is grouped as disaster dependent and shown in the part C of Fig. 8. It is labelled as D1.2 which means it is a disaster dependent subroutine 2 belongs to model 1.

The needs classification scheme used for the selection of modular subroutines is effective and efficient. It is effective because all modular subroutines derived from a model can be classified according to the decision support needs they are built for and the output they generate to fulfil those needs. It is efficient because it reduces the time spent in search for a model suitable to solve a decision task. Therefore, the discussion of modular subroutine selection based on a needs classification scheme, lays the foundation for the development of an integrated model for decision support in disaster management.

11. Experimental Results

This section contains experiment results (based on a subroutine selected from Table 5: Calculating Limit of Distance for Fire Spread) conducted to justify the proposed work as described in the previous sections.

11.1. *Calculating limit of distance for fire spread*

In fire simulation modelling, Eq. (11.1), representing spread speed to leeward proposed by Hamada[55,57]

$$D = 1.15(5 + 0.5v) \tag{11.1}$$

where v is the wind velocity meter per second (m/s) and D is the limit of distance which fire can spread (m). The limit of distance D, is important subroutine, because it is used to calculate the time until an adjust house to the point of fire origin ignites

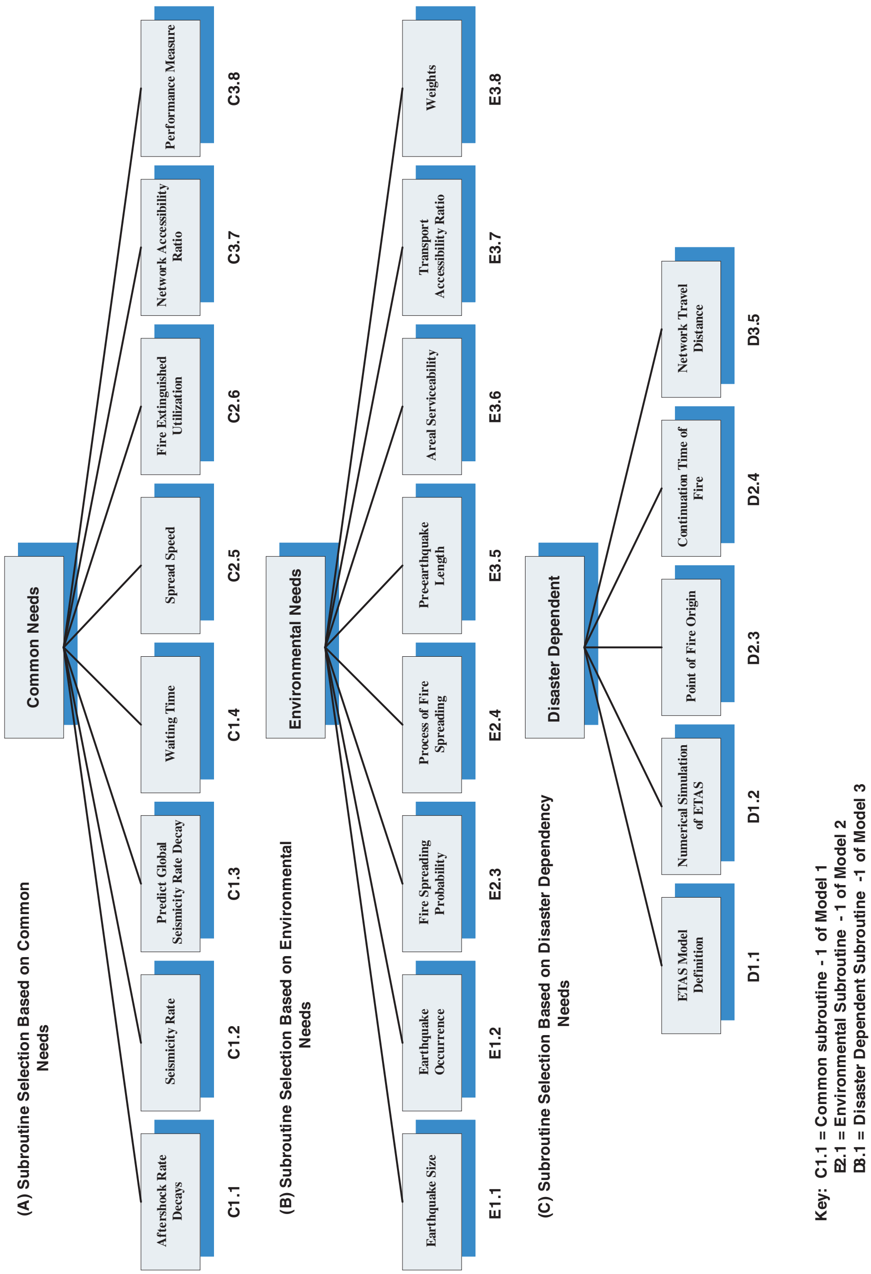

Fig. 8. Selected modular subroutines on the basis of needs classification scheme.

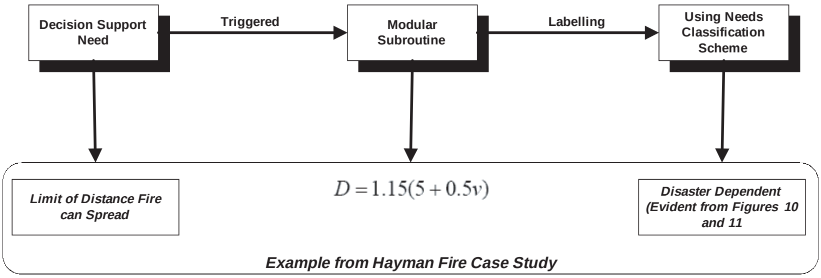

Fig. 9. Needs classification scheme for disaster dependent subroutines.

Table 6. Wind speed calculated for year 2001.[58]

Wind (m/s)	D
4.47040	8.320480
7.15264	9.862768
5.36448	8.834576
3.57632	7.806384
5.36448	8.834576
8.94080	10.890960
15.19936	14.489630
6.70560	9.605720
5.81152	9.091624
6.70560	9.605720
6.70560	9.605720
1.78816	6.778192
2.23520	7.035240
4.47040	8.320480
3.57632	7.806384
.	.

Table 7. Wind speed calculated for year 2002.[58]

Wind (m/s)	D
7.15264	9.862768
5.36448	8.834576
6.70560	9.605720
1.78816	6.778192
3.12928	7.549336
5.81152	9.091624
4.91744	8.577528
1.78816	6.778192
2.23520	7.035240
5.36448	8.834576
5.81152	9.091624
1.34112	6.521144
1.78816	6.778192
3.57632	7.806384
7.59968	10.119820
...	...

after catching fire in the origin. Therefore, by using D, we can calculate the time until a building becomes having the ability to cause fire spreading after catching fire. The limit of distance, D, has only one parameter which is wind velocity.

Figure 9 shows Eq. (11.1) within the framework of the Hayman Fire case study (which is used to completely validate the needs classification scheme and reported in our earlier publications) and categorized as Disaster Dependent under needs classification scheme. The dataset selected to validate this argument was used for two different years such as 2001 and 2002.[58] Tables 6 and 7 show first 15 records for the years 2001 and 2002, respectively.

Figures 10 and 11, illustrate that the subroutine is highly specific to the fire disaster and can only be utilized in the fire spread modelling simulations; therefore,

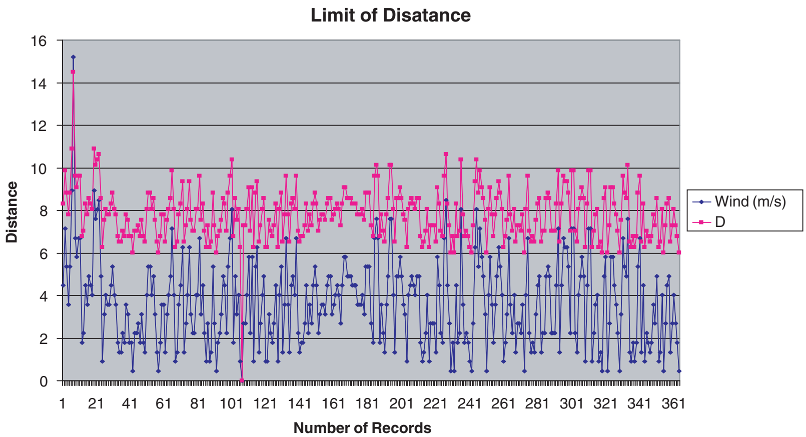

Fig. 10. Limit of distance for year 2001.[58]

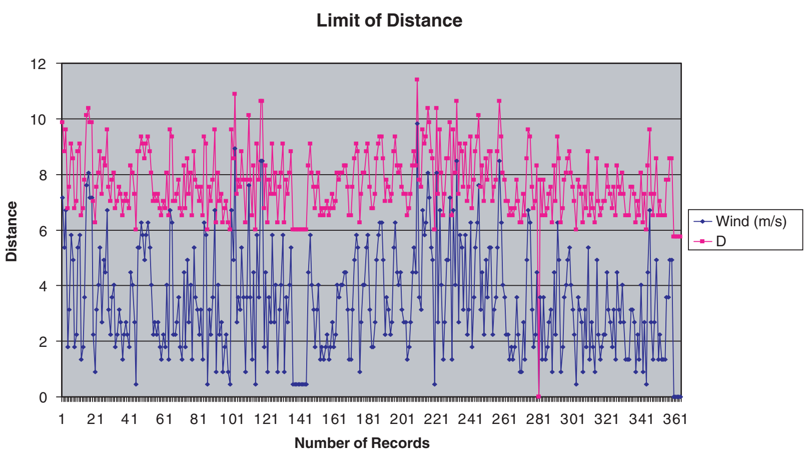

Fig. 11. Limit of distance for year 2002.[58]

it is disaster dependent. With the change of wind speed there is very slight variation in the limit of distance because careful observation of the Eq. (11.1) shows that limit of distance can only be used in fire spreading simulations and cannot be used in other disasters. We have demonstrated the validity of the proposed needs classification scheme by using the above-mentioned experiments; similarly, other subroutines can be also verified.

12. Conclusion

In this paper, we presented a brief overview of decision support systems and elaborated on the development process for disaster management decision support system. The traditional development process of DMDSS involves difficulties and present problems because of the complex nature of the disaster management domain. We have highlighted such difficulties and problems associated with disaster management and elaborated on the limitations of existing DMDSS models. To address these problems, we have suggested a new process of DMDSS model development. The outcome of this process is an integrated model for disaster management based on a given disaster scenario. In order to achieve this, selection of modular subroutines is required. These modular subroutines are collected from the traditional decomposition of DMDSS models. In this paper, we have proposed a new classification scheme for the selection of modular subroutines which is based on decision support needs. The proposed scheme of modular subroutine selection can be considered a preliminary step for model integration. Such scheme was validated by using a subroutine known as *Calculating Limit of Distance for Fire Spread*. We also described approaches used to identify such needs and mapped them against traditional activities of disaster management. Finally, the architecture of the MILD DSS is tested by implementing a prototype with data and an integrated model drawn from the disaster management domain. The prototype is implemented in Java. A complete validation of the proposed architecture was testing by using different hypothetical scenarios, which has been reported in other publications.

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