DECISION SUPPORT MODELING FOR COASTAL GATE OPERATIONS

INTRODUCTION

The coastal lands are one of the most important areas intensely settled by human beings owing to their fertility and abundance of natural resources. Such areas also support several agricultural activities such as rice farming, aquaculture, horticulture and so forth. However, at present, all natural resources, especially forests and water sources, have been considerably deteriorated leading to serious adverse effects on environment. For example, during dry season there is inadequate freshwater for agricultural and domestic consumptions and the problem of saline water intruding into upstream freshwater due to tidal effect and low flow in the river. In addition, water pollution problems come up due to wastewater releasing into river from both urban and agricultural areas and no sufficient freshwater for dilution of the poor quality water. On the contrary, there is abundance of excessive water in wet season, resulting in inundation and destruction of human's properties and lives.

Several methods, both structural and non-structural measures, have been proposed to cope with these problems. One of widespread structural measures is to build coastal gates to prevent saline water intrusion and store freshwater as the main purposes. The coastal gates have been built in several countries around the world, which have been facing with such problems like Thailand, Vietnam, and United State of America. In addition to constructing coastal gates, the operations of coastal gates to manage such complex problem are now becoming more and more an important issue and are nontrivial task due to the fact that it is necessary to consider multiple objectives , which is often conflicting, at the same time.

A number of mathematical simulation models have been developed and used extensively in recent years as decision support tools for coastal gate management. Gate operators can use these models for planning schedules of coastal gate operations in advance by means of trial-and-error process to find the optimal gate opening or setting. However, such method needs the considerable experiences of the user, is also very time-consuming process, especially for the complex systems, and does not guarantee to obtain optimal solution. Most of the existing gate operation module, which is sub-module of hydrodynamic model, cannot consider both water quality and water quantity criteria simultaneously. Consequently, by using only gate operation module, the coastal gates cannot be suitably operated according to the desired criteria. As a result, it is necessary to develop a new methodology or mathematical simulation model as the decision support tool for determining the optimal coastal gate operations, which correspond to multiple desired objectives. The developed model could be useful to assist gate operator for making a decision to suitably operate coastal gates.

This research presents a new methodology for solving a complicated task of multi-objective problem for coastal gate operations through using simulation and optimization approach. The development consists of two main steps. Firstly, multiple objective functions, which were called satisfaction functions herein, were designed. The weighting technique was used to convert the multi-objective decision-making problem into a single objection function. Hence, the users are free to set their own priority level of concerned parameters. The parameters used for controlling coastal gate operations were water levels, salinity concentrations, and dissolved oxygen concentrations at specified control points along the river. Secondly, a computer program that links between mathematical simulation model (e.g. hydrodynamic and water quality model) and optimization procedure altogether, was developed and consequently named CoastalGate model. The existing mathematical simulation model of River Operation Model (ROM) developed by Thai Royal Irrigation Department (2004) was utilized and the Differential Evolution (DE) optimization technique was modified for this particular task. The capabilities of the developed model are demonstrated through applications to an existing coastal gate system of Pak Phanang River Basin. The study results were presented and discussed for various study cases.

In addition to CoastalGate model developed in this research, the Artificial Neural Networks (ANNs), which is machine learning or data-driven model, was investigated the possibility for deriving the coastal gate operation rules. There are two main steps for the development of coastal gate operation rule by using ANNs approach. Firstly, the use of CoastalGate model generates numerous pair data sets of optimal gate setting and the influencing parameters (e.g. water levels, salinity concentrations, and dissolved oxygen concentrations) at specified control points along the river, from several concerned events. Secondly, the use of ANNs learns the relationship between selected influencing parameters and optimal gate setting. Two supervised neural network types; namely:- Back-Propagation (BP) and General Regression Neural Network (GRNN), were investigated and compared in terms of the learning's performance using two statistical indices: Average Absolute Error and Correlation Coefficient. Consequently, the combination of trained ANNs and River Operation Model (ROM) known as neural network controller was developed and used for controlling costal gates instead of CoastalGate model. The neural-optimal control algorithm was demonstrated in a simulated real-time control experiment for the Uthokawiphatprasit water gate, which is the main controlled gate of Pak Phanang River Basin. The advantage of using this approach is no need to rerun CoastalGate model every time for planning the operations of coastal gates. Furthermore, this model may save computation time, especially for complex system which requires high computational time resulting from routinely calling mathematical simulation model several thousands of times.

As mentioned previously, in the present work, two artificial intelligence techniques, e.g. differential evolution approach and neural network model, and an existing mathematical simulation model (River Operation Model) were applied. The details of each model can be described briefly as follows.

Differential Evolution (DE) is an evolutionary optimization technique based on stochastic approach. DE, introduced and developed by Price and Storn (1997), is an improved version of Genetic Algorithms (GA) for simple structure, ease of use, speed and robustness. The principal difference between GA and DE is that GA rely on crossover, a mechanism of probabilistic and useful exchange of information among solutions to locate better solutions, whilst DE uses mutation as the primary search mechanism. DE uses a non uniform crossover that can take child vector parameters from one parent more often than it does from others. By using components of existing population members to construct trial vectors, recombination efficiently shuffles information about successful combinations, enabling the search for an optimum to focus on the most promising area of solution space (Vasan and Raju, 2005).

Artificial Neural Networks (ANNs) (Tsoukalas and Uhrig, 1997) is an information processing system that roughly emulates the behavior of a human brain by replicating the operations and connectivity of biological neurons. In supervised learning, series of connecting weights are adjusted in order to fit the series of inputs to another series of known outputs; that is, the knowledge is acquired by the network through a learning process, and synaptic weights are used to store the knowledge. The advantages (Cancelliere, Giuliano, Ancarani, and Rossi, 2002) of ANN which is more effective than other techniques for deriving general rule are as follows: a) ANN require no programming, but it can directly learn from data, and b) ANN can extend their decision making to novel data not seen by network during training: the capability of network depends on the set of training data.

River Operation Model (ROM), developed by Royal Irrigation Department [RID] (2004), was used as mathematical simulation modeling in this work. This model includes five main sub-modules, namely:- Hydrodynamic Model (HD model), Water Quality Model (WQ model), Water Demand Model (WD model), Rainfall-Runoff Model, and Forecasting Model. The HD model based on Saint-Venant equations can be applied to analyze the behaviors of water level, velocity, and discharge in the river network for both steady and unsteady flow. The WQ Model is another sub-module of ROM which uses for the study of mass transportation in watercourse. Both aforementioned models utilize finite difference technique for solving the governing equations. The Tank model is adopted herein as rainfall–runoff model to determine upstream boundary data used as input data for HD model. In the case of water management in advance, Auto Regressive & Updating Procedure model (AR model) and harmonic analysis model as two Forecasting models are applied to synthesize upper boundary and lower boundary data, respectively. ROM can be used for simulation both event mode and real time mode, which cooperates with the data obtained from telemetering system. In the present study, DE was developed using Delphi programming language and subsequently linked with two sub-modules, e.g. hydrodynamic model and water quality model for determining optimal gate opening corresponding to multiple purposes of integrated water resources management.

OBJECTIVES

The principal objective of present research is to develop decision support model as a tool for appropriate multi-purpose coastal gate operations. The specific objectives of the study are as follows:

1. To design and develop methodology for solving a complex problem of coastal gate operation through simulation-optimization approach;

2. To apply Artificial Neural Networks model for deriving general coastal gate operation rules for real time control task;

3. To demonstrate and evaluate the proposed methodologies by using both hypothetical and existing coastal gate system as two study cases.

Scope of Research

To achieve the proposed methodologies for management of optimal costal gate operations, the following scopes are applied.

1. The considered parameters for coastal gates operation consist of water level, salinity concentration, and dissolved oxygen concentration;

2. Hourly coastal gate operation basis is only considered in present study;

3. The data used in this study such as rainfall data, upstream discharge, sea water level, water quality load, and others are available from study reports concerning the operation of Uthokawiphatprasit water gate. Those reports were prepared by the Royal Irrigation Department. In addition, some data are also collected from telemetering system at Pak Phanang River Basin Development Project, Nakorn Si Thammarat province;

4. River Operation Model (ROM), developed by RID (2004), is used as mathematical simulation model in this experiment.