MULTIAGENT DECISION SUPPORT FOR FLOOD EMERGENCY MANAGEMENT

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Abstract

An emergency situation is a complex and dynamic environment whereby the situation is always changing, uncertain and unpredictable. Consequences of an emergency or crisis whether natural or man-made disaster are loss of human lives and damages to property. In many instances, human responses to emergency are reactive in nature and in an 'ad-hoc' manner. The response operation also involved a lot of people from various level of jurisdiction and organization. Decision makers are under stress, have to response urgently without considering all possible alternatives due to the time limitation and incomplete information, at the same time preserving reliability, consistency and coherency in their decisions and coordinated activities.

An assistant technology rooted from an intelligent agent based system is an appropriate approach in guiding and assisting decision making processes of emergency managers especially during an emergency response operation. The nature of agents behavior which are autonomous, cooperative and proactive makes them a suitable method for designing and deployment of a dynamic and complex system.

This paper presents a conceptual multi-agent architecture in the area of active decision support systems for flood emergency management. This model is aimed at providing an autonomous monitoring system that will assess river and reservoir water level based on an online hydrological data. If the system detects a potential flood occurring, a self-triggering mechanism will form an agent task force that will assist the response operations. The lifetime of this team of agents ended when floods are over. An ontology on flood warning has also been developed using Protege2000 ontology development tools. This ontology was reused in the multi-agent framework developed.

1. Introduction

Loss of lives and damages to properties are the two main concern in a crisis. In this paper, crisis refers to natural disaster such as floods, earthquakes, typhoon or man-made disaster such as industrial accidents or terrorist attack. The terms crisis, disaster and emergency will be used interchangeably in this paper which refers to the state of danger or calamity. Number of death, evacuation operations, emergency centers, roads closed, food supplies are among the usual subject of communications in an emergency. Normally, the population will react on the onset of a disaster and response in an ad-hoc manner.

Emergency situation is a dynamic environment where events are always changing with a lot of uncertainties on what is/will be happening. The situation is unpredictable, full of stress and at the same time requires an urgent and rapid response in order to save lives and reduce further damages to properties. Emergency response operation also involves many people from various jurisdictional level and organizations from local, state and federal government including voluntary organizations. It is a complex system where the complexity arises from four factors: dynamism, interaction among many parts, uncertainty and risk. [1]

2. Emergency Environment and Complex Adaptive Systems

Comfort [2],[3],[4],[5],[6],[7],[8] has done extensive studies in crisis management in particular natural disaster like earthquakes from a complex adaptive systems (CAS) perspectives. CAS contains unique properties such as non-linearity, self-organizing and emergent behavior. Table 1 below shows the characteristics of complex adaptive systems.

Table 1 Characteristics of Complex Adaptive Systems

Characteristics of Complex Adaptive Systems
• Interaction and interdependent among components • Uncertainty and Limited Information • Non-linearity • Dynamism • Risk • Emergence of new structures • Self-organization

A self-organize system consists of autonomous, interrelated units that can create an organization or change its basic structure as a function of its experience and operating environment [5], [7] ,[9]. These interdependent units are capable of adapting to new information, reallocating its resources and actions to achieve a collective goal under changing conditions. This spontaneous and rapid process however vary significantly in timing, efficiency, effectiveness and reliability in practice, with associated cost of lives and property. A self-organize system produces an emergent behavior as a result of collective reaction of each autonomous unit. An emergency response operation is a self organize systems where new structure emerge as a result of a disaster consist of various organizations and volunteers working together with shared goal of saving lives. These separate units: the Fire, Police, Army and Medical Services and others move smoothly into coordinated action along with their emergency responsibilities.

3. Emergency Decision Making

Disaster environment and decision-making in this environment are fundamentally non-linear. Non-linearity can result an unpredictable emergent behaviors due to the interaction among components and between components and the environment. Building a model for complex adaptive systems is difficult due to the non-linearity and adaptivity of each components. A linear models or problem-solving approach are singularly not adequate for a non-linear systems [3]. In an emergency environment where timeliness and risk to lives and property are the main focus, analytical decision model is not appropriate [10], [11], [12], [13], [14], [15].

3.1 Naturalistic Decision-Making

In 1989, in a conference in Dayton, Ohio sponsored by The Army Research Institute, the term naturalistic decision-making (NDM) was first introduced [14]. In the NDM framework, research focuses on actual decision-making processes in the real world rather than laboratory settings where sizing up situations is critical and decision analysis is based on experiences of decision-makers. NDM is a recent approach of studying how human make decisions in the natural and field settings where rapid decision has to be made due to the time stress and high risk to human lives and property. Lipshitz [14] cited Zsambok's [16] definiton of NDM as " the way people used their experience to make decisions in the field settings"

NDM environment are characterized by factors such as time pressure, uncertainty, Ill-define or shifting goals, high stakes, ill-structured task, dynamic and continually changing conditions, multiple event feedback loops, multiple players, experienced decision-maker and organization goals and norm. A detail explanation of these characteristics are given by Deitch [17].

NDM is a paradigm shift in decision-making theory from the classical analytical and rational approach to an intuitive decision-making model [17]. In the classical approach, basically, the decision model are based on defining the problem, identifying alternatives, weighing each alternatives and choose the best or optimum decisions. This traditional model uses mathematical or probability techniques in weighing the alternatives whereas NDM uses a natural human approach which are knowledge and intuitive based. NDM is a descriptive approach of arriving with decision. Wong [18] further summarized the key feature of NDM decision models is situation assessment which is based on feature matching, story building and cues presented over a period of time. Single option is generated where evaluation on options are done serially or sequentially. The first option that works will be taken as the solution.

In an emergency situation where urgency is one of the main characteristics, a rapid decision model need to be used. In the classical method, every alternative will be evaluated against each other, a substantial amount of time will be spend on the choosing the most optimal option. Since the situation is also dynamic, the initial conditions might change which makes the option that will be selected is not relevant or effective anymore. Klein has came up with a model named 'recognition-primed decision" (RPD) to describe the decision process in an NDM kind of environment [10],[11]. RPD model is one of the most recognized model to describe decision-making for emergency situations and has been used as decision analysis techniques in various studies such as in military [12], marine [19], air force [13], fire fighting [20] and medical nurses [21].

3.2 Recognition Primed Decision Model

The RPD model was developed by Klein based on a cognitive task analysis of firefighter commander decision-making process in the field environment. The model describe how human working in an unpredictable environment make life and death dynamic decisions in the field settings. The basis of this model is situation assessment, pattern recognition and mental simulation. The key features in RPD model are single option where first option is a workable solution. If the option cannot meet the goals then the next option is considered or modified and improved from the previous option. Options are evaluated one at a time in serial. Due to the bounded rationality of human being, a satisficing solution or first solution that works will be selected. This option is evaluated mentally not through any mathematical, or statistical method. Table 2 below shows a comparison between analytical and the recognition approach.

Table 2 Comparison of Analytical and Recognitional Approach [12],[13],[16,[23]

	Analytic Mode	Recognitional Mode
Characteristics	Many alternatives Concurrent Evaluation Optimal Rational Prescriptive Quantitative	Single option Serial evaluation Satisficing Intuitive Descriptive Qualitative, Mental Simulation Experience based Situation Assessment centered Pattern Recognition
Strengths	Systematic procedures In depth course of action assessment Detailed comparison of options	Leverage expertise and experience Commander centered Rapid response Minimal resources required
Weaknesses	Limited effect of expertise and experience Garbage in Garbage out Dependent of accuracy of weight and scores Resource intensive	Limited analysis of options Shallow assessments of outcomes Potential “garden path” effects Limited number of options considered

The main focus in the recognitonal approach is rapid decision-making techniques in a naturalistic environment where analytical method will fail due to the stress of the disaster. Although analytical strategy sounds good but it often fails in practice. Figure 1 shows the RPD model in three basics formats. In its simplest version, decision maker recognizes the situation and knows the appropriate response. In second level, decision maker uses feature matching or story building techniques to derive to a solution. The third level indicates that a mental simulation activity take place before action is implemented.

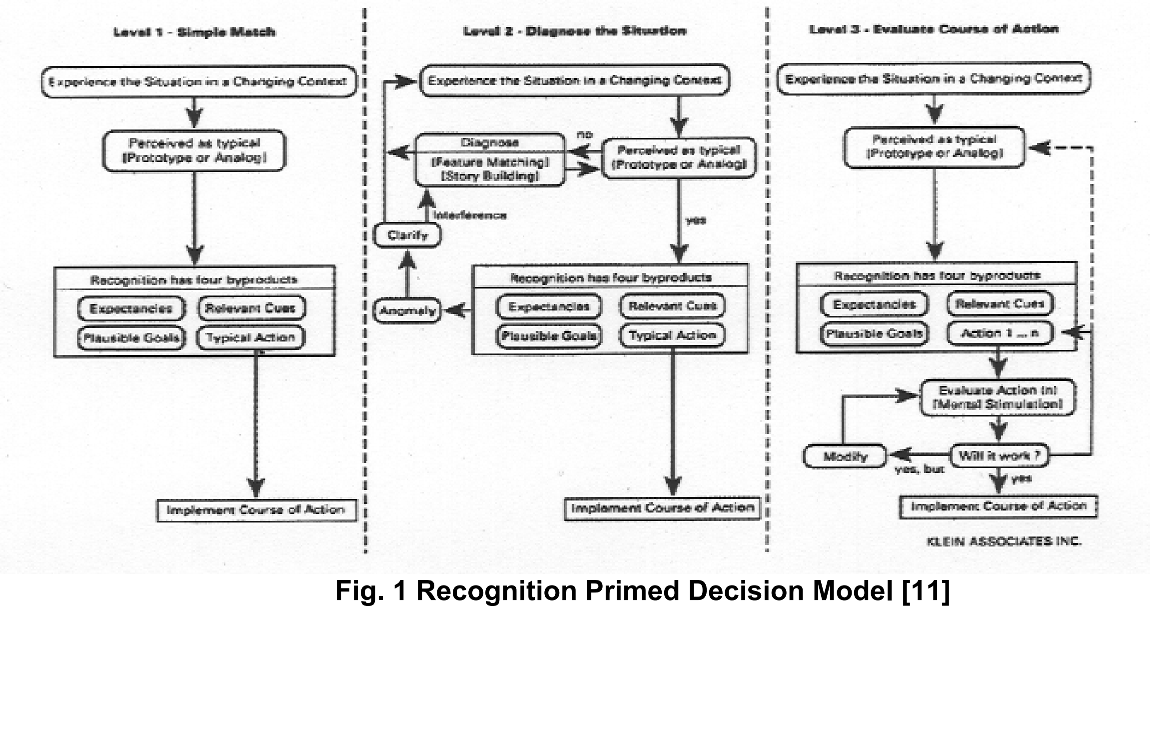


Fig. 1 Recognition Primed Decision Model [11]

According to Czerwinski [15], RPD is a type of pattern recognition approach where fifty to eighty percent of decisions made by experienced decision-makers use recognitional strategies and the rate goes higher for non-routine decisions.

Various studies has been done, applying the concept of NDM and RPD such as by Allardice [13] . His study links NDM theory and complexity theory and suggested a decision centered approach to command and control systems. He claimed that a decision centered approach of designing provides a more flexible and natural approach and will also reduce long term costs. Hoyman [21] examined the timeliness of nursing team's recognition of pressure ulcer risk using the RPD framework. If the delay is related to information overload she suggested that a computerized alert systems should offer an opportunity in assisting the nurses.

In another study, Brann et al. [23] proposed a conceptual architecture that uses case-based reasoning (CBR) to facilitate RPD model in supporting operations planning and automatic control at NASA Goddard Space Flight Center. A blackboard data structure were chosen for planning, control and assessment process. Norling et al. [24] also proposed a multi-agent based simulation using RPD model to enhance an agent architecture with human-like decision making strategies.

4. Multi-agent Decision Support for Flood Emergency Management : A Conceptual Model

The advancement in computer and communication technology enable significant improvements in crisis management and crisis response activities by providing better and wider communication infrastructure such as mobile wireless network and the Internet. Information can be reallocated and disseminated in a wider geographical area in distributed locations supporting decision-makers role in such a situation.

In a workshop held by Computer Science and Telecommunication Board (CSTB) of National Research Council, United States (1996) [26], issues and ideas regarding the adoption of technology in crisis management were discussed at length focusing on four main frameworks: networking, computation, information management and user-centered systems. However, in a non-linear and dynamic systems, linear problem-solving and management approach is not suitable

Agent oriented application development is a good match for complex and dynamic systems with ever changing situation. An agent is a computational entity that can perform task on behalf of user or other agents. Iba and Gervasio [26] recommended that a computational assistant rather that an automation technology is much more beneficial for crisis responders. This assistant technology rooted from an intelligent agent based systems have special characteristics such as autonomy, proactive, cooperative, communicative and reactive. Autonomous agent can change its behaviors with minimal human intervention according to the current situation. It can work in concert with other agents in a structure, working towards a similar goal asynchronously or sequentially depending on the situation. This collection of computational entity is called *multi-agent systems* (MAS). The organizational structure usually resembles a human organization or animal colonies such as ants and bees. Joint activities, interaction and cooperation are a natural approach in this social structure. Agents can enter, reenter or remove from the team according to the current needs of the system. These agents can communicate with each other, share knowledge of current situation, exchange needed information and share a common goal.

An MAS approach has potential advantages in developing complex software systems where managing complexity through agent-oriented decomposition, abstraction and flexible management of organization structural changes can be done naturally with agent oriented mindset and philosophy [28], [29]. The approach is suitable for applications that are inherently distributed whether in functions, control, location, resources or even expertise where each components in the systems need to be inter-connect and interact. An MAS can enhance overall system performance along the dimensions of computational efficiency, reliability, extensibility, robustness, maintainability, responsiveness, flexibility and reuse taking advantage of concurrency and parallelism of this approach and sophisticated pattern of interactions based on cooperation, coordination and negotiation [29],[30],[31],[32],[33].

In an emergency, various levels of jurisdiction and organizations will be involved in the emergency response operation representing a hierarchical structure of management. Each organization are given task and responsibilities where operations will be coordinated from a emergency operation center. Information and resources need to be moved, shared and distributed. Rapid decisions need to be made in this time stress situation. In a high risk situation, a decision aid can assist an emergency managers with information gathering tools. An intelligent systems that can reason, learn and guide decision processes can improve the response operation performance. Table 3 below summarizes the matching characteristics of emergency environment and multi-agent approach.

Table 3 Matching Characteristics of Emergency Environment and Multi-agent Systems

Emergency Environment	Multi-agent Systems
Involves many organizations and levels of jurisdiction	Collection of autonomous computational units called agent
Two main structures : command and control; coordination and cooperation	Sociable, Cooperative, Collaborative
Uncertain and dynamic	Adaptive to changes
Common Goal (saving lives and protecting property)	Goal–oriented : pro-active and reactive, shared mental model or goals
Distributed in nature (functions, location)	Distributed problem-solvers and mobile
Complex systems	Manage complexity by agent decomposition, interaction mechanism and flexible organizational structure

Due to the distributed nature of the emergency environment whether in functions, locations and resources, a multi-agent approach in building a support systems for emergency managers will be appropriate. Agents that are adaptive, pro-active and reactive can be designed to suit the ever changing situation in the environment. The self- organize and pro-active behavior of multi agents can enhance the preparedness activity in an emergency management phase and also later in the response and learning phase.

4.1 Problem Domain Analysis

Emergency or crisis management consists of five phases of interrelated activities: preparedness, mitigation, response, recovery and learning. Emergency response phase consists of several steps as shown in Figure 2 below.

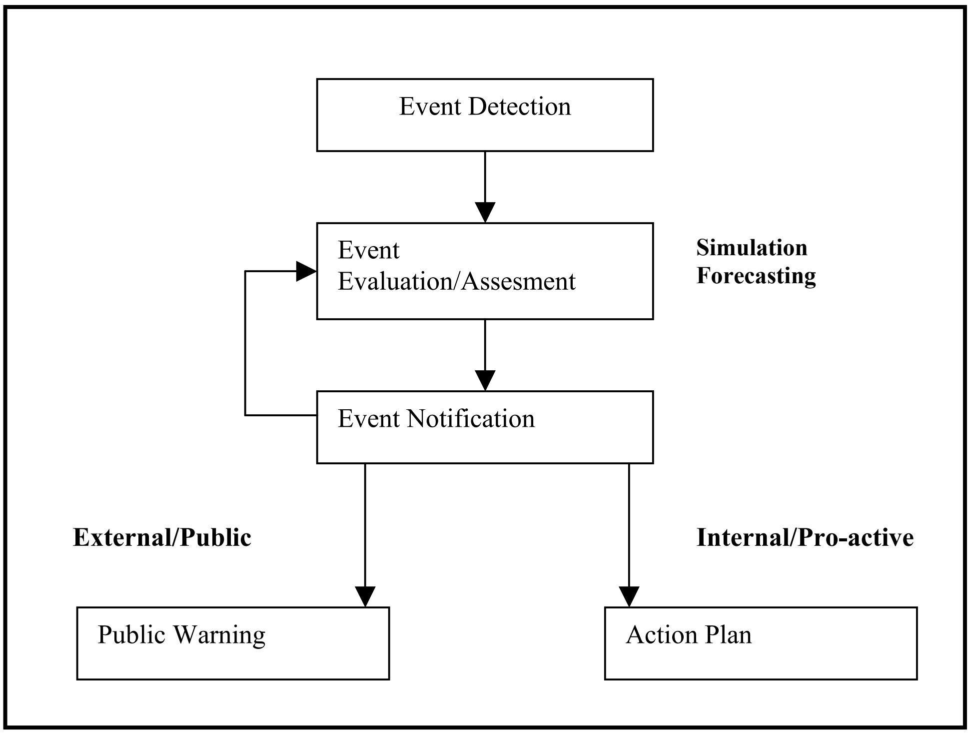


Fig. 2 Emergency Response Phase

Event Detection will answer question of *what is happening*. *What will or may happen* will be answered by the event evaluation or assessment. Event notification and action plan are activities in the *what to do* step. The action plan that will be implemented in this study is on the operation of a spillway gate based on Timah Tasuh Dam, in the State of Perlis, Malaysia. It involves a decision-making process determining the number of gates to be opened and the size of each gate openings. The decisions will be based on the most recent hydrological data obtained from the Drainage and Irrigation Department online-hydrological data web site and weather data from Meteorological Department website. Figure 3 below shows a use case diagram representing the general view of the proposed systems.

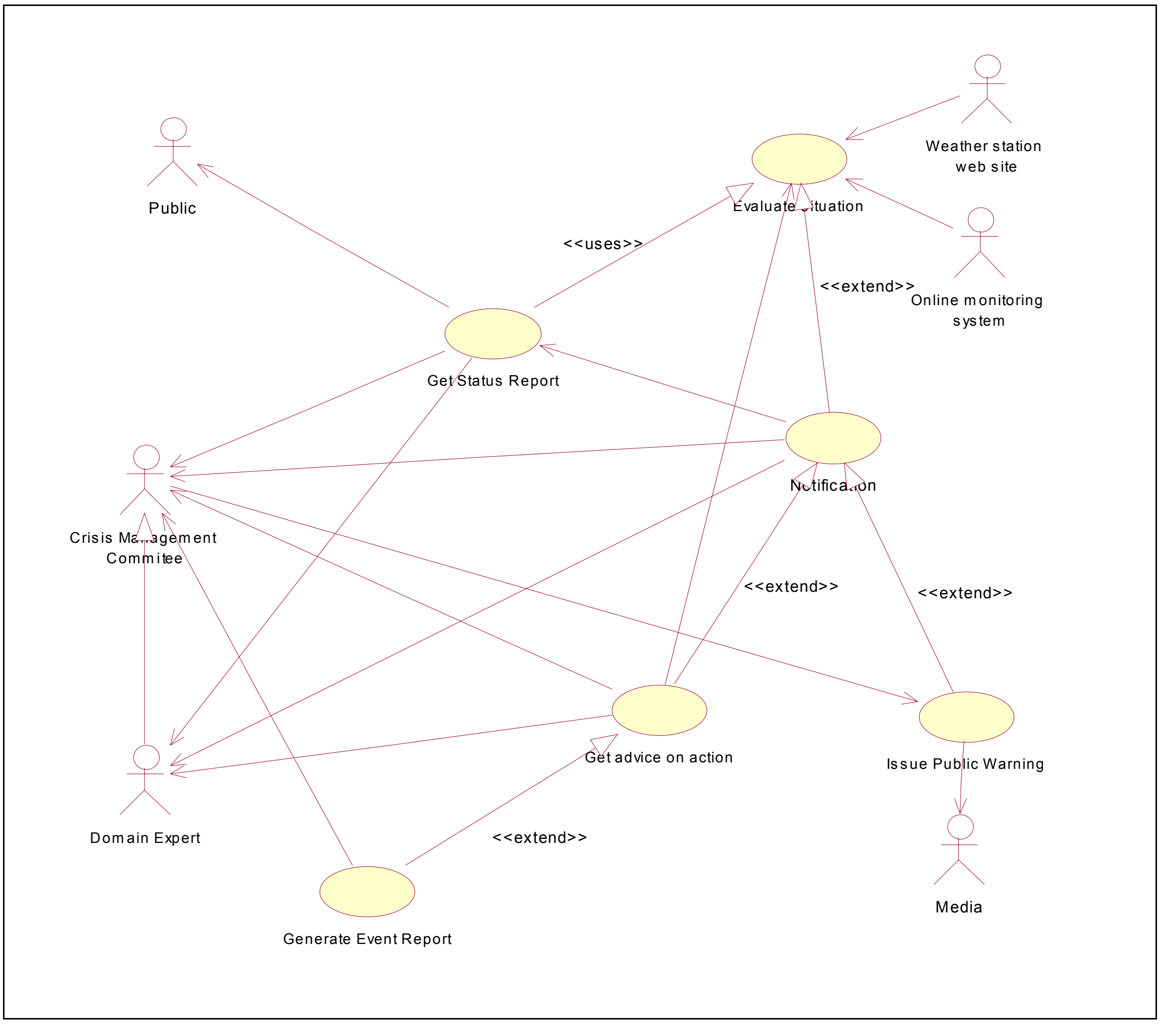


Fig. 3 Use Case diagram for Flood Emergency Response System

Based on ZEUS agent design methodology [34], two agent identification metrics: the sphere of responsibility test and the point of interaction test were used for the *agentification* steps. This process were further refined using Park et al. [35] agent selection rule. From this two methods five agents were identified:

i. *Facilitator agent :*Administrator for the multi-agent systems. Select agent and assign responsibilities according to situation

ii. *Monitoring agent:* Collect data and assess current situation based on schedule set by the facilitator. When the agent detect a potential event, it will send a message to the facilitator. Upon receiving request for report on current situation, it will display the report.

iii. *Notification agent :*Upon detection of a potential disaster, facilitator will activate Notification agent. Using a database of contact person, agent will send an automated email messages to the recipient in the list according to current stage of the flood. An alert signal will only requires notification to be send to domain expert. Danger and warning signals will automate email messages send to the emergency management committee and the mass media upon approval by the chairman of the committee. The agent operation will be adaptive to the stage of the flood.

iv. *Dam Management agent :*This agent act as an advisor to the domain expert thus the committee. It will give a recommendation on a suitable gate operations based on the current situation. This agent will be activated by the facilitator on reaching alert stage. The agent decision model will be based on RPD model. Case-based reasoning will be implemented to facilitate this model.

v. *Emergency Operation Center (EOC) agent :* This agent will activate the virtual eemergency operation center. In this study the detail implementation of this virtual EOC center is outside the scope.

Figure 4 shows the creation of each agent according to the current situation of the event to model a self organizing behavior of a complex system. Notification, Dam management and virtual EOC agent will be created at runtime upon detection of flood event. In the normal days, only facilitator and monitoring agent will be active.

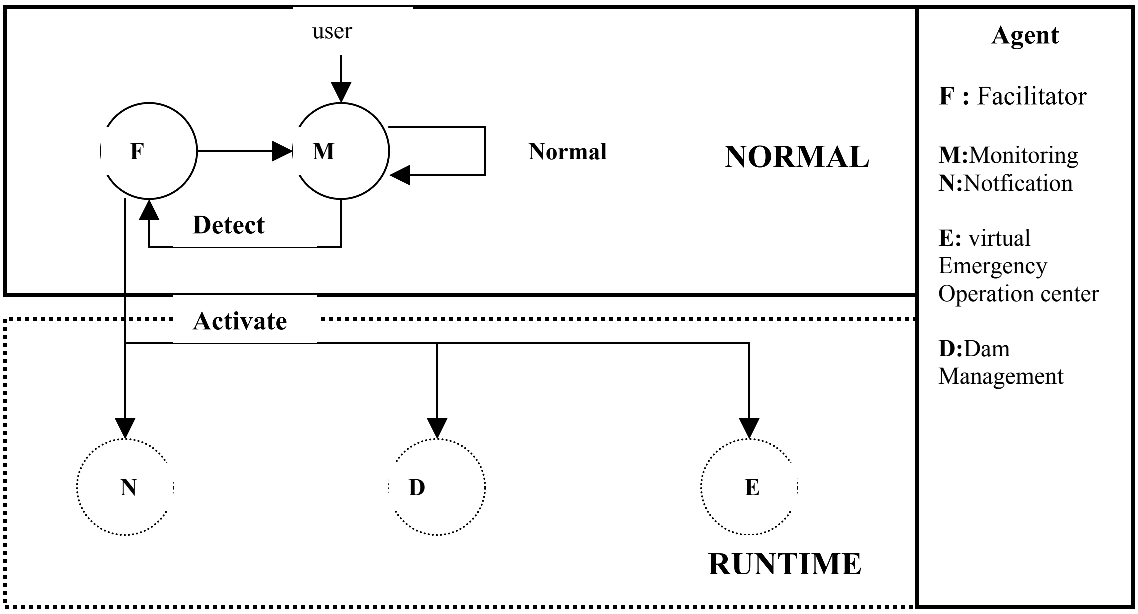


Fig. 4 Self-organizing multi-agent in flood response systems.

An ontology for the flood response systems has also been created based Methontology methodology and using Protege2000 as the ontology development environment. This ontology has been tested with a Java Expert System shell (JESS). Figure 5a,b and c below shows the preliminary ontology developed.

Flood Analysis
- Report Date
- Flood Location
- Description
- Report by

Flood Location
- District
- State
- Date
- Location
  - Station ID
  - Stage

Flood Response
- Stage
- Action Plans
  - Action Line
  - Action By
  - Output

Fig. 5a:Concept Classification Tree of Flood Ontology

Hydrology Network
- State
- River Level Stations
  - Station ID
  - Station Name
  - River Basin
  - Normal Level
  - Alert Level
  - Danger Level
- Rainfall Station
  - Station ID
  - Station Name
  - District

Hydrology Data
- River Level Information
  - Station ID
  - Update Time
  - Update Date
  - River Level
- Rainfall Information
  - Station ID
  - Update Time
  - Update Date
  - Today's Rainfall
  - Daily Rainfall
    - Today – 1
    - Today – 2
    - Today –3

Fig. 5b : Concept Classification Tree of Hydrology Data Ontology

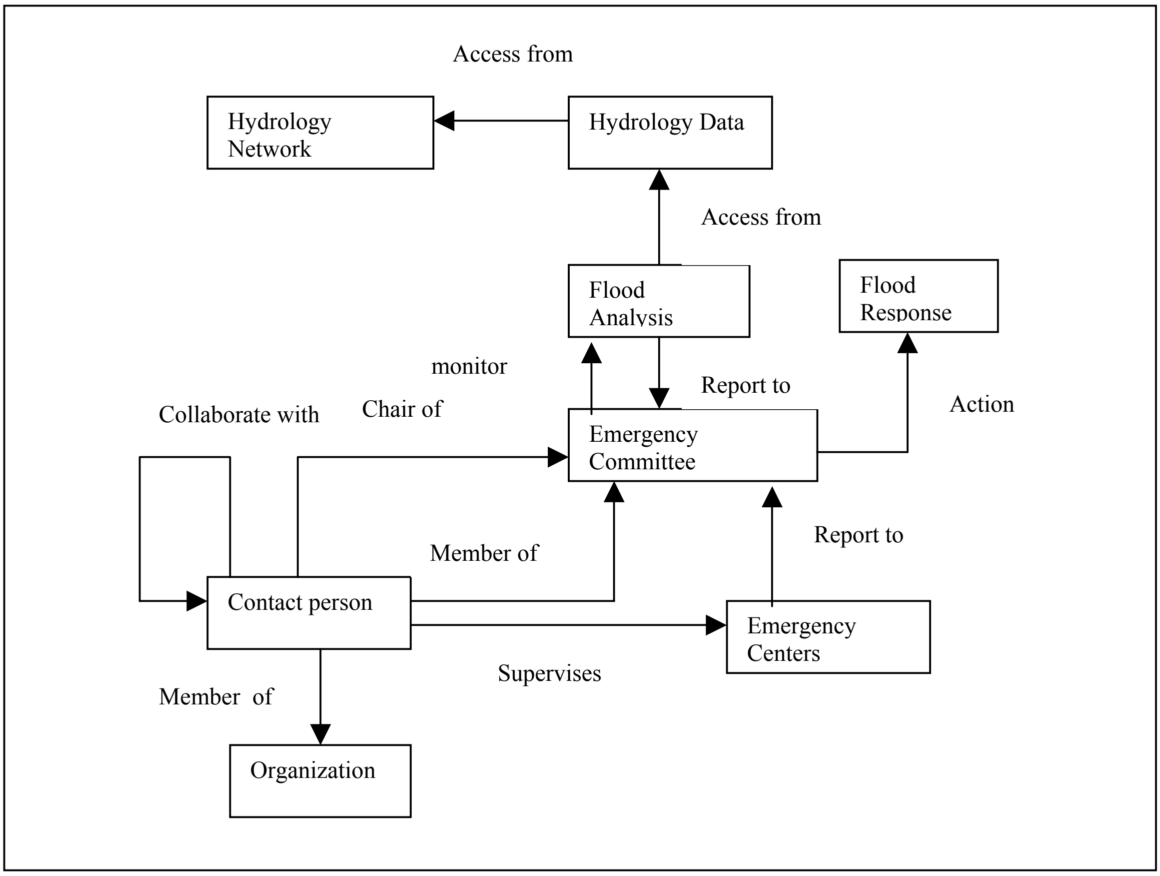
Emergency Committee
- Chairman
- Committee
  - Supplies and Assistance Chairman
  - Evacuation Chairman
  - Transportation Chairman
- Human Resource Chairman
  - Information Chairman

Contact Person
- Name
- Position
- Organization
- Office Phone
- Home Phone
- Hand Phone

Emergency Centers
- Sector
- Area
  - Evacuation Center
  - Officer In Charge
    - Name
    - Position
  - Front Base

Figure 5c: Concept Classification Tree of Emergency Management

Figure 6 shows the most representative "ad-hoc" binary relationships describe in the Diagram of Binary Relations of the ontology conceptual model. For example , Emergency Committee monitors floods from the flood reports generated. This diagram establish relationships between concepts of the same or different ontologies.



5. Conclusion

A prototype of monitoring, notification and dam management agent has been developed using rule-based reasoning techniques. This approach is rather rigid where decisions are hard wired as a situation-action match. New addition to rules needs to ensure it preserves the consistency and coherency in decisions. Future works will look at computational techniques that can facilitate RPD model such as case based reasoning. Ways to improve the current multi-agent architecture will also be look at closely especially in the communication, messaging and coordination mechanism.

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