SIMULATION TECHNIQUES IN RESERVOIR PLANNING AND OPERATION

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INTRODUCTION

Simulation can be defined as the process of designing a (computerized) model of a system and conducting experiments with this model either for better understanding of the behaviour of the system or for evaluating various strategies for its operation. Here the important point to be considered is that simulation is related to the traditional approach of using models for problem solving. However, the type of models generally used has undergone change as a consequence of impact of computers. Nevertheless, the essence of simulation is to reproduce the behaviour of the system in every important aspect.

At this stage it may be asked as to what is the need of simulation ? The answer can be obtained by pondering over the definition of simulation. The experiments on the models are conducted to verify the analytical results or to get an answer to the question **WHAT IF** ? In the area of water resources management, the computerized models are becoming very popular nowadays. Although the physical models are in use for a very long time, these are not suitable for analysis of water resources systems. The model building for the water resources systems is a time consuming and costly affair and the testing of say different operating policies is not possible through these models. Further complications arise in the physical models in case it is required to evaluate the alternate configurations and sizes of the facilities. In such situations, the mathematical models are the most convenient to use.

DEFINITIONS

Central to any simulation is the concept of a system. The term system refers to a collection of objects with a well-defined set of interactions among them. The systems can be natural, for example solar system, or man-made, for example a flood control system.

A real world object is called an entity and the properties of the entities are called attributes. A process which causes changes in a system is called an activity. All external factors which are capable of causing a change in the system are termed system environment. The collection of information using which the future behaviour of the system can be predicted is the state of the system. The process or event which changes the system state is called an activity. The state of the system may change due to the activities which are exogenous (external to the system) or endogenous (internal to the system). A system which does not have any exogenous activity is called a closed system; those which have are open systems.

There are several ways in which the systems can be classified. A system in which the variables can assume any value in the specified interval is a continuous system and this contrasts with a discrete system in which the variables assume only particular values from a specified finite set. A system can also be classified as continuous or discrete. A detailed exposition from the point of view of water resources is available in Hall and Dracup(1979).

TIME MANAGEMENT IN SIMULATION

The two common ways of time management in simulation models are periodic scanning and event scanning. In the period scanning or fixed time scanning, the whole computation time is divided into smaller time periods. The simulation clock is incremented by the predetermined step and the system is examined to check whether any event has taken place during this interval. If such events have occurred these are simulated otherwise no action is taken. The clock is again advanced and the procedure is repeated till the end of period of analysis. For example, in case of simulation of operation of a reservoir system, the time horizon may be divided into months. The clock may be initialized to the first month. The events occurring in a particular month are simulated and then the clock is advanced to next month.

A judicious choice of time increment is necessary in the periodic scanning approach. This increment should be small enough so that no significant information is lost. However, the smaller the time increment, the larger will be the amount of computations to complete the simulation which results in added cost for each run. On the other hand, the amount of computations and hence cost will reduce with increase in time period of computations but there are higher chances that an event of interest may be missed.

In the event scanning approach, the clock is advanced by the amount of time which is required for the occurrence of next event. In many natural phenomena, the periods of high activity are separated by long periods in which the system lies inactive. This approach is suitable for this type of situations. It requires some scheme to determine the time when the events take place. Although the computations are substantially reduced in this approach, the models become considerably complex. In case of water resources systems modelling, the fixed time scanning approach is mostly used.

Interpretation of Results

The interpretation of simulation output is a very important step in the simulation analysis. It is also very much necessary for proper choice of variables to be changed for the next steps of computations. Before interpretation of results the analyst must specify a performance criterion to evaluate the alternate strategies. In case of reservoir operation, the concept of reliability is used quite often. An operation policy is considered satisfactory or otherwise depending upon how well the various demands are satisfied. The relative impact of various decision variables on the performance of the system should be known. The text from Loucks et al (1981) is recommended for further reading.

In most of the computer based models, the user has options open to determine as to how detailed results he wants. Too many details in the printout may tend to hide the important aspects besides making the output unwieldy and too few variables may lead to wrong interpretation. Thus a clear balance has to be maintained. It is often very useful to have the summary of results for quick interpretation. The details needed for interpretation also vary depending upon the stage of analysis. For example, if the performance of the various operation policies is being studied than in the intermediate stages only brief results may be sufficient. After a satisfactory policy has been arrived at, detailed results may be required for the purpose of presentation.

Limitations of Simulation

The following are the major limitations of simulation technique :

The simulation analysis does not yield an immediate optimal answer. This technique is most suitable to answer the question - what if ? Thus each answer basically pertains to a combination of selected variables. A number of iterations are to be performed to arrive at the optimum. Since in a real life problem, it may not be possible to examine all the related variables at sufficiently close interval, the sampling must be done judiciously.

The second major limitation of simulation is that the models generally lack the flexibility in terms of operating procedures of the system. For example, in a programme dealing with reservoir operation, the criteria as to whether water is to be released from a particular zone and so on is specified in the programme. Any major change in this criteria requires corresponding modifications in the programme and then re-testing of the programme.

The third drawback of simulation arises because the historical streamflows are used in simulation. Sometimes, these streamflows may not be representative for that basin. Moreover, it is quite unlikely that the streamflows will repeat in the same order in the future as they did in the past.

RESERVOIR PLANNING USING SIMULATION

The attractiveness of the simulation model lies in the fact that using them it is very easy to examine various alternatives. A simulation programme can be easily developed and used for reservoir operation planning. This is explained here with the help of a simple example.

Let there be a given site identified for the construction of a reservoir. The reservoir has to cater for irrigation for a nearby area and the target demand of water for different months is given. The elevation-area-capacity table for the site is available. A sufficiently long series of streamflows at the site is available. Further, it is required that the reliability of the reservoir should be least 75 percent. An efficient procedure of binary search can be used in the present case. In this method, first the upper bound and lower bound on the capacity of the reservoir are determined. The lower bound can be taken to be zero or the dead storage and the upper bound can be determined from physical factors such as water availability etc. A trial value for the reservoir capacity is selected which lies at the center of the feasible region (i.e. at the mean of upper bound and lower bound).

Now, starting with a suitable value of initial storage content, the reservoir is operated using the streamflow data. The effect of this initial storage value will not be very significant if the inflow series for a sufficiently long period, say 30-40 years is being used. During any time period, the release is made equal to the demand if that much water is available in the storage. Otherwise whatever can be made available is released and the reservoir is said to have failed in that period. The evaporation losses can be easily considered here if the information about the depth of evaporation is available. In this way, the reservoir is operated for the entire period of record. Now the number of periods during which the reservoir has failed is counted and the reliability is computed. If this reliability is less than the desired value, it means that the capacity of the reservoir must be increased. In this case the present capacity is adopted as the lower bound for next iteration. The feasible region below this lower bound is discarded and the trial value for the next iteration is chosen midway the upper bound and new lower bound. If, however, the reliability comes out to be higher than the required limit, the size of the reservoir is bigger than what it should have been and hence the region between the current value and upper bound is discarded for further examination. The present capacity value becomes the new upper bound. Again the trial value for the next iteration is chosen as mean of new upper bound and old lower bound.

The computations are repeatedly performed in this manner and they are terminated when the required number of iterations is over. This method converges quite rapidly as the feasible region is halved every time. It may be seen that in this method, generation of hydro-electric power can also be easily considered.

GENERALIZED PROGRAMMES FOR RESERVOIR OPERATION SIMULATION

A number of general purpose computer programs are available nowadays which can be used to analyze virtually any configuration and any combination of purpose of a reservoir system. Some of these are being described in the following.

The SIMYLD Programme

The SIMYLD-II is a versatile quasi-simulation model developed by Texas Water Development Board (1972). This model can be used to simulate operation of reservoirs subject to a specified sequence of demands and hydrology.

In the SIMYLD-II model, the physical water resource system is transformed into a capacitated network. The conceptual network consists of two components - nodes and links. A node is a connection and/or branching point within the network and is analogous to a reservoir or non-storage junction in the physical system. A node has the capacity to store a finite and bounded quantity of water and can serve as a branching point. Thus a diversion can be treated as a node point whose storage capacity is zero. Any water which enters the system does so at the nodes only and all the demands are assumed to be placed at node points.

The water is transferred from one node to another by the links. Thus a link may represent a river reach, canal or a pipe of the physical system. Each link has a specified flow direction and maximum carrying capacity. A minimum carrying capacity may also be associated with each link to represent requirements of minimum flow along the corresponding element.

As input to the model, the user is required to supply priorities between meeting demands and satisfying final end of month storage requirements in the reservoirs. The priorities are converted into cost in the model. Those related with demand and desired storage are assigned negative costs or benefits, more negative is the number, higher is the priority for meeting the upper constraint. The idea is to meet targets of demands and desired storages in order of the priorities while minimizing the canal pumping and spill from the system.

The optimal allocation of network flows is accomplished by using the 'Out-of-Kilter' algorithm. This is an optimization algorithm which finds the minimum total cost of water circulation within the network subject to flow constraints. In Out-of-Kilter algorithm, it is required that the objective function and the constraints must be linear in nature.

To provide flexibility in operation, the SIMYLD-II model allows for three sets of operating policies depending upon the hydrologic state of the system. The three hydrologic states typically are, wet, average and dry. Thus the user can specify different set of priorities of maintaining a particular storage and meeting demands corresponding to the hydrologic state of the system.

The HEC Programmes

A number of generalized computer programmes, e.g., the HEC-3, HEC-5, have been developed by the Hydrologic Engineering Center (HEC) of US Army Corps of Engineers. The program HEC-5 is extensively used for simulation of reservoir systems and is being described below.

The program 'Simulation of Flood Control and Conservation Systems', HEC-5 has been developed for simulation of operation of a reservoir system for flood control and conservation purposes such as water supply, irrigation, hydroelectric power generation, navigation and low flow augmentation. The system consists of a number of control points linked with each other. Reservoirs are control points which have a finite amount of storage associated with them. The operating criteria of a reservoir has to be supplied. Each reservoir is operated to meet the streamflow targets at specified locations in the system. To do this, each reservoir is divided into a number of zones by imaginary horizontal planes and withdrawals are made from the highest zone first and so on. As far as possible, all reservoirs, in the system are kept in balance.

The system is operated by considering the requirements at pertinent control points in the system, starting at the most upstream control point and moving in the downstream direction. The required release is determined by evaluating all operational needs and other constraints. After the requirements have been made or shortages declared, the system requirements are examined to determine additional releases which may be required to meet the system power demands. If these releases are required then they are proportioned among the projects which are supposed to cater for them. These additional releases are added to obtain the total releases. This process is repeated for each period. The system can also be operated for flood control in which the peak flow at a damage center is kept below a maximum limit. The hydrologic accounting is done by use of continuity equation at each control point.

The various features of this programme have been described in detail in the users manual for this programme, HEC (1982). This manual also describes the input and output of the programme for various test problems. Recently, a PC version of this programme has also been brought out by HEC.

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