A DYNAMIC INTEGRATED MODEL FOR DISASTER MANAGEMENT DECISION SUPPORT SYSTEMS

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Abstract: Model integration is one of the most important and widely researched areas in the model management of Decision Support Systems (DSS). In current disaster management applications, independent DSS models handle specific decision-making needs but there are many advantages in combining these models. Therefore, there is a need for the selection and integration of such models. Previously, we presented a framework of modular decision support systems for disaster management. This paper extends our work towards the integration of modular subroutines which have evolved from the modular decomposition of DSS models. Model integration refers to the integration of different models into a single logical composite model. To achieve this, different approaches have been used in the past such as object-oriented, relational, graph-based, knowledge base and structured modeling. Our approach to the design and implementation of a dynamic integrated model for disaster management is based on four steps: (1) intelligent selection technique, (2) representation of the integrated model (3) creation of a domain base and (4) simulation of the integrated model. To further support our technique, a prototype has been implemented. We have demonstrated the usefulness of our approach by taking a hypothetical disaster scenario. The proposed technique to obtain an integrated model has been explored as a solution to reduce the complexity and inefficiency of dealing with multiple DSS models for disaster management.

Keywords: Model Integration, DSS, Disaster Management, Integrated Model, Modularization.

1 INTRODUCTION

Model management is one of the most important areas and is widely recognized as a key component of decision support systems. One of the primary tasks of model management is to perform model integration which consists of combining existing DSS models and components. It involves tasks such as connecting models, formulating composite models from existing models, collection of models and model reuse and analysis. Model integration, over the past two decades, has emerged as one of the most widely researched topics in the field of model management [Geoffrion, 1989], [Dolk and Kottermann, 1993], [Basu and Blanning, 1994], [Gagliardi and Spera, 1995], [Tsai, 1998], [Shiba et al, 1999], [Chari, 2002]. In this paper, we propose a technique to achieve a dynamic integrated model from previously developed modular subroutines for disaster management.

"Disaster management is a collective term encompassing all aspects of planning for and responding to disasters, including both pre and post-disaster activities namely, prevention, mitigation, preparedness, response, recovery and rehabilitation. It may refer to the management of both the risks and consequences of disasters" [DPLG-1, 1998].

In order to produce effective decision making in disaster management that can also easily maintain adaptiveness, special consideration is given to the modular approach for the development of decision support systems for disaster management. In our previous work, modularity has already been suggested as one of the possible solutions to the problems in the development of decision support systems for disaster management [Asghar et al, 2005b]. The design of this system has clearly shown the most promise and brings to bear a variety of technical and theoretical aspects such as modularity and model reusability approaches to model decomposition.

Different DSS systems have been developed for various categories of disasters they are based on specific models and decision support needs. Due to the different decision support needs that arise in disaster management, one single model is not sufficient to cope with them. As there are many advantages and efficiencies to be gained by using 'combined' models, there is a need for an integrated model for dynamic disastrous situations. The integrated model can be achieved by making use of modular subroutines developed for disaster management.

According to Schneid, disaster management is a challenging area with dynamic needs and an adaptive nature [Schneid, 2001]. For example, each disaster category such as flood, fire or any terrorist attack has dynamic decision support needs. The proposed integrated model based on different subroutines is an attempt to support this application area and to provide appropriate solution to the currently facing problem, such as dynamically changing needs and dynamic disaster scenarios, in the development of decision support system for disaster management.

The objective of this paper is to present a framework for an integrated DSS model which integrates different DSS modular subroutines and suggests a dynamic integrated model for a new situation in the disaster management domain. In the devised framework, we investigate model integration techniques based on four steps: (1) intelligent selection technique, (2) representation of the integrated model (3) creation of a domain base and (4) simulation of the integrated model. It makes the following important contributions:

1. the design and development of an intelligent technique to select subroutines from a knowledge base for a disaster scenario. We have also presented a flowchart and a psuedocode for the proposed technique
2. the selected group of subroutines for a particular disaster scenario produce the dynamic integrated model
3. a basic representation of the integrated model using the concepts of the Entity Relationship (ER) with a dynamic relationships that exist between the subroutines and the subsequent development of the domain base
4. the domain base is used to perform the simulations in order to predict the impacts of a disaster scenario

The structure of the paper is as follows: Section 2 provides an overview of our previous (modular decomposition of DSS models) and current work (dynamic integrated model); Section 3 is a survey of related work in two directions: firstly, DSS models developed for disaster management is discussed and secondly, a summary of model integration techniques used in the past; Section 4 presents the proposed framework for a integrated model and elaborates the main components of the integration model; Section 5 illustrates the application of the integrated model with a hypothetical disaster scenario and Section 6 outlines the conclusions and future work.

2 OVERVIEW OF PAST AND ONGOING WORK

During the last decade, decision support needs for disaster management have been studied and various approaches suggested. The studies have produced decision support systems that satisfy the requirements of decision making in the disaster management area. The approach adopted by the research and development community has been developed decision support systems to support the appropriate decision making based on the specific and particular needs of the disaster management domain. These systems are capable of providing the great majority of decision making based on specific requirements.

One of the limitations however is that they cannot be readily modified to adapt to the dynamic needs of disaster management area. Secondly, particular attention has not been paid on commonality of decision support needs in the area.

Another significant fact is that the environment has not been considered as an essential and common factor with the ability to change the severity of a disaster. This may be due to the fact that the environment is considered as only one of the disaster categories. The environment was provided with another definition and dimension within the context of disaster management in our earlier work [Asghar et al, 2005a].

Due to the diversity in the disaster management domain, it is impractical to formulate decision support system models for each disaster category (or various issues within a disaster). The practical alternative is to develop a decision support model which can be easily tailored for different disasters.

In DSS, the user may have different decision support needs and requirements which motivate the creation of a new model. Therefore, a DSS model is created as a result of different decision support needs. Since one application can have several needs, users may require multiple models in order to fulfill decision support needs and requirements. On the basis of needs (such as disaster dependency and environmental) we have designed a modular framework which produces different organizations of subroutines and propose the integration of such subroutines, which evolved from modular decomposition, to formulate a dynamic integrated model based on changing decision support needs.

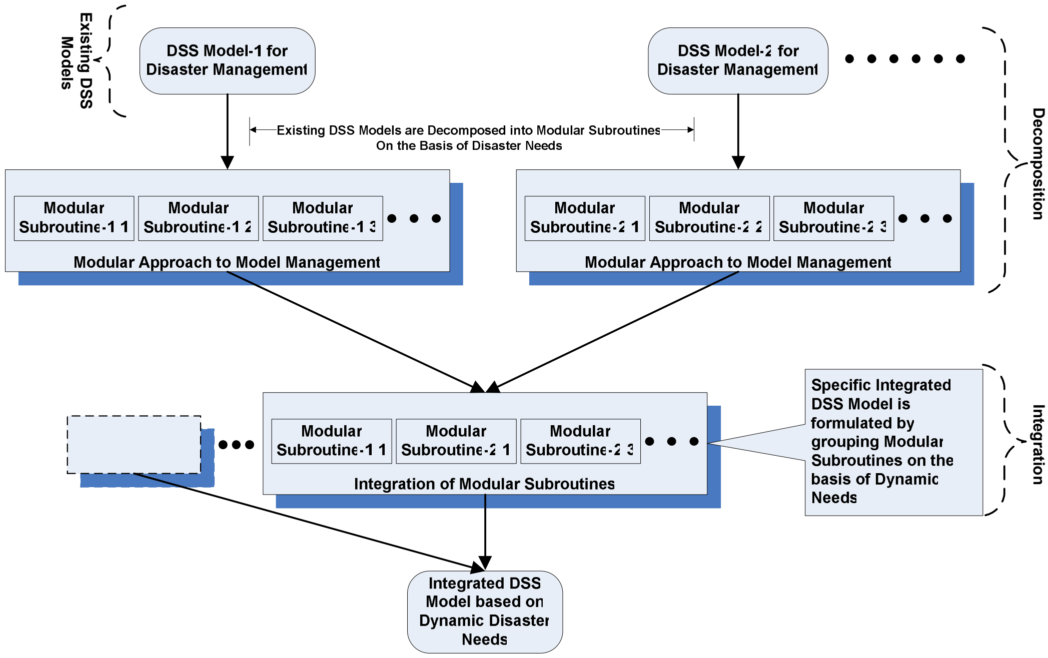

Figure 1: Modular Framework for Disaster Management DSS

Modularity is an approach to break a problem into smaller parts or modules such that the modules when put together, can perform as a system. It is possible that a module may be used as a part of another solution to a problem. The major advantage of using a modular approach in DSS development is that modules can be reused in order to put together a different DSS model for new requirements. This can be considered a preliminary step before performing model integration and composition.

The modular approach greatly facilitates the integration of existing models. For example, some DSS models have been developed and are currently used for flood risk assessment and management such as RAMFLOOD [Onate and Piazzese, 2004]. If we decompose them into smaller modules using our proposed technique, some of these flood management subroutines can be used to establish wild-fire management DSS models. The modularization is a promising technique for modeling complex decision support systems. It helps to reduce the complexity of the DSS by decomposing the models into smaller sub-routines. There can be certain situations in which user needs can be fulfilled by executing one or more subroutines. 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 [Pidd et al, 1996] can decomposed into modular subroutines, the decision support need in flood management "timely distribution of flood emergency information" can be fulfilled by execution few of the subroutine of evacuation DSS system instead of developing the complete DSS model from scratch.

Figure 1, shows that existing DSS models are decomposed into modular subroutines, and a new integrated model can be developed by using these modular subroutines. We emphasize that the existing DSS models are decomposed into subroutines such that each subroutine is functionally independent. Finally, these subroutines are grouped to develop an integrated model.

The decomposition is carried out on the basis of disaster needs at two levels (see Figure 3):

1. on the basis of disaster independent and dependent needs
2. environment independent and dependent needs.

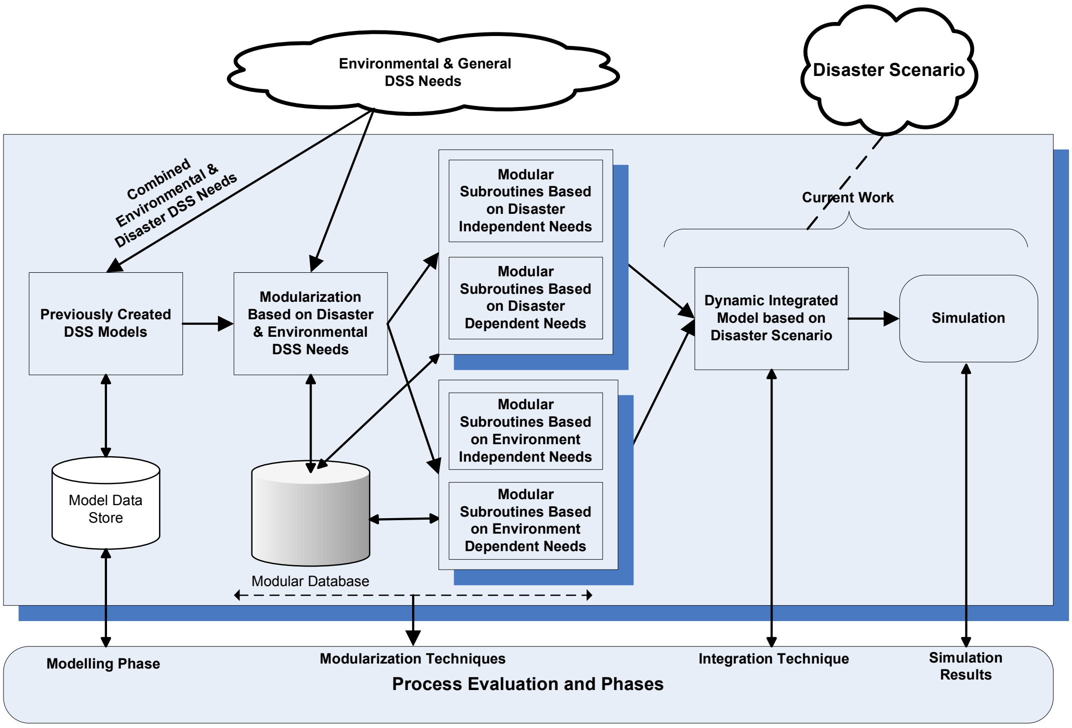

Figure 2: Overview of Previous and Current Work

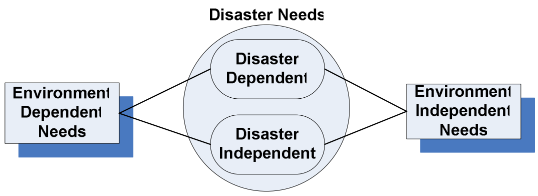

Figure 3: Basis of Decomposition

The advantage of such modularization is that different modules which describe the same functionality can be reused easily to develop an integrated model for a new dynamic disaster situation. This facilitates the development of a new integrated model from existing modular subroutines and improves the reusability.

Figure 2 illustrates an overview of our previous work with a modular approach and our current work in integrating modular subroutines which evolve from this modular decomposition. The focus of our current work is to provide a technique to integrate these modular subroutines to form an integrated model based on a new disaster scenario.

3 RELATED WORK

In this section, we describe the related work with an introduction to the decision support systems developed for disaster management, and to the work carried out in the field of model integration. This section not only summarizes related past work but also provides a summary of various DSS developed for disaster management and useful model integration techniques used in the past. We also compare these models and techniques with the proposed work.

3.1 Decision Support Systems for Disaster Management

Disasters such as earthquake, flood, fire, and tsunami result in catastrophic human suffering, loss of property and other negative consequences. Large numbers 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.

Table 1: Summary of Main DSS Developed for Disaster Management

DSS Developed for DM	Description	Based on DSS Needs
A simulation model for emergency evacuation [Pidd et al, 1996].	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.
Computer-aided DSS for hillside safety monitoring [Cheng and HoKo, 2002].	Describing the development of DSS for safety monitoring of hillsides.	Monitoring.
Towards intelligent decision support systems for emergency managers: the IDA Approach [Gadomski et al, 2001].	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 [Yong and Chen, 2001].	Provides a web based decision support tool "WaveLet" for expected damage and loss assessment, also identification of effective response measures to strong earthquakes.	Damage assessment and identification of effective response measures.
The Muse system [Arcand, 1995].	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.
Earth observation and case-based systems for flood risk management [Henry et al, 2002]	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 [Farinelli et al, 2003].	Describe the development of a multi-agent system based on RoboCup Rescue simulator to allow monitoring and decision support that is needed in rescue operations.	Searching and rescue of victims in large-scale disasters.
A study of forest fire danger prediction system in Japan [Kohyu et al, 2004].	Developed a system to predict forest fire danger.	Forecasting forest fire.
Decision support system of flood disaster for property insurance.[Wang et al, 2004].	Developed a DSS of flood disaster for property insurance.	Property insurance needs in disaster recovery and rehabilitation phase.
Federal Emergency Management Information System (FEMIS) [Hwang and Wofsy, 1995].	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 behaviour prediction and fuel modeling system [Andrew and Chase, 1989].	System developed for the prediction of fire behaviour and fuel modeling.	Fire prediction.
Some fire behaviour-modeling concepts for fire management systems [Rothermal, 1994].	Describe fire behaviour modeling concepts.	Fire management needs.
Providing decision support for evacuation planning: a challenge in integrating technologies [Silva, 2001].	Identifies and analyze the challenge issues faced in linking two technologies: simulation modeling and GIS, to design evacuation planning.	Evacuation planning.
Decision support system in oil spill cases [Pourvakhshouri and Mansor, 2003].	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 [Tufekci, 1995].	Developed a DSS for hurricane emergencies to support decision making in evacuation planning and modeling.	Evacuation planning, modeling and estimation of evacuation time for hurricane emergencies.

These man-made disasters include cyber-terrorism, product tampering, biological threats and ecological terrorism. The recent threats of these disasters have reaffirmed the urgency and importance of loss assessment and the need for decision support tools. In order to fulfill these needs and requirements different decision support systems have been studied and developed. Some of the major activities along with some decision-making needs (shown inside brackets) in disaster management are as follows:

- Hazard assessment (vulnerability analysis, frequency of hazard occurrences)
- Risk management (analysis of disaster risks, evaluating risks and treating risks)
- Mitigation (developing mitigation plan, analysis of measures)
- Preparedness (planning and resource management)
- Response (emergency response plans, analysis and evaluation)
- Recovery (assessments, re-settlement issues)

Table 1 illustrates 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 the field of disaster management. In order to develop a new system for a different disaster category (or issues within a disaster), the existing systems cannot be reused. With the use of our previously proposed modular technique, these models can be broken-down into smaller modular subroutines and can be integrated by using our proposed approach to support the dynamic needs of decision making in disaster management.

The existing DSS models provide the foundation of our work. As stated in Table 1, we use them as the source of modular subroutines and to apply proposed integration technique for recombining.

3.2 Existing Model Integration Techniques

As stated earlier, model integration is one of the most important and widely researched areas in the model management of decision support systems. Model integration is a way of creating decision models from existing ones and is a reusable approach for creating models [Geoffrion, 1989]. The integration of dynamic models in DSS is an important research topic according to modern modeling paradigms. Based on extended structured modeling Tian and Ma [Tian et al, 1998] suggested the integration of dynamic models.

Lee [Lee and Huh, 2003] presented a model-solver integration framework that enables a decision support system to autonomously suggest the compatible solver and to apply it to the model, even though the users are not sufficiently knowledgeable about all the details of the models and the solvers. They also designed a model solver agent to infer the compatibility of a solving service with a certain model and to understand their parameter matching patterns.

Banerjee and Basu [Banerjee and Basu, 1993] presented a framework to support the model selection process based on a broad set of criteria. They designed a methodology to systematically guide the users to progressively obtain the required information and to make intelligent trade-offs for selecting model types.

Dolk and Kottermann [Dolk and Kottermann, 1993] have surveyed the main aspects of model integration, particularly the schema and process integration. They also highlighted the limitations of using the relational database theory as a paradigm for model management theory and have expanded its functionality.

Piramuthu and Raman [Piramuthu et al, 1993] introduced a model management framework with learning capabilities using inductive learning methodology for DSS. This framework learns from past experiences in the domain of interest. It acquires the knowledge by itself and refines it through feedback from a critic module using pre-performance criteria.

Chang and Holsapple [Chang et al, 1993] discussed models and their contexts and also offered a survey of representative research impinging on various aspects of model management. They concluded with a new direction for model management research, which involves a hyper-knowledge paradigm.

Basu and Blanning [Basu and Blanning, 1994] used meta-graph approach for model integration. They showed that useful insights into the input/output relationship between modules can be gained through their meta-graph representation and structured procedures for the identification of candidate integrated models for specific user problem instances can be constructed. The meta-graph analysis was used to achieve the model integration process.

Table 2: Summary of Existing Model Integration Techniques

Authors	Integration/Composition Approaches Used	Summary
Basu and Blanning 1994 [Basu and Blanning, 1994]	Meta-graph	Implementation issues not addressed, integration based on specific user problems
Blanning 1986 [Blanning, 1986]	Relation (ER Approach)	Theoretical concept, only provide a model representation in ER framework
Jeusfeld 1997 [Jeusfeld and Bui, 1997]	Script-Based	No implementation details and scripts are required to model every different situation
Dolk and Kottermann 1993 [Dolk and Kottermann, 1993]	Suggested MML to support integration	Survey main aspects of model integration, identified limitation of relation theory to build theory of models.
Tian 1998 [Tian et al, 1998]	Extended Structure Modeling	Integration of dynamic models based on extended structured modeling paradigm is shown using examples and formal notations without implementation details
Geoffrion 1987 [Geoffrion, 1987]	Structured Modeling	Model representation framework and using genus graphs for model integration
Tsai 1998 [Tsai, 1998]	SML	Defined schema operations for model integration
Gagliardi and Spera 1995 [Gagliardi and Spera, 1995]	Structured Modeling	Defined automated procedures, which can be used to replace genera, modify definitional dependencies among models
Muhanna and Pick 1994 [Muhanna and Pick, 1994]	Graphical	Implementation does not support model automation.
Holocher 1997 [Holocher et al, 1997]	Knowledge-Based	Approach only caters structured models
Chari 2002 [Chari, 2002]	Knowledge-Based	Implemented the approach and handle integrated partial solutions.
Muhanna 1993 [Muhanna, 1993]	Object-Oriented	Proposed conceptual framework

There has been significant work done in the field of model integration and composition (summarized as in Table 2). Our work is contrasted to the existing standard model integration techniques. The existing techniques are conceptual and have been implemented within different domains. Our work 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 gained when applied to disaster management applications where dynamic decision making is required.

3.3 Significance of Our Work

The following describe our research contributions and highlight the difference from the previous work in this area.

1. Decomposition of existing DSS models based on disaster dependency and environmental dependency needs is extended to design a framework for an integrated model by grouping subroutines evolved from it on the basis of a dynamic disaster scenario.

2. Model integration technique is based on the concepts of intelligent selection of the subroutines from the knowledge base, formal representation of the integrated model, and model schemas creation which is used to perform simulations for further predictions.

4 A FRAMEWORK FOR DYNAMIC INTEGRATED MODEL

There are different decision support systems models developed to help decision makers to make an informed decision. These DSS models focus on different domains and applications. The decision support needs for the disaster management domain require focusing on many different

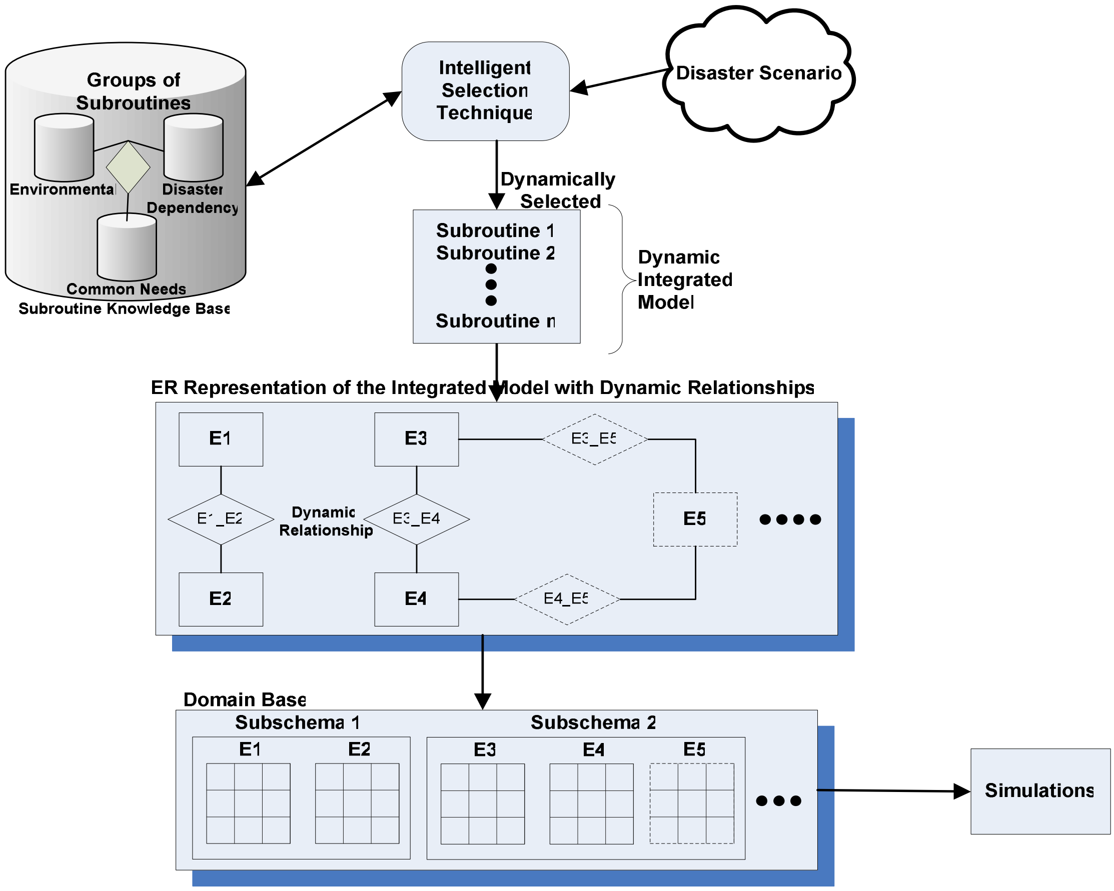

Figure 4: Proposed Framework of Integrated Model for Disaster Management Decision Support Systems

aspects, as highlighted in the previous section, and therefore is a good candidate for an application area requiring model integration. As mentioned earlier, in disaster management the decision making needs change dynamically and therefore the need for the use of model integration arises.

We have stipulated a framework (depicted in Figure 4), which dynamically selects the different DSS modular subroutines based on a disaster scenario and suggests a collection of subroutines. Such dynamically selected subroutines can be executed in a specialized sequence and considered as an integrated model. The main components of the proposed framework are as follows:

- Subroutine Knowledge Base
- Intelligent Selection Technique
- Integrated Model
- ER Representation of Integrated Model
- Domain Base
- Simulation

Each of the major components of the framework is briefly described below.

4.1 Subroutine Knowledge Base

In the disaster management domain there are not only different types of disasters such as floods, earthquakes, fire, collisions, crashes, blasts and tsunami, but also different issues and activities related within a disaster, which might have different decision support needs and requirements. It is evident from the literature that those traditional decision support systems were developed for a particular disaster category and based on a specific model (see Table 1). A single DSS model, which encapsulates different disaster issues, could be more efficient and effective.

In the disaster management domain, where real world problems are complex, manual and traditional software solutions have been shown to be inadequate to satisfy the dynamic needs and requirements of the domain, while a modular approach has made a significant contribution [Asghar et al, 2005b].

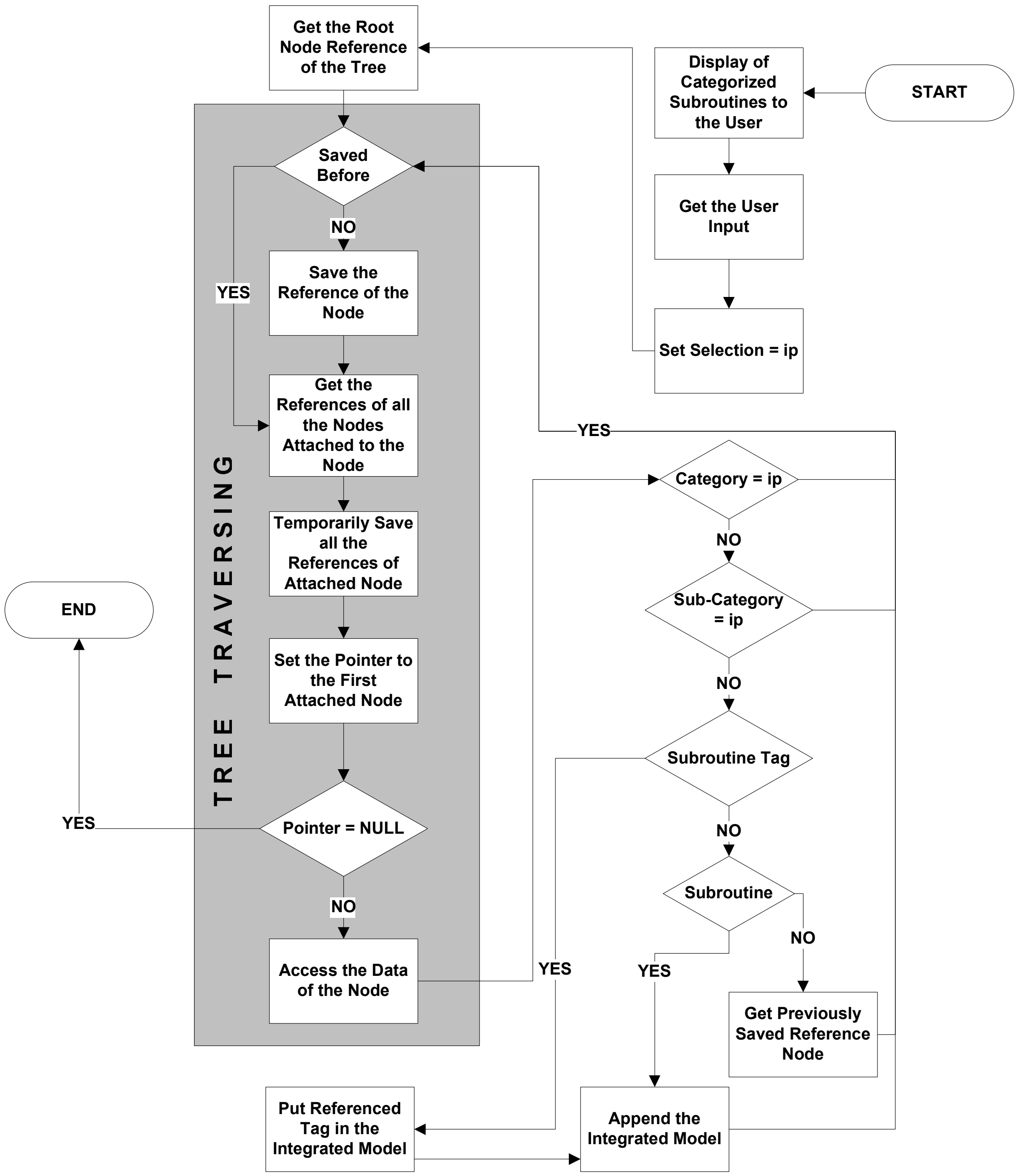

Figure 5: A Flowchart of the Intelligent Technique

Once the modular decomposition is achieved, the task is to develop a knowledge base which is grouped into three categories of subroutines: (1) environmental (2) disaster dependency and (3) common needs subroutines. The labelling and grouping of the subroutines are performed at the time of insertion into the knowledge base. The following are examples of three different categories of subroutines stored in the knowledge base [Westphal et al, 2003], [Lu et al, 2000], [Kim and Valdes, 2003]:

1. Drought forecasting algorithm (*disaster dependency*):
   $Ci^{I}(k) = WT(x(I : k)h)$
   $C_i^T(k + t) = WT(x(I : k + t)h)$
   $C_i^T(k + t) = f(C_i^I(k)\ C_i^I(k - l))\ A)$
   $C_i^I(m) = WT(x(l : m), h)$
   (f) $\delta_i(m + t) = f(C_i^I(m),\ C_i^I(m - l),\ A)$
   $x(k) = g(C_i^T(k), C_2^T(k),\ A)$
   (g) $x(m + t) = g(\delta_1(m + t),\ \delta_2(m + tl)\ A)$
2. Soil moisture storage (*environmental*)
   $S_t = Y_t\ exp(-P\ E_t / b)$

3. The cost model of SRCCP evacuation planning algorithm (*Common Need*): $Cost_{SRCCP} = C_{sp} + C_{ss} + C_{sr} = O(n_s * nlogn) + O(n_s logn_s) + O(n * n_g)$

4.2 Intelligent Selection Technique

The intelligent selection technique facilitates the selection of subroutines from the knowledge base on the basis of user specified decision support needs which arise from a new disaster scenario. It interacts dynamically with the knowledge base and performs the selection according to the desired situation. The component also restricts the overlapping of subroutines because one particular subroutine can be part of more than one group. A flowchart is presented in Figure 5 that summarizes the flow of the program for the intelligent technique. This flowchart describes the technique at a level of abstraction between the problem statement and the actual programming of the technique.

The final output of the flowchart is based on the decision made after considering the conditions of each individual processing module of the traverse tree. For example, if the input is based on categories and sub-categories, the selection is done and then this combination uses the tree traversing, which leads to the selected subroutines. Thus the output selected in this situation could be appended in the integrated model. The system would output different groups of subroutines, depending on different combinations of the categories selected as the input based on the conditions in a scenario. A psuedocode (as shown in Figure 6) is also presented to further support the intelligent technique.

4.3 Integrated Model

As mentioned earlier, model integration can be described as a way of developing decision models from existing models instead of starting from scratch. In the integrated model approach we do not intend to propose a composite model, which is developed by merging or combining two or more models, which is to be applied to a new situation.

The problem with this approach is that a composite model may perform best in one case but may not be sufficient in another. Therefore, the need for an integrated model arises which can be developed dynamically based on a particular given scenario.

To address the problem, we propose a dynamic integrated model which is based on a group of subroutines selected by the intelligent technique. Dynamic means the model is achieved according to a given disaster situation.

In this case our goal is to offer a selected group of subroutines (evolved from modular decomposition) that can be easily extended and flexible for a new disaster scenario. Such a group, based on a specific disaster scenario, can be considered as a dynamic integrated model for disaster management decision support systems.

We emphasize that the subroutines included in the integrated model belong to at least one of the three categories that we have explained in the knowledge base.

***Psuedocode* for Intelligent Technique**

```
Class refLL {
        refLL next
}
Class treeNode{
        Object nodeData
        refLL nodeRef
}
userInput =  new Array[]
Get the reference of the root node;
For (search input array) {
        userInput[i] = input selected from the user
}
Create a dynamic multidimensional array to store the node
references
Do {
        Copy rootNode->next in the multidimensional array
        appendIntegratedModel();
        Store root node reference
        If (userInput[i] matches refNode->data {
                Pop ()
        }
        If (userinput[i] matches category) {
                Store category node reference
                Store all of its sub-categories
                Move to the next node;
        }
        If (userInput[i] matches sub-category) {
                Store sub-category node reference
                Store all of its subroutine tags
                Move to the next node;
        }
        Else {
                Get the subRountine from the referenced node
                appendIntegratedModel ();
                Check the NULL pointer occurrences
        }
} while (referencedNode->next = NULL)
```

Figure 6: A Psuedocode for Intelligent Technique

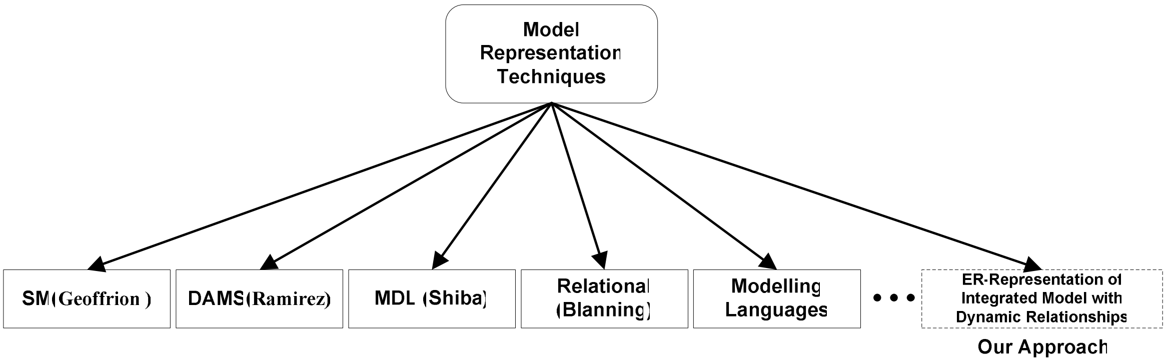

Figure 7: Our Approach towards Integrated Model Representation

4.4 ER Representation of the Integrated Model

In this section, we consider how the dynamic integrated model is represented using relational concepts. However, it is important to provide the need for and justification of the formal representation of the dynamic integrated model. There are three reasons:

I. The subroutines stored in the knowledge base are not related to each other. After the selection of subroutines from the knowledge base, on the basis of a disaster scenario, a dynamic relationship exists between different subroutines. In order to capture this relationship, we need a formal representation technique. Therefore, we have represented the integrated model as ER diagrams.

II. A very large number of disaster-related DSS models have been developed and reported in the past covering disasters such as flood, wildfire, droughts and earthquake. In addition, several models of one specific category of disaster have been reported in the past describing different issues of decision making. There have been increasing demands from decision makers for models that can handle more complex disaster situations. The obvious solution is to merge the existing models to cope with a new situation, but most of the models are not designed to standards that allow for such merging. It is impractical to formulate the model integration without making a generic standard. The lack of standardization when defining models is a major obstacle in the area of model integration. We highlight the importance of the standardization of different models in the model management. In order to overcome the problem of standardization, we emphasize model representation and their subsequent storage in relational schemas for the purpose of standardization. We standardize the models in terms of their representation.

III. It is evident from the literature that a formal technique is always required to represent a model.

Model representation is one of the most important components because it provides the foundation for our work towards model simulation. Representing a model for a semi-structured or complex problem is not simple because it is related to the problem of the identification of complex real world objects.

There are many different approaches to model representation. For example, the structured modeling approach uses a hierarchically-organized, partitioned and attributed acyclic graph to represent a model [Geoffrion, 1987]. This approach is widely used in different applications. Modeling definition in DAMS is based on structured modeling and utilizes the same basic concepts [Ramirez et al, 1993].

Blanning [Blanning, 1982], used relational algebra and relational calculus to define models in model management. With advancements in this, the use of modeling languages has increased. To cite a few, there are SML [Geoffrion, 1987], DAM SQL [Ramirez et al, 1993], MDL [Shiba et al, 1999]and LINDO [Schrage, 1999].

We have provided a brief overview of the approaches and languages used to define models in order to explain the benefit gained in the context of modeling for the disaster management domain.

For model representation, we use an entity-relationship approach to model management [Blanning, 1986]. There are usually four important concepts in ER modeling: entities, their attributes, the relationships between them and the value set. An entity is a conceptual representation of a real world object [Date, 1995]. We use the semantics of the relational representation method to represent the varied structure of an integrated model. Figure 7 shows existing approaches and the approach we use for the representation of the integrated model.

4.5 Domain Base

We illustrated the conceptual model representation technique in the previous section with ER. Once the integrated model is represented we can raise the definition as well as the structures of the integrated model to schema level. Such structure is named as Domain Base (DB). Domain Base consists of a model schema and the instance of the model schema called subschemas. Therefore, the union of all the subschema instances defines the structure of the domain base. For this purpose a domain base can be defined by the following structure:

$$DB = \{Subschema^{1}_{db}, \ldots, Subschema^{n}_{db}\} \quad (1)$$

We take an example entity to demonstrate the model schema and the instance of that model schema. After this, the model schemas and the instances can easily be developed, and represented in any relational language. We highlight the important issue of differentiating between a model schema and an instance of model schema. A model schema corresponds to the structure of a subroutine which is represented in ER. An instance of schema corresponds to relations created in the domain base and populated with real data.

Figure 8 shows a fragment of a model schema for the domain base developed. It models entities, their parameters (three different types of parameters such as input, local and output types), four types of constraint and a unique identification of the entity. Therefore, we can generate an instance of this model schema by taking an example from the problem domain, which is disaster management. Suppose we have a subroutine of rainfall, the fragment instance of model schema for rainfall is shown in Figure 9.

It is noted that the graphical representation of an instance of a model schema, shown in Figure 9, is created inside the domain base.

As stated earlier, each subroutine is associated with three different types of parameters as: input, local and output. The subroutines were represented as entities and subsequently instance of the schemas are created. Such parameters are associated with each instance of a schema and can formally be specified as follows. The notations are i_b, I_b, o_b inputs, local and output parameters respectively.

$$i_b = \{(RelationParam, i_1) \ldots, (RelationParam, i_m)\} \quad (2)$$

$$I_b = \{(RelationParam, l_1) \ldots, (RelationParam, l_p)\} \quad (3)$$

$$O_b = \{(RelationParam, O_1) \ldots, (RelationParam, O_q)\} \quad (4)$$

The fundamental challenge in the area of model management is to develop a technique for model representation and storage. Our approach of model representation and storage, by creating domain base of model schemas, can be considered as a solution. Moreover, the design of the domain base has laid the foundation for the model simulations which is described in the next section.

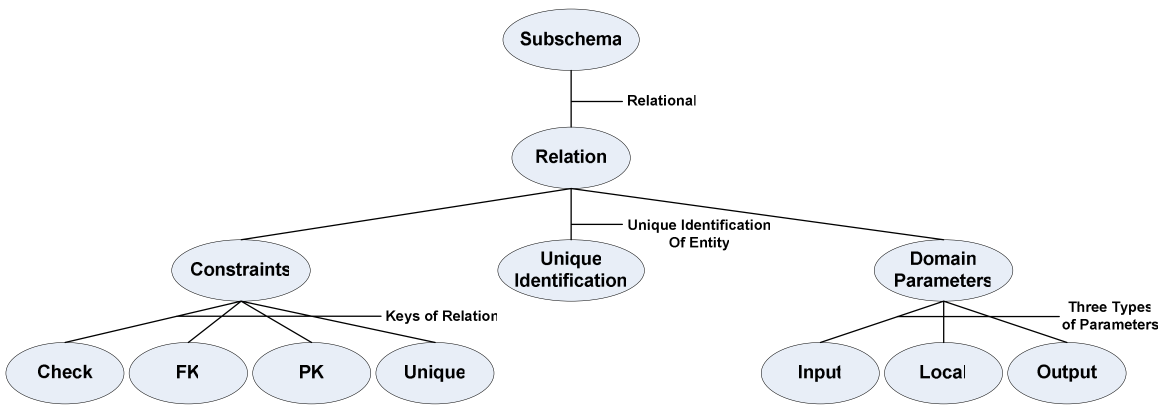

Figure 8: A Fragment of a Model Schema

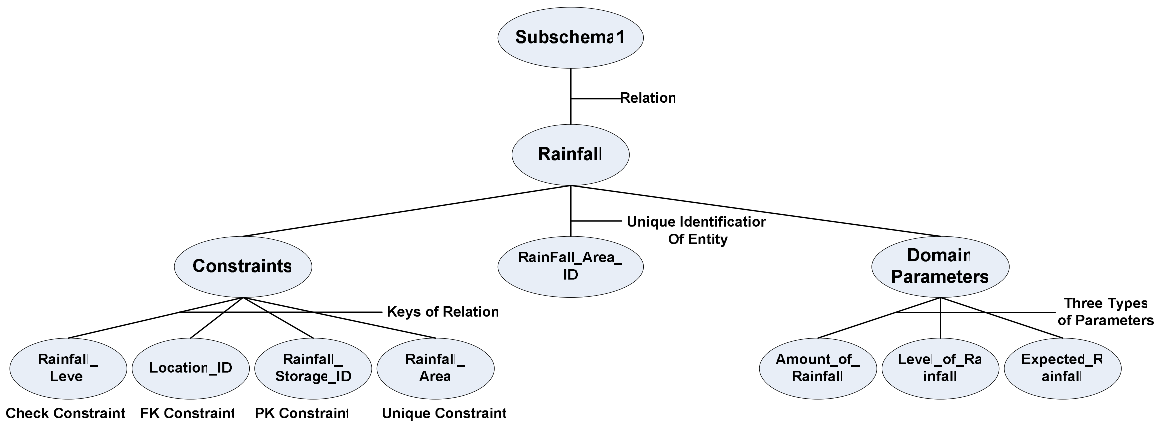

Figure 9: A Fragment Instance of Model Schema: An Example of the Rainfall Entity

4.6 Simulations

Simulation can help address many of the challenges brought forth by the disaster management area. A recent survey indicates that a number of simulation applications for analyzing various disaster incidents exist [Jain and McLean, 2003]. Not only do we need to make plans and design decision support systems to handle the aftermath of a disastrous event, we need to plan what indirect impacts can occur with such incidents. This is especially relevant since the outcomes of man-made disasters (terrorism) can in some instances be similar to natural disasters (for example a terrorist bomb blast may lead to fire spreading into a densely populated area). The simulation models for studying such indirect impacts can be beneficial and useful to predict other disastrous events. The dynamic integrated model can be used to perform such simulations which are developed and based on the dynamic integrated model. It has been shown in the simulations how subroutines are dynamically related to each other and can be simulated to predict future disaster situations.

This section has demonstrated the usefulness and described the main components of the integrated model. As mentioned above, model integration can be described as a way of developing decision models from existing models. Such techniques have made model creating cost-effective and more efficient.

5 PUTTING THE INTEGRATED MODEL TO WORK

In this section, we describe how the proposed technique of developing an integrated model can be achieved in a given hypothetical disaster scenario of heavy rainfall and possible flood disaster.

Hypothetical Disaster Scenario

Heavy rainfall has occurred in Victoria. In Melbourne city, an hourly precipitation of 89 mm has been recorded and the total precipitation amounted to 322 mm. The highest 1 hour precipitation records in the last 23 years have been revised at 3 observatories and the highest 24-hour precipitation revised at 4 observatories, based on the data of the Bureau of Meteorology, Australia. In this heavy rainfall, 30 persons have been killed, 101 houses destroyed, and about 2,800 houses inundated. While the residents are taking shelter, debris flow has killed 9 people in the city. The evacuation issue by Melbourne city was announced after the debris flow occurred. The devastation has affected the area socially, economically and physically. A flood disaster also occurred in the city in 1999. The previous threat of flood disaster and heavy rainfall event in the region has created the need for a decision support system to implement disaster management actions. The aim now is to identify a model which would be helpful in developing decision support systems for the forecasting of floods and the consequent land incursion. It is important to examine methods of utilizing real time rainfall information.

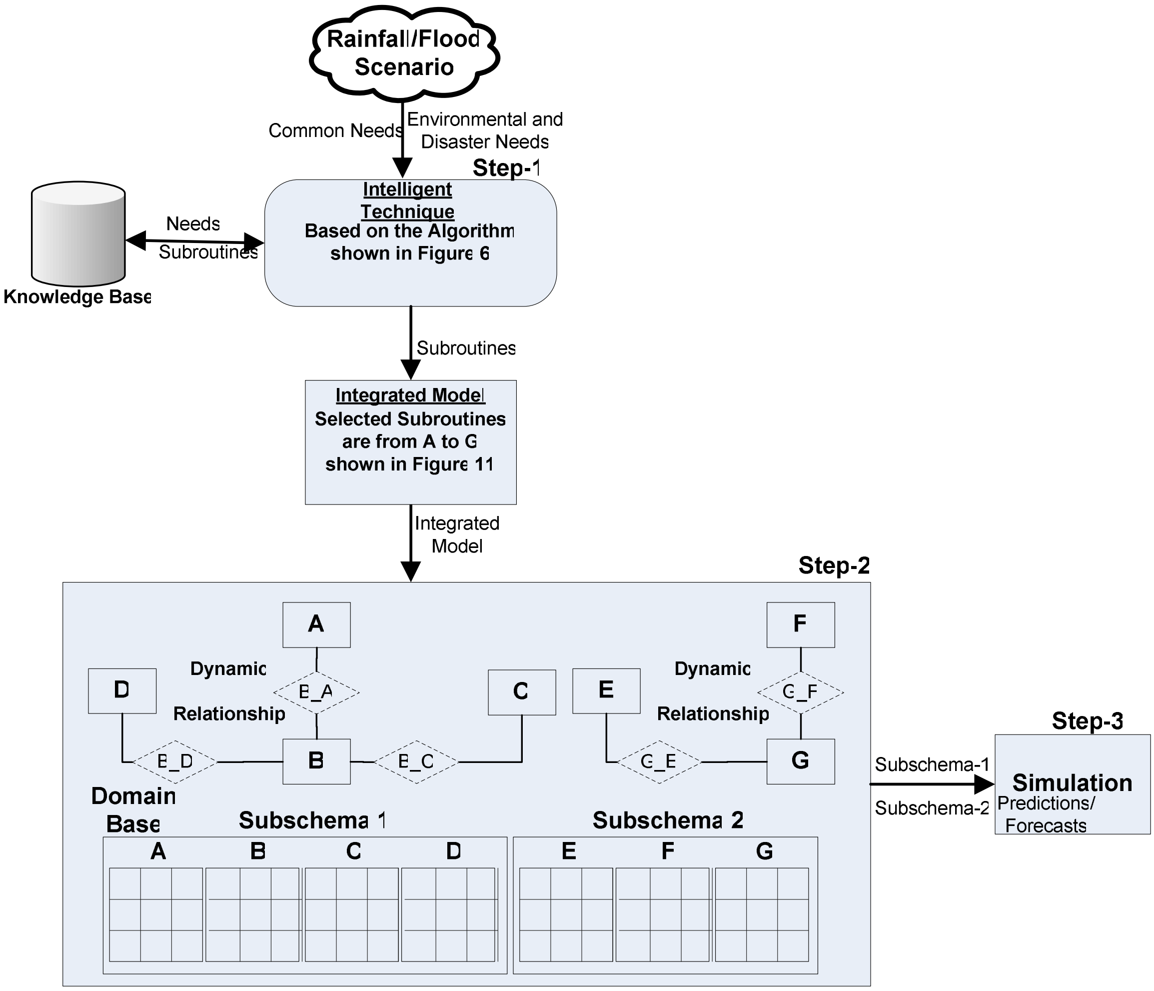

Figure 10: Flowchart of Major Interactions to Develop Integrated Model based on Disaster Scenario

Figure 10 shows the flowchart of the major interactions between different components of the framework. It also illustrates that the heavy rainfall and possible flood scenario activates the intelligent technique to use the knowledge base and formulate a dynamic integrated model that can be helpful in developing a decision support system for effective decision making in this particular disaster scenario. The three main steps (highlighted in Figure 10) are described briefly as follows:

Step-1: Intelligent Technique

Based on the disaster scenario, the intelligent technique was used to select the subroutines from the knowledge base. The selected groups of subroutines are shown in Figure 11. Such group of subroutines (from equations 5 to 11) can be considered to be our proposed dynamic integrated model based on the specific disaster scenario. A brief description of each subroutine is as follows:

A: calculates the daily runoff [USDA, 1972].
B: calculates the retention among sub basins [USDA, 1972], [Arnold et al, 1996].
C: compute fluctuations in soil water content [Arnold et al, 1996].
D: calculates the maximum land incursion [Alpar et al, 2003].
E: estimates peak runoff rate [Arnold et al, 1996].
F and G: calculates rainfall infiltration and duration respectively [Ouyang and Bartholic, 1997].

Step-2: ER Representation for Dynamic Relationship and Creating Instances of Model Schemas

The subroutines in the knowledge base, prior to the selection process, are random and no relationship exists between them. Once they are selected on the basis of a disaster scenario, the dynamic relationship is created between them. Such a dynamic relationship arises due to the following three factors:

Dynamic Integrated Model

Daily Runoff: (A) $$Q = \frac{(R - 0.2\,S)^2}{R + 0.8\,S} \quad (5)$$

Sub basins Retention: (B) $$S = 254\left(\frac{100}{CN} - 1\right) \quad (6)$$

Soil Fluctuations: (C) $$S = S_1\left(1 - \frac{FFC}{S3}\right) \quad (7)$$

Where $S3 = FFC + \exp[W_1 - W_2\,(FFC)]$

Landward Incursion: (D) $$X_{max} = (Hs)^{1\ 33}\, n^2 K \quad (8)$$

Peak Runoff Rate: (E) $$q_p = \frac{(p)(r)(A)}{360} \quad (9)$$

Average Infiltration: (F) $$F = \frac{(R - Q)}{DUR} \quad (10)$$

Rainfall Duration: (G) $$DUR = \frac{(4.605)R}{r_p} \quad (11)$$

Figure 11: The Dynamic Integrated Model Based on a Disaster Scenario

1. the different decision support needs of a disaster scenario which have created the relationship
2. commonality of subroutine parameters (different subroutines can have common parameters)
3. the output of a subroutine can be the input to another (referred as input_output relationship)

The integrated model showed in Figure 11 needs a formal representation due to the dynamic relationships that exist among different entities. As mentioned earlier, the ER approach is chosen to describe such relationship. The ER representation of this integrated model subroutine in Figure 12 (parts A and B) shows the dynamic relationship in diamond boxes, which is created due to the given scenario. For example, the input_output relationship between the entities daily runoff and sub-basin retention shows that the output of the retention entity becomes the input to the daily runoff entity. Similarly, the rainfall duration helps to calculate the average infiltration rate.

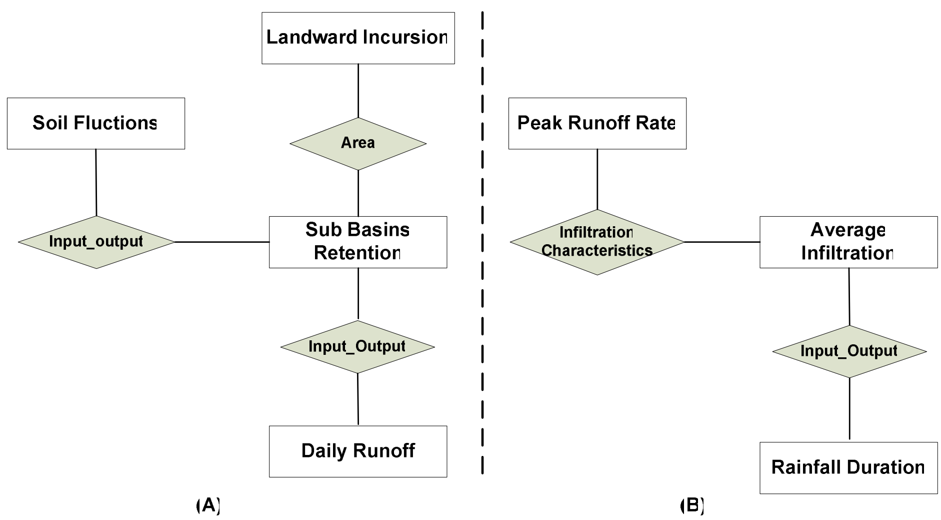

Figure 12: ER Representation of the Integrated Model with Dynamic Relationship

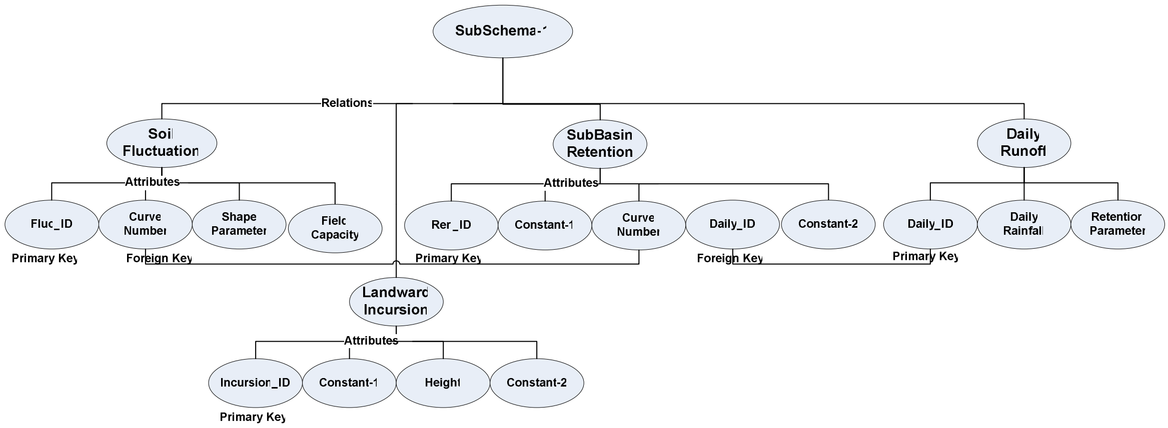

Figure 13: Model Instance for Subschema -1

Once the integrated model is represented, instances of the model schemas can be created in the domain base. The structure of the fragment of a model schema is already described in the previous sections (see Figure 8). To demonstrate the application, we only need to create the instances of model schemas, called subschemas. There are two subschemas for the integrated model such as subschema-1 as shown in Figure 13 and subschema-2 as shown in Figure 14. The creation of the domain base was necessary for the development of the simulation.

Step-3: Simulation

The simulation was performed to demonstrate the forecasting of the integrated model based on real data, collected from the Bureau of Meteorology, Australia [Meteorology, 2005]. The purpose of the simulation was twofold: firstly to compare the results with the observed and forecasted data and secondly, to highlight the dynamic relationship that exists between the subroutines in the integrated model. The data was collected and analyzed from several different stations in Australia (including all states). The results of six months were observed and use to predict the next month.

The forecasting procedure used was Adaptive [Lapin, 2002]. The Adaptive forecasting methods are used to make short-term forecasts. These methods may be appropriate when no constant long-term trend is present in the data. The term 'adaptive' refers to the fact that each period's forecast is updated by subsequent observations before the next forecast is made. Adaptive methods include Exponential Smoothing to predict one period ahead. It is also known as one-step forecasting. Using Exponential Smoothing, we forecasted for the next month which is equal to the forecast for the current period plus a proportion (α) of the forecast error in the current period. The mathematical notation is as follows [Lapin, 2002]:

$$F_{t+1} = F_t + \alpha(Y_t - F_t) \qquad (12)$$

where
F_t is the forecast value
Y_t is the observed value
α is the smoothing factor (between 0 & 1)
t is the time index

Figure 15, based on the empirical results (see Table 3), shows the dynamic relationship between two subroutines of subschema-1 (see Figure 13). Figure 15 (A) illustrates that runoff and retention are inversely proportional upto the month of December. Between the months of December and January the retention has highly increased with a slight increase in the runoff. After that, both retention and runoff start decreasing. Figure15 (B) also forecasts similar facts until the month of December. Following that there is a slight variation in the slope of the forecasted retention as compared to the observed. In the months of February and March both retention and runoff start increasing.

Figure 16, based on the empirical results (see Table 4), shows the dynamic relationship between two subroutines of subschema-2 (see Figure 14). Figure16 (A) illustrates that a slight increase in the rainfall duration has highly increased the infiltration rate. Similarly, Figure 16 (B) shows that, in the forecast, there is a smooth increase as well as a decrease as opposed to the observed.

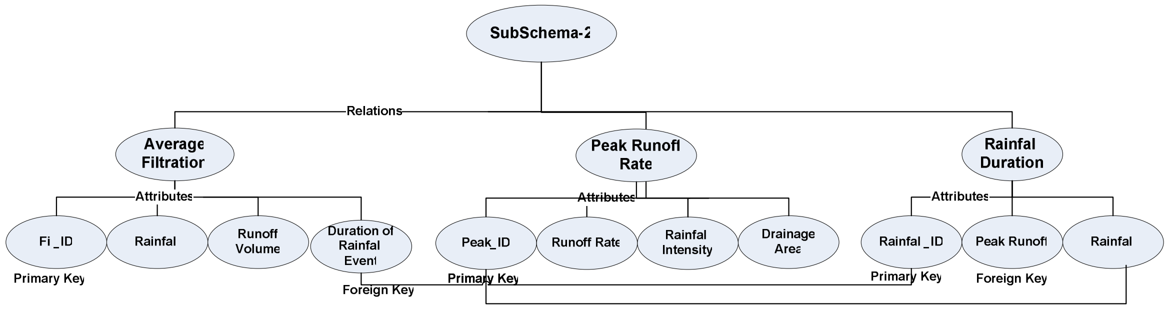

Figure 14: Model Instance for Subschema-2

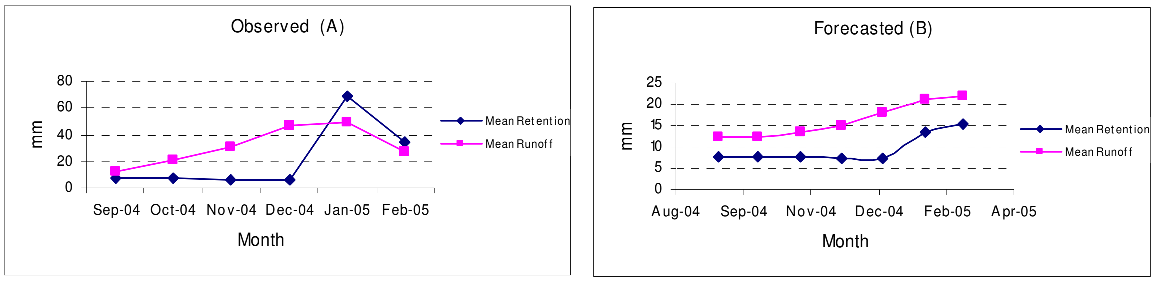

Figure 15: Simulation Results of Subschema-1

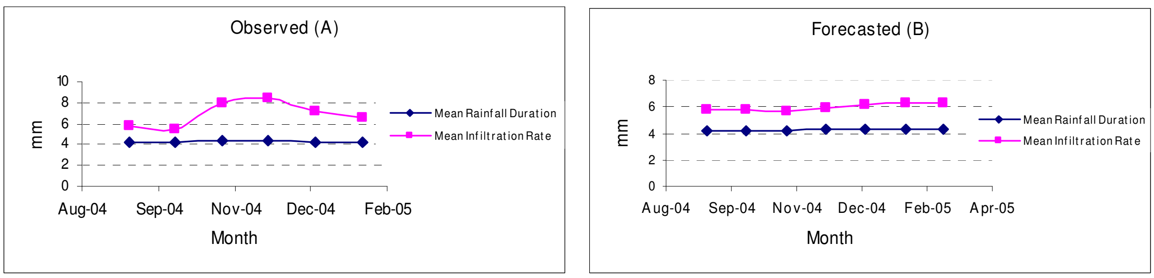

Figure 16: Simulation Results of Subschema-2

Table 3: Empirical Results of Subschema-1

Subschema-1		Sep-04	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05
Observed	Mean Retention	7.67637	6.90873	6.28067	5.75728	69.08732	34.54366	
	Mean Runoff	12.43979	21.05113	30.51624	46.57219	48.82549	26.83462	
Forecasted	Mean Retention	7.67637	7.67637	7.59961	7.46771	7.29667	13.47573	15.89418
	Mean Runoff	12.17800	12.17800	13.04911	14.76711	17.89910	20.96447	21.53502

Table 4: Empirical Results of Subschema-2

Subschema-2		Sep-04	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05
Observed	Mean Rainfall Duration	4.23043	4.21028	4.44507	4.42555	4.24046	4.26898	
	Mean Infiltration Rate	5.69804	5.53662	7.90478	8.43028	7.26724	6.50289	
Forecasted	Mean Rainfall Duration	4.23043	4.23043	4.22841	4.25008	4.26762	4.26491	4.26531
	Mean Infiltration Rate	5.69804	5.69804	5.68190	5.90418	6.15679	6.26784	6.29134

6 CONCLUSIONS AND FUTURE WORK

We have presented a framework for a dynamic integrated model for disaster management decision support systems. The model is created on the basis of a given disaster scenario. We have elaborated the main components of the framework and demonstrated the construction and usefulness of the proposed integrated model by taking a hypothetical disaster scenario. The intelligent technique is used to select the group of subroutines to create the integrated model. This technique attempts to support a complex decision making process in a disaster management environment by providing the ability to select modular subroutines to make a dynamic model. In addition, we have suggested using the ER approach for the representation of an integrated model and creating a domain base to support the dynamic relationship that exists in the integrated model. To further strengthen our integrated model, we have shown simulations of the integrated model based on real data. The simulations facilitate the decision makers in evaluating and forecast the decision situation at hand. Due to the nature of this domain, we have presented an integrated model integration framework which not only develops a new model from existing subroutines but also adaptively reacts to the needs of the environment and disaster situations. We summarize our work by investigating the following main components of the proposed framework: the knowledge base, the intelligent technique, the creation of an integrated model, the model representation, the domain base and simulations. We have also elaborated the design, algorithm and implementation details of the intelligent technique to further strengthen our approach. It is concluded that the simulation, along with the implemented integrated model, will significantly improve decision making in disaster management. The integrated model has shown a capability that can be used for applications ranging from the mitigation to the recovery phases of disaster management scenarios.

In future, we will investigate more complex disaster scenarios to further improve the usefulness of integrated model and simulation results. Our simulation results in this work show that their performance and accuracy can be improved by selecting new test cases.

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