Conceptual Framework for Intelligent Decision Support System in Emergency Management

Wan Hussain Wan Ishak[1], Ku Ruhana Ku Mahamud[2], Norita Md Norwawi[3]

[12]*College of Arts and Sciences, Universiti Utara Malaysia*

[3]*Faculty of Science and Technology, Universiti Sains Islam Malaysia*

ABSTRACT

Emergency is a critical situation that emerges due to number of circumstances, typically natural disasters or technological disasters. Emergency demands immediate action from the authority and the public involved. A failure to response and making earlier decision to emergency situation could cause severe damages and possibility of loss of life. Computer application known as decision support system (DSS) has been introduced to model and support human decision making. The DSS is an interactive computer based system with the aim to assist user to make decision using available resources (information and knowledge) in a specific domain. In conjunction to DSS, an Intelligent Decision Support System (IDSS) has been introduced. IDSS is an integration of DSS and Artificial Intelligence (AI). To date, AI techniques that demonstrate high level of machine learning quotient is constituent by computational intelligence (CI) paradigm. In this paper, the general characteristics of the emergency situations are identified and mapped with the Naturalistic Decision Model. The conceptual framework for IDSS in emergency management, particularly for reservoir operation management is proposed.

Keywords: Decision Support System, Intelligent Decision Support System, Emergency Management, Reservoir Operation Management

INTRODUCTION

Emergency is a severe situation or occurrence that could happen without warning. Emergency situations can be distinguished by two generic categories that are natural disaster and technological disaster as initiated by Centre for Research on the Epidemiology of Disasters (CRED) (Table 1). Natural disasters include earthquake, landslips, mud flows, fires, typhoon, floods and avalanches that happen due to natural phenomenon (IFRC, 2009). Technological disasters are those that caused by human being which are associated to industrial or economic activities. Emergency situation cause hazard to human life, environment and physical structure resulting the loss of life, deterioration of environment and damage to the physical structure.

Table 1: Category and Types of Disaster

Category	Sub-groups	Type of Disaster
Natural	Biological Disaster	insect infestations, epidemics and animal attacks
	Geophysical Disasters	earthquakes and tsunamis, volcanic eruptions, dry mass movements (avalanches, landslides, rockfalls and subsidence of geophysical origin)
	Climatological Disasters	droughts, extreme temperatures and wildfires
	Hydrological Disasters	floods (including waves and surges), wet mass movements (avalanches, mud/landslides, rockfalls and subsidence of hydrological origin)
	Meteorological Disasters	storms
Technological	Industrial Accidents	chemical spills, collapse of industrial infrastructure, explosions, fires, gas leaks, poisoning, radiation
	Transport Accidents	transport by air, rail, road or water
	Miscellaneous Accidents	collapse of domestic/non-industrial structures, explosions, fires

Source: IFRC, World Disaster Report (2009)

The characteristics of emergency situations have been explicitly or implicitly highlighted and discussed in most of the related literatures. Table 2 summarizes the characteristics of the emergency situation.

Table 2: Characteristics of Emergency Situation

Characteristic	References
Dynamic	Philips-Wren (2009), Becerra-Fernandez et al. (2008), Rao et al. (2007), Gaynor et al. (2005), Norwawi (2004), Shrestha (2001)
Urgency	Philips-Wren (2009), Becerra-Fernandez et al. (2008), Gaynor et al. (2005), Iba and Gervasio (1997)
Uncertain	Philips-Wren (2009), Rao et al. (2007), Gaynor et al. (2005), Iba and Gervasio (1997)
Complex	Becerra-Fernandez et al. (2008), Norwawi (2004)
High Risk	Raschky (2008), Iba and Gervasio (1997)
Previous action dependent	Feigh and Pritchett (2006)

Dynamic is a state that is continuous, changing and not static. Dynamism associated with the emergency environment is the main characteristic of emergency situation. In dynamic environment the situation can change rapidly, thus force time-pressured decisions (Philips-Wren, 2009; Gaynor et al., 2005). Situation that associated with time will need a quick and fast decision due to time constraint. In typical emergency situation, quick decision will determine the survival of victim and minimize the lost.

Uncertainty pervades the whole process of decision during emergency situation. Uncertainty occurred in many form such as incomplete information, vagueness, and ambiguity. Sources of uncertainty would be many such as faulty of the devices, wrong interpretation of the data due to poor handwriting, interruption or noise in communication and others.

Emergency situation is complex in nature. The complexity arises due to dependency of the elements in emergency situation. In reservoir flood control for example, the water release decision is highly dependent on the rainfall and the increase of water level. The water release decision is also influenced by the water use policy.

Another common characteristic of emergency situation is risk. Risk is “The probability that negative consequences may arise when hazards interact with vulnerable areas, people, property and environment” (Abarquez and Murshed, 2004, p.6). Risk is produced both by natural and man-made disasters. Earthquake for example will cause damage to the infrastructure and also kill the living. Some of the disasters occur as a result of the occurrences of the event. For example, flood occurs due to the heavy rain for two or three days earlier.

In this paper, the emergency environment chosen is the reservoir management due to its critical function in flood control and drought management which are common disasters in Malaysia. Reservoir management has been one of the potential applications in IDSS due to the complexity of the operation, expert knowledge requirement and intelligent judgement (Simonovic and Savic, 1989). Reservoir plays an important function in water resources planning and management. Typically two categories of reservoir have been established around the world which are single and multi-purpose reservoir. The operation problem for a single-purpose reservoir is to decide the adequate release volume so that the benefits for that purpose is maximized. The operation of multi-purposes reservoir inherit the same problem, additionally, the release need to be optimally allocated among purposes.

EMERGENCIES ASSOCIATED WITH RESERVOIR

Reservoir is a physical structure such as pond or lake either natural or artificially developed to impound and regulate the water. Reservoir dam is built using materials such as concrete, steel, soil and sand is prone to damage due to aging, environmental effect, human and technological error. Mohd-Hassin (2008) has compiled some of the dam failure cases from 1828 to 2006. The typical factors identified are heavy rainfall, geological, and poor maintenance. Heavy rainfall increases the reservoir water level up to the maximum water level cause overflow and reduces the integrity of the reservoir dam wall. Geological factor such as earthquake causes crack and leakage to dam structure. In a period of time, the structure might burst or collapse. Poor maintenance of the reservoir dam especially old dams could affect dams’ operation which may result malfunction or failure to dam’s components.

Dam failure will not only affect its purposes, but the major effect is flooding. Flood is one of the severe emergencies which are associated with reservoir operation. This is a fact as most of dams' failure that resulted collapse or burst will discharge large magnitude of water to the downstream. The impact is devastating; major flood, heavy flow wash away everything on its path, leaving damages to infrastructures, death and injuries These impacts are evident by Situ Gintung Dam incident located at the south-west edge of Jakarta, Indonesia (BBC News, 2009).

Another emergency that is associated with the reservoir is water shortage (drought). Drought is a critical situation causing more death compared to other natural disasters (Below et al., 2007). The reservoir operation during less intense rainfall is aimed to impound water and the water release is constraint to its major usage that is water supply. During this period, the flood-control reservoir has to establish operating policies for water allocation so that the supply can be optimized (Chang et al., 1995). Similar to other hazards, drought can be described by its magnitude, duration, location, and timing (Below et al., 2007).

INTELLIGENT DECISION SUPPORT SYSTEM

Emergency management is inherently complex and dynamic task, requiring quick knowledge sharing and decision coordination among parties involved (Becerra-Fernandez et al., 2008). According to Rao et al. (2007):

> "Making good decisions and taking appropriate action during extreme events require having access to communications, data, and computational resources that can be used to effectively coordinate a large number of geographically dispersed participants and assets, to exchange a wide variety of types of information, and to evaluate many scenarios and responses-all of which are changing dynamically."

In emergency situation, "decisions must be made in human perceptual timeframes under pressure to respond to dynamic uncertain conditions" (Gaynor et al., 2005). Moreover, "information can be inaccurate or obtained from multiple sources that are inconsistent with each other, resulting in uncertainty and information overload for the user" (Philips-Wren, 2009). Uncertain conditions are very difficult to interpret as the data are vague and incomplete. Access to the data is difficult (Philips-Wren, 2009) where a presentation in a form that can be understood by the management is very crucial (Gaynor et al., 2005). In addition, the interdependence between subsequent decision and the time constraint (Feigh and Pritchett, 2006) increase the complexity of the decision process. The complexity of the problem required experience decision maker to make an accurate decision (Sinha, 2005). These problems are the criteria that are considered in naturalistic decision making (NDM).

NDM is one of the approaches to model the decision making in emergency environment (Lipshitz et al., 2001). An intelligent decision model, namely intelligent decision support system (IDSS) is one of the potential solutions to support decision maker in emergency situation. IDSS is an integration of decision support system (DSS) and Artificial Intelligence (AI). In line with NDM, IDSS is dynamic, capable to utilize the situation information and manipulating experience as the system's knowledge. To date, AI techniques that demonstrate high level of machine learning quotient is constituent of computational intelligence (CI) paradigm (Jain et al., 2008).

The CI provides "intelligent" capability that will enhance DSS. The capabilities include exhibit adaptive goal-oriented behaviour, learn from experience, use vast amounts of knowledge, exhibit self-awareness, interact with humans, tolerate error and ambiguity in communication, and respond in real time (Reddy, 1996). These capabilities are what have been expected to be integrated in DSS to improve its efficiency and effectiveness (Shim et al., 2002; Karacapilidis, 2006) by given the DSS the capability to reason, make judgements, and even learn (Wallace and Balogh, 1985). Utilizing these capabilities will create an intelligence assistance that can be used to ease the burden of the expert routine tasks (Miksch, 1995).

CONCEPTUAL FRAMEWORK FOR IDSS IN RESERVOIR EMERGENCY MANAGEMENT

A reservoir system can be divided into four components namely, upstream, reservoir catchment, the spillway gate, and downstream (Figure 1). The upstream consists of one or several rivers that carry the water into the reservoir. The water is stored in the reservoir catchment before releases through the spillway gate to the downstream. This kind of system is designed to ensure that the upstream water flow does not directly flow to the downstream. The reservoir system will control the water flow and the releases within the safe carrying capacity of the downstream river (Smith and Ward, 1998), thus minimize the downstream damages (Jain and Singh, 2003).

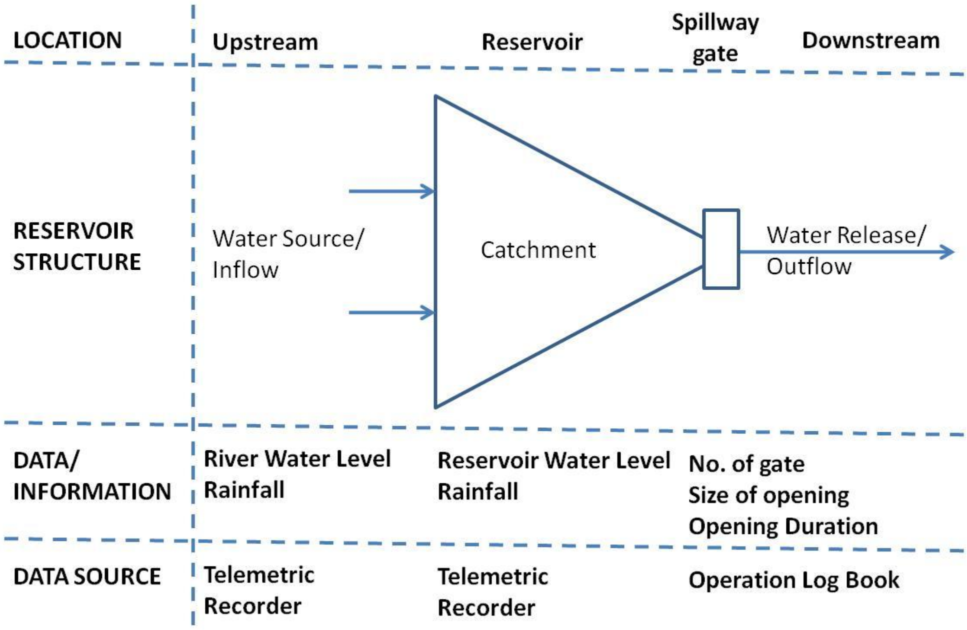

Figure 1: Conceptual Model of Reservoir System

As shown in Figure 1, each component of the reservoir system is associated with data or information. The water level and rainfall are prevalence in both upstream and the reservoir catchments. These data are recorded hourly using the telemetric recorder situated at the strategic location of both upstream river and reservoir. At the spillway gate, the typical data are no. of gate opened, the size of opening, and the opening duration. These data are recorded manually by the reservoir operator in the operation log book.

The theoretical framework in Figure 2, shows the mapping between the conceptual and computational level, and the relationship between the emergency environment and the real world practice. The emergency situations inherit several characteristics namely, dynamic, urgency, uncertain, complex, high risk, and previous action dependent. These characteristics are also apart of the problem that solved by naturalistic decision making (NDM). An intelligent decision model is view as apart of NDM, consists of three main sub-models: situation assessment model, expectancy forecasting, and decision model. The emergency management consists of three major tasks required an adaptive and dynamic system to enable fast decision.

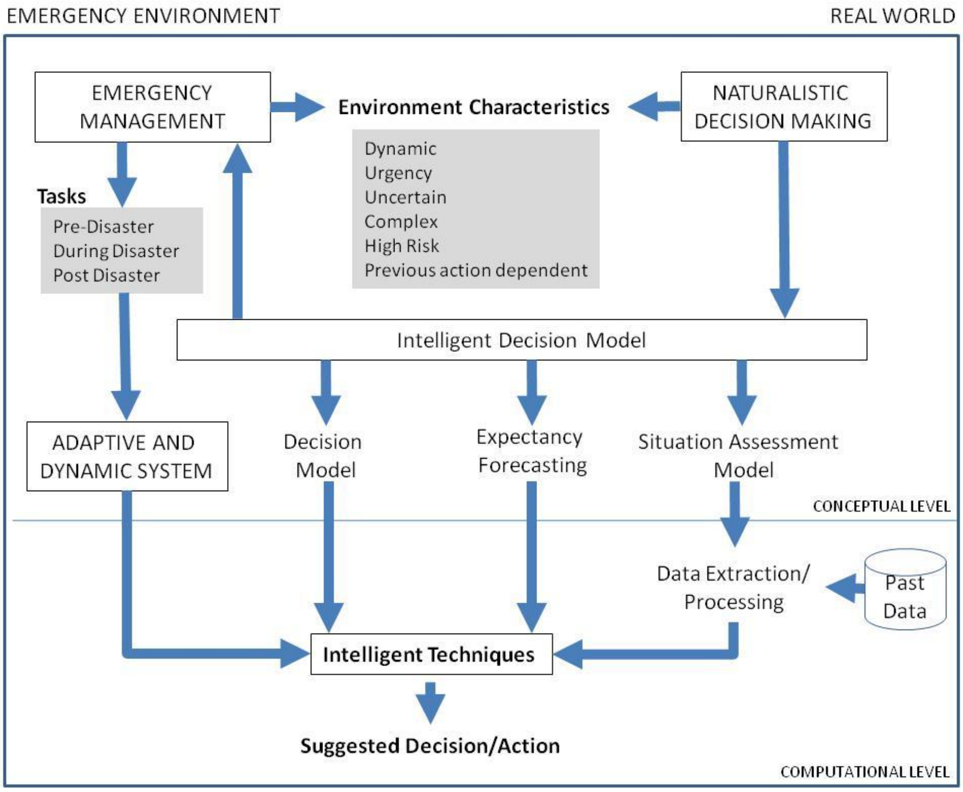

Figure 2: Theoretical Framework

In a computational level, the adaptive and dynamic system and the intelligent decision model are implemented using intelligent techniques. The inference is based on past data which is extracted from multiple databases for example, telemetry and reservoir operation database. Figure 3 shows the conceptual of IDSS for reservoir operation.

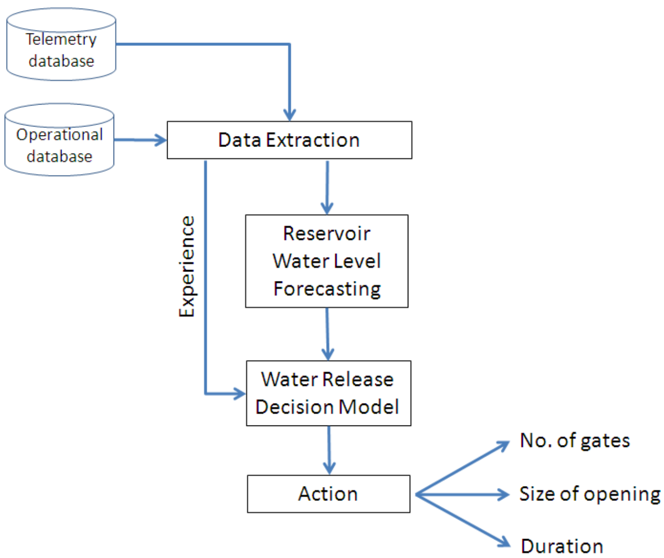

Figure 3: Conceptual Model of IDSS for Reservoir Operation

As shown in Figure 3, data extraction component will extract the data from both databases. The extraction process will include data integration, data preprocessing, temporal data mining, and post processing. The extracted data will be feed into forecasting model, which will calculate the probability of the rising of reservoir water level using AI technique based on data at time *t-1, t-2,* and *t-n*. The result of this model is the forecasted water level at time *t*. The forecasted data will be used in the decision model. Finally, the decision which includes the no. of gates, size of opening, and the opening duration will be produced.

CONCLUSION

Emergency situation is caused by disaster, which has been categorized as natural and technological disasters. Natural disasters are those that caused by natural phenomena, while technological disasters are related to technology developed by human being. Emergency situation has been characterized as dynamic, urgency, uncertain, complex, high risk, and previous action dependent.

Reservoir operation management has been identified as one of the emergency environment. Two major emergency situations that are associated with the reservoir are flood and drought. Flood is a situation that cause by heavy rain, while drought is a situation where water level is dropped down due to less intense rain fall. Both situations are severe as flood can drown and damage the area effected, while drought cause waterless.

The characteristics of the emergency situation have made it difficult for the decision maker to take fast and accurate action. Typically, during emergency the decision is made by selecting the best course of action without evaluating different alternatives. An intelligent approach to support the decision making has been discussed to be one of the promising alternatives in emergency situation, particularly during flood and drought. The intelligent decision model is capable to perform the situational assessment and utilizing decision maker experience as apart of its functionalities. These characteristics have satisfied the requirement of NDM.

REFERENCES

Abarquez, I. and Murshed, Z. (2004). *Field Practitioners' Handbook*. Thailand: Asian Disaster Preparedness Center.

Becerra-Fernandez, I., Xia, W., Gud, A., and Rocha, J. (2008). Emergency Management Task Characteristics, Knowledge Sharing and Integration and Task Performance: Research Agenda and Challenges. In Frank Fiedrich and Bartel Van de Walle, *Proceedings of the 5th International ISCRAM Conference*, pp: 88-92. Retrieved from http://www.iscram.org/ on 12 Ogos 2009.

Below, R., Grover-Kopec, E., and Dilley, M. (2007). Documenting Drought-Related Disasters: A Global Reassessment. *The Journal of Environment & Development, 16(3),* pp: 328-344.

Chang, T. J., Kleopa, X. A., and Teoh, C. B. (1995). Use of Flood-Control Reservoirs for Drought Management. *Journal of Irrigation and Drainage Management, 121(1),* pp: 34-42.

Feigh, K. and Pritchett, A. (2006). Design of Support Systems for Dynamic Decision Making in Airline Operations. Proceedings of the 2006 Systems and Information Engineering Design Symposium, pp: 136-141. Retrieved from IEEE Xplore DOI: 10.1109/SIEDS.2006.278727

Gaynor, M., Selltzer, M., Moulton, S., and Freedman, J. (2005). A Dynamic, Data-Driven, Decision Support System for Emergency Medical Services. In Sunderam, V.S., Albada, G. D., Sloot, and Dongarra, J. J. (Eds), *Computational Science – ICCS 2005, Lecture Notes in Computer Science,* Vol. 3515, pp: 703-711. Springer-Verlag: Berlin. Retrieved from SpringerLink DOI: 10.1007/b136571

Iba, W. & Gervasio, M. T. (1997). Crisis response planning: a task analysis. Preliminary Technical Report. Institute for the Study of Learning and Expertise, California. Retrieved from: http://www.isle.org/~gervasio/mycrisis.html on 11 Ogos 2009.

IFRC (2009). *World Disaster Report 2009: Focus on Early Warning, Early Action*. International Federation of Red Cross and Red Crescent Societies.

Jain, L. C., Tan, S. C., and Lim, C. P. (2008). An Introduction to Computational Intelligence Paradigms. In Jain, L. C., Sato-Ilic, M., Virvou, M., Tsihrintzis, G. A., Balas, V. E., and Abeynayake, C. (Eds.). *Computational Intelligence Paradigms: Innovative Applications, Studies in Computational Intelligence,* Vol. 137, pp: 1-12. Springer-Verlag: Berlin. Retrieved from SpringerLink DOI: 10.1007/978-3-540-79474-5

Karacapilidis, N. (2006). An Overview of Future Challenges of Decision support Technologies. In J. Gupta, G. Forgionne and M. Mora (Eds.), *Intelligent Decision-Making Support Systems: Foundations, Applications and Challenges*, Springer-Verlag, London, UK, 2006, pp. 385-399.

Miksch, S. (1995). Artificial intelligence for decision support: needs, possibilities, and limitations in ICU. In: Gullo, A. (Ed.), Anaesthesia, Pain, Intensive Care, and Emergency Medicine (APICE-95), Proceedings of the 10th Postgraduate Course in Critical Care Medicine, Springer, Berlin. pp. 901-908.

Mohd-Hassin, M-H. (2008). Temporal Case-Based Reasoning Model for Reservoir Spillway Gate Operation Recommendation. *MSc IT Thesis,* Universiti Utara Malaysia

Norwawi, N. M. (2004). Computational Recognition-Primed Decision Model Based on Temporal Data Mining Approach in a Multiagent Environment for Reservoir Flood Control Decision. *PhD Thesis*. Faculty of Information Technology, Universiti Utara Malaysia.

Philips-Wren, G. (2009). Adaptive Decision Support for Dynamic Environments. In Nakamatsu, K., Phillips-Wren, G., Jain, L.C., and Howlett, R.J. (Eds.), *New Advances in Intelligent Decision Technologies,* Vol. 199/2009, pp: 235-243, Springler-Verlag Berlin. Retrieved from SpringlerLink DOI: 10.1007/978-3-642-00909-9

Rao, R. R., Eisenberg, J., and Schmitt, T. (2007). *Improving Disaster Management: The Role of IT in Mitigation, Preparedness, Response, and*

Recovery. National Academy Press: Washington. Retrieved from: http://www.nap.edu/catalog/11824.html on 11 Ogos 2009.

Raschky, P. A. (2008). Institutions and the Losses from Natural Disasters. *Nat. Hazards Earth Syst. Sci,* 8, pp: 627-634.

Reddy, J. (1996). The Challenge of Artificial Intelligence, *Computer, 29(10),* pp: 86 - 98

Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., and Carlsson, C. (2002). Past, Present, and Future of Decision Support Technology. *Decision Support System*, *33,* pp: 111-126.

Shrestha, B. K. (2001). Disaster Reduction and Response Preparedness in Japan: A Hyogo Approach. *The Second Tempere Conference on Disaster Communications, 28-30 May 2001*. Retrieved from: http://www.reliefweb.int/telecoms/conference/cdc2001/cdc2001program.html on August 4, 2008

Simonovic, S. P. & Savic, D. A. (1989) Intelligent decision support and reservoir management and operations. *Journal of Computing in Civil Engineering, 3,* pp: 367- 385

Sinha, R. (2005). Impact of Experience on Decision Making in Emergency Situation. *Psychology C/D: Extended Essay*. Department of Human Work Sciences, Lulea University of Technology

Wallace, W. A., and Balogh, F. D. (1985). Decision Support Systems for Disaster Management. *Public Administration Review,* 45, pp: 134-146.

BBC News (2009, May). Indonesia dam burst kills dozens. Retrieved from http://news.bbc.co.uk/go/pr/fr/-/2/hi/asia-pacific/7967205.stm on Sept. 10, 1009.