Conceptual Model of Intelligent Decision Support System Based on Naturalistic Decision Theory for Reservoir Operation during Emergency Situation

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***Abstract*—Emergency situation required fast and accurate decision as every decision is very critical to save human lives. Naturally, during this situation humans made decision based on their past experiences by which their nerves and brain system will perceive the situation and mapped with their experiences to produce action. This naturalistic decision making approach has been one of the attention in emergency management research. In this paper a conceptual model of Intelligent Decision Support System for reservoir operation during emergency situation is proposed. This model simulates human decision based on three models: situation assessment, expectancy forecasting, and decision modeling. Situation assessment is to extract the temporal data from the hydrological and operational databases. This data will be used in the forecasting module, to forecast the future event. The decision module will utilized the temporal and the forecasted data to produce the final decision. Artificial intelligence techniques are utilized in every model. The model is expected to assist reservoir operator in making decision during emergency situation; typically during heavy rainfall when early and fast decision is required to release the reservoir water in order to leave enough space for incoming water and to release the water in the save carrying capacity of the downstream channel. Thus avoiding flood in downstream areas.**

***Index Term*— Emergency Management, Reservoir Management, Intelligent Decision Support System, Soft Computing, Naturalistic Decision Making**

I. INTRODUCTION

Decision commonly is defined as making a choice from a set of alternatives [1,2]. It involves series of action which resulted from an inference of facts or information. Typically, modelling decision making is based on two main approaches [3]: classical and naturalistic decision theory. Classical decision making (CDM) is the oldest theory in decision making. CDM focus on how people make decision based on the choices [3]. The essential characteristics of CDM were choice (choosing among concurrently available alternatives), input-output orientation, comprehensiveness and formalism [4].

Bohanec [2] stated that DM refers to "the whole process of making the choice" which begins from problem assessment, information gathering, identifying alternatives, anticipating consequences, action and evaluating the decisions. The major activities in DM processes are problem recognition, information search, problem analysis, alternative evaluation, and decision [1,2]. The interrelation among the activities is shown in Figure 1.

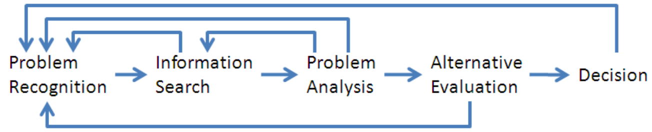

Fig. 1. Major Activities in Decision Making Process [1]

During emergency, DM is more complex and made in an urgent, real time and uncertain situations. Each step in the decision making process is interrelated and very crucial to ensure the relevance and the success of the decision. CDM provide a prescriptive guideline for making better decision, however failed to address how people actually make decisions [5]. This limitation has lead to the introduction of a new theory called naturalistic decision making (NDM).

NDM is a study of how people make decision in dynamic, challenging and emergency situations [3,5,6]. The essential characteristics for NDM are process orientation, situation-action matching decision rules, context-bound informal modelling, and empirical-based prescription [4]. Table 1 summarizes the different between CDM and NDM.

Information [7,8], knowledge [8] and experience [9] are very important in DM. Diverse information and knowledge required in making the decision bound the cognitive limits of the decision maker. Cognitive limit is the limited coverage of individual's problem-solving capability [10]. Zack [8] highlighted four major challenges faced by the decision maker related to the use of information and knowledge in DM; uncertainty, complexity, ambiguity and equivocality.

TABLE 1
COMPARISON OF CDM AND NDM [3,4,6]

	CDM	NDM
Type	Normative and Prescriptive	Descriptive
Strategy	Analytical	Intuitive
Human Experience	Ignored	Experience-based
Orientation	Input-output Orientation	Process Orientation
Decision rules/judgment	Based on rational choice or alternative	Situation assessment
Data Criteria	Fixed set	Dynamic
Modelling	Context-free formal modelling	Context-bound informal modelling

Uncertainty is cause by the information deficiency in DM. It is one of the important factors in DM [3]. The complexity problem arises due to overload of information which causes difficulty to decision maker as they are not easily processed and interpreted. The lack of knowledge in DM process cause ambiguity problem, which causes difficulty in interpreting the information. However, too much knowledge could cause equivocality problem due to inconsistency of the knowledge. Due to this deficiency computer has been used as one of the aiding tools to assist decision maker [11]. This tool is known as computerized decision support system (DSS). It has been predicted that, the computer will not only display factual real-time data, but also statistical extrapolations, decision, and risk prediction with alternative courses of action [12]. Rao et al. [13] highlighted:

> "The challenge of disaster management is reducing the harm disasters cause to society, the economy, and the lives of individuals and communities. That task requires disaster managers to reduce uncertainty, to calculate and compare costs and benefits, and to manage resources, often on a much larger scale and at a much faster pace than are supported by methods and means for solving ordinary problems. IT provides capabilities that can help people grasp the dynamic realities of a disaster more clearly and help them formulate better decisions more quickly. And IT can help keep better track of the myriad details involved in all phases of disaster management."

Experience during the emergency, is one of the most influential factors that affect the decision making process [9]. Experience helps decision makers select the best course of action based on the situation that they are facing. In NDM, experience is one of the main facets of decision making.

II. INTELLIGENT DECISION SUPPORT SYSTEM FOR EMERGENCY MANAGEMENT

In real world environment, decision maker may experience several limitations namely faulty in data, different observation frequencies, different regularities, different data types, fuzzy and incomplete knowledge [14]. These limitations cannot be solved using traditional DSS approach. The traditional DSS does not support decision but dump data on the screen assuming that the user will know what to do, thus limit the interaction with the user [15]. This limitation reduces the efficacy of the DSS. Decision support framework [10] categorised decision into three types: structures, semi-structured and unstructured. Each category is practical at different type of controls: operational, managerial and strategic planning. Unstructured type of decision and control at the strategic planning typically required advance supporting technology such as expert system and neural networks.

The intelligent system 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 [16]. These capabilities are expected to be integrated in DSS to improve its efficiency and effectiveness [17,18] in term of capability to reason, make judgements, and even learn [19]. Utilizing these capabilities will create an intelligence assistance that can be used to ease the burden of the expert routine tasks [14].

Intelligent Decision Support System is an integration of DSS and artificial intelligence (AI) technology combining the basic function of DSS and reasoning capabilities of AI techniques [20]. AI is viewed as a system that has the ability to "think" and "act" [21]. Based on discussion in Russell and Norvig [21], AI definitions can be viewed into two dimensions (Figure 2). In the first dimension, AI can be regarded as a system that think like humans or that thinks rationally. In the second dimension, AI is viewed as a system that acts like humans or that act rationally.

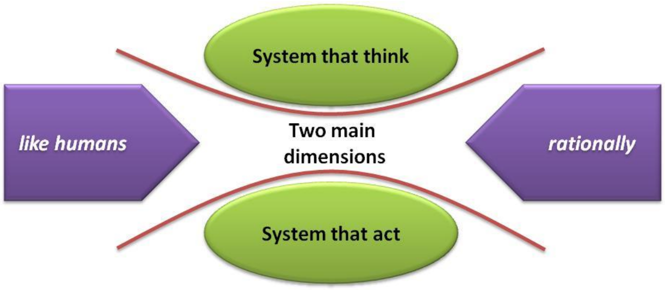

Fig. 2. Dimension in AI Technology

The efficacy of AI in DSS depends on AI techniques that is embedded in DSS. Expert System, Fuzzy Logic, Neural Network, and Genetic Algorithm are among AI techniques that have been popularized in DSS. Expert System utilized human expert knowledge in its knowledge-base, capable to mimic the decision capability of human expert to assist them on their routine tasks or replace them during their unavailability [22]. Fuzzy Logic is an alternative method of interpretation that is based on fuzzy sets [23] rather than numbers [24]. Fuzzy Logic has been used in conjunction to Expert System to increase its reasoning capability, thus improve the quality of decisions [25]. The functions of DSS based on fuzzy Expert System as pointed by Kildisas [25] are: a) standardize the conclusions for a given set of data, b) enable the combination of expertise from different experts and sources in the domain,

c) ease the exploration of options and changing assumptions for a given problem, d) transference of expertise between one level in the organization to different levels is improved, e) can be used as training tools, f) building a knowledge base helps to establish generalizations, identify gaps and inconsistencies in current knowledge and provide a stimulus for further research.

Neural Network is an algorithm that dynamically inherits human neuron information processing capability [27]. This capability enables Neural Network to perform a brain like function such as forecasting, classification, and pattern matching. Genetic Algorithm is an evolutionary algorithm that inspired by natural selection and natural genetics [27]. Genetic Algorithm being used to solve problems related to numerical optimisation. It has been applied in wide range of application including image processing, medicine, robotics, water networks, job scheduling and control.

Guerlain et al. [28] has identified six characteristics of successful IDSS; interactivity, representation aiding, event and change detection, error detection and recovery, information extraction and predictive capabilities. Interactivity is the interaction between the system and user. The IDSS is expected to support interactivity, in which user can present the input and receive the output as the feedback. The presentation of the information on the interface should be readable and understandable by the user. The system should aid the user and explain the output or how it derives the conclusion. The intelligent capability of the system should be intelligent enough to detect and adapt the changes in user input or the surroundings which might influence the operation or the processes in the system decision making. The system should be prone to error by integrating the error detection and recovery facility.

The most important component of the IDSS is the information extraction and predictive capability. Information extraction is the capability to extract the useful information from the abundance of information. This information will serve as the input to IDSS or to be represented to the user in a meaningful format. The IDSS predictive capability will use and analyze the information into a pattern by which represents a trend of the event. This trend will be learned and to be used to predict the future event. These facilities exhibit intelligent behaviour of the IDSS and very useful in assisting the decision maker.

III. EMERGENCY SITUATION ASSOCIATED WITH RESERVOIR

The reservoir is a physical structure such as pond or lake either natural or artificially developed to impound and regulate the water. It has been used as one of the structural approaches for flood defence and water storage. Flood defence is a mechanism use to modify the hydrodynamic characteristics of river flows in order to reduce the flood risk downstream [29]. Water storage is to contain water in order to maintain water supply for its use such as in agriculture, domestic and industry.

The term “reservoir” often used in conjunction with “dam” which refers to a structure typically made from concrete material constructed across a waterway to confine and control the water flow [30]. The dam will eventually raise the level of water in river to form a reservoir [31]. Dam outflow can either with uncontrolled spillways or gated spillways [33]. Uncontrolled spillways would come to its function once the reservoir exceeded its full supply level (FSL). FSL is the maximum capacity of the reservoir storage. Gated spillways function under a sequence of rule triggered by specific reservoir water levels which typically above the FSL.

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 [33] 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. The geological factor such as earthquake causes crack and leakage to the dam structure. In a period of time, the structure might burst or collapse. Poor maintenance of the reservoir dam especially old dams could affect the dams operation which resulted malfunction or failure to the dam’s components.

The dam failure will not only affect its purposes, but the major effect is flooding. Flood is one of the severe emergencies that are associated with the 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 anything on its path, leaving the ruins of the infrastructures, the dead and injured. These impacts are evident by Situ Gintung Dam incident located at south-west edge of Jakarta, Indonesia [34].

Another emergency that is associated with reservoir is water shortage (drought). Drought is a critical situation causing more death compared to other natural disasters [35]. Reservoir operation during less intense rainfall aims to impound water and the water release is constraint to its major usage that is water supply. During this period, flood-control reservoir has to establish operating policies for water allocation so that supply can be optimized [36]. Similar to other hazards, drought can be described by its magnitude, duration, location, and timing [35].

IV. RESERVOIR AS STRUCTURAL MITIGATION DURING FLOOD

Mitigation, one of the tasks in emergency management cycle, is a process of reducing risk in disaster. Mitigation related to water disaster, can be divided into structural and non-structural approaches [37]. Structural approach such as defence mechanism [29] is related to physical control of the emergency situation. Reservoir is one of the defence mechanism for both flood and drought disaster.

Defence mechanism is use to modify the hydrodynamic characteristics of river flows and coastal waters [29]. Defence can be achieved by traditional water engineering methods and by water abatement methods. Traditional water engineering methods using ‘hard’ defences include river channel modifications or using artificial materials like concrete which specifically shaped and designed to control water flows. While, water abatements methods using ‘soft’ defences rely on essentially natural materials, whether of geological or biological origin and existing environmental processes. One of the popular defence mechanisms that are currently being used by many countries in the world is dam.

The use of dam for flood mitigation aims to impound water in a reservoir during periods of high flow in order to maintain safe downstream discharges [29]. The opening of the dam’s spillway gate must be adequate to ensure that the reservoir capacity will not over its limits and the discharges will not cause overflow downstream. During drought, the reservoir needs to impound water and release adequately to fulfil its purposes. During both situations, the decision to open and close the water gate is a critical action need to be undertaken by the dam operator as late decision will not only cause flood downstream but also will damage the dam structure. Releasing the water earlier before the reservoir reaching its full capacity might reduce the flood risk downstream. However, one cannot be sure that water released will be replaced as to serve its usage during less intense rainfall. As for multi-purpose dams low water in the reservoir will cause conflict on its usage. The use of forecasting and warning system might improve the dam operation and decision [37].

Forecasting and warning system are example of the non-structural approach when is a non-physical control where emergency is control using a procedure. Example of non-physical control is flood insurance [38], flood zoning [39] and flood forecasting [40]. In term of implementation, structural solution cost is higher compare to non-structural solution. However, non-structural solution is constraint to its political implementation [37].

The combine implementation of structural and non-structural approach is vital to avoid casualty and false sense of security at storage [41]. Structural approach such as dam is a solid structure that holds water for a certain period or at maximum reservoir water level. In practice, water release or gate opening decision depends on the operating rules [42]. These rules are static and do not consider the dynamic nature of the hydrology systems. Therefore, non-structural approach such as forecasting is vital to support water release or gate opening decision. The dynamic of the forecasting system will be able to cope with the event frequency and triggered alert to the authority when situation is at the severe level. Flood forecasting is significant to cope with the great floods [43].

V. 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 3). The upstream consists of one or several rivers that carry the water into the reservoir. 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 during heavy rainfall, 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 [29], thus minimize the downstream damages [44].

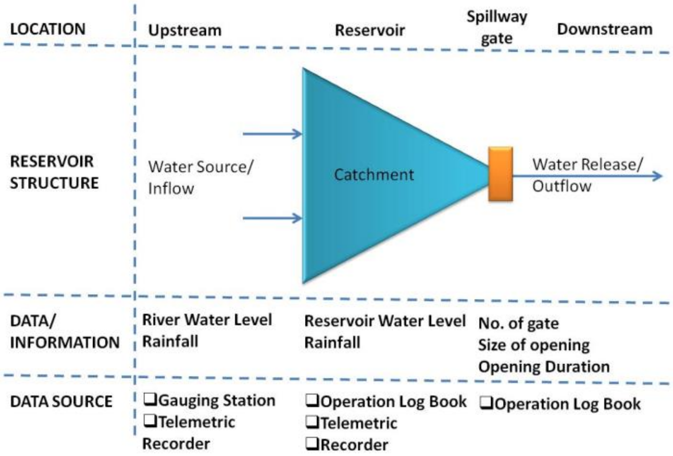

Fig. 3. Conceptual Model of Reservoir System

As shown in Figure 3, 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 telemetric recorder situated at strategic location of both upstream river and reservoir. Additionally, manual reading of the rainfall are recorded through the gauging stations. At the spillway gate, typical data are number of gate opened, the size of opening, and the opening duration. These data are recorded manually by reservoir operator in the operation log book.

The theoretical framework in Figure 4 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 through naturalistic decision making (NDM). This problem can be solved using adaptive and dynamic system approach: Intelligent Decision Support System (IDSS). The proposed IDSS consists of three main sub-models: situation assessment model, expectancy forecasting, and decision model. Situation assessment model can utilized data mining technique to extract temporal data sets from the data sources. Expectancy forecasting model is to forecast the future effect of the known factors. Neural network can be used as the forecasting technique. The decision model will produced the final output of the IDSS. In this model, expert system, fuzzy logic or neural network can be utilized as the decision engine.

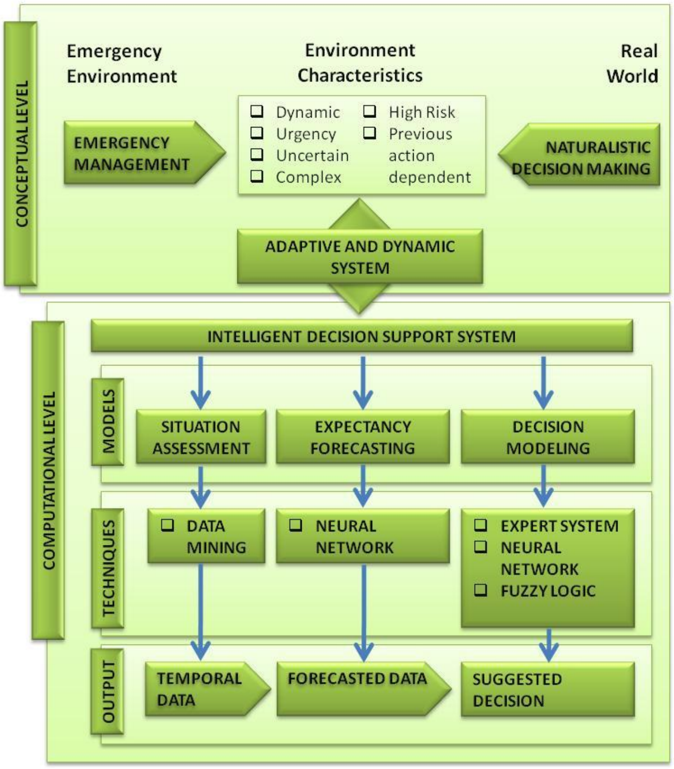

Fig. 4. Theoretical Framework

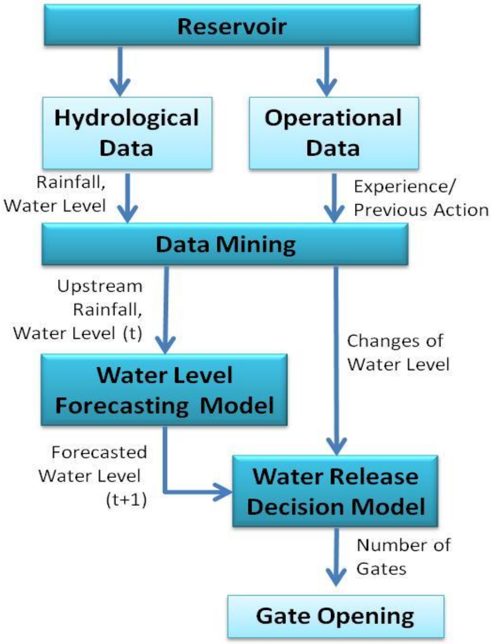

Fig. 5. Conceptual Model of IDSS for Reservoir Operation

Figure 5 shows the conceptual model IDSS for reservoir operation. As shown in Figure 5, data mining will combine both hydrological and operational data and extract the temporal data that maintain the temporal relationship of the data. The extraction process will include data integration, data preprocessing, temporal data mining, and post processing. The extracted data will be feed into water level forecasting model, which will calculate the probability of the rising of reservoir water level using neural network. The result of this model is the forecasted water level at time *t+1*. 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.

VI. MODEL IMPLEMENTATION

In our future work, the proposed model (Figure 5) will be implemented based on a case study at Timah Tasoh Reservoir. This reservoir is one of the Malaysia's largest multi-purpose reservoirs located in the Perlis. Timah Tasoh was designed as flood defence mechanism to reduce the flood risk at the downstream areas, which include Perlis major cities. Additionally, Timah Tasoh also serves water for household usage, industrial, agricultural and as a recreational park.

Timah Tasoh reservoir operational data that include upstream rainfalls, reservoir water level, and water release decision (number of gate opened, size of opening and opening duration) will be obtained from Department of Irrigation and Drainage (DID). DID is the authority that is responsible for monitoring and managing Timah Tasoh reservoir. The data will be pre-processed and cleaned to remove noise and outlier.

Once the data is ready, the situation assessment procedure will be executed. In this procedure, data mining technique called temporal data mining will be implemented to extract relevant data from the reservoir operational record. This technique is chosen as to preserve the temporal information in the data set. Extracted data will be used as input for the reservoir water level forecasting and decision modules. In the forecasting module, neural network will be implemented to learn the data pattern and later to apply the "knowledge" on other similar pattern. In the reservoir water release decision module, neural network will be applied for classification of the reservoir water release pattern.

VII. CONCLUSION

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 IDSS is consisting of situational assessment and utilizing decision maker experience as apart of its functionalities. These characteristics have satisfied the characteristics of NDM.

The IDSS can be used to aid the reservoir operator to make fast decision during the emergency situation: typically flood. IDSS utilized operator's previous experience on the reservoir operation to produce decision for the current scenario. The IDSS will recommend when to release water and the number of gate to be opened. The water level forecasting model will forecast the next day water level, thus, decision can be made on water release. This decision will reduce the risk of downstream flood due to massive release from the reservoir.

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