Introduction to Simulation

What means

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Course Presentation

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- Course: Discrete-Event Simulation
- Aim: to introduce simulation concepts, techniques and metodology, with emphasizes on Discrete-Event Simulation

Topics

Not necessary in this order

1. Introduction to Simulation

Topics

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1. Introduction to Simulation
2. Review of Probability and Statistics

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2. Review of Probability and Statistics
3. Random Numbers and Random Variables Generation

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4. Discrete Event Simulation Approach

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5. Input Modeling

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6. Verification and Validation of Simulating Models

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7. Output Analysis

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8. Variance Reduction Techniques

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9. Markov Chain Monte Carlo Methods

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10. Applications

Definition of Simulation

- *Simulation* is the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented.
- Simulation is used to describe and analyze the behavior of a system, ask "what if" questions about the real system, and aid in the design of real systems.
- Both existing and conceptual systems can be modeled with simulation.
- Simulation [lat. "imitate"] the representation or replication as a model of certain aspects of a real or planned cybernetic system, in particular of its behaviour over time. (Brockhaus Lexikon)

Modeling concepts I

- A *system* is a collection of entities that act and interact together toward the accomplishment of some logical end.
- A *model* is a representation of an actual system. Immediately, there is a concern about the limits or boundaries of the model that supposedly represent the system. The model should be complex enough to answer the questions raised, but not too complex.
- Consider an *event* as an occurrence that changes the state of the system. In the example, events include the arrival of a customer for service at the bank, the beginning of service for a customer, and the completion of a service. There are both internal and external events, also called *endogenous* and *exogenous events*, respectively. For example, an endogenous event in the example is the beginning of service of the customer since that is within the system being simulated. An exogenous event is the arrival of a customer for service since that occurrence is outside of the simulation.

Modeling concepts II

- Discrete-event simulation models are contrasted with other types of models such as mathematical models, descriptive models, statistical models, and input-output models.
- Most mathematical, statistical, and input-output models represent a system's inputs and outputs explicitly, but represent the internals of the model with mathematical or statistical relationships. An example is the mathematical model from physics

$$Force = Mass \times acceleration,$$

- Discrete-event simulation models include a detailed representation of the actual internals.
- Discrete-event models are dynamic, i.e., the passage of time plays a crucial role.
- Most mathematical and statistical models are static in that they represent a system at a fixed point in time. Example: annual budget of a firm — resides in a spreadsheet — the passage of time is usually not a critical issue.

Modeling concepts III

- The *system state variables* are the collection of all information needed to define what is happening within the system to a sufficient level (i.e., to attain the desired output) at a given point in time.
- Determining the system state variables is as much an art as a science. However, during the modeling process, any omissions will readily come to light. (And, on the other hand, unnecessary state variables may be eliminated.)
- The system state variables in a discrete-event model remain constant over intervals of time and change value only at certain well-defined points called *event times*.
- Continuous models have system state variables defined by differential or difference equations giving rise to variables that may change continuously over time.
- Some models are mixed discrete-event and continuous.
- There are also continuous models that are treated as discrete-event models after some reinterpretation of system state variables, and vice versa.

Modeling concepts IV

- An *entity* represents an object that requires explicit definition. An entity can be dynamic in that it "moves" through the system, or it can be static in that it serves other entities. Example: customer - dynamic, bank-teller - static
- An entity may have *attributes* that pertain to that entity alone. Thus, attributes should be considered as local values. In the example, an attribute of the entity could be the time of arrival.
- A *resource* is an entity that provides service to dynamic entities. The resource can serve one or more than one dynamic entity at the same time, i.e., operate as a parallel server. A dynamic entity can request one or more units of a resource. If denied, the requesting entity joins a queue, or takes some other action (i.e., diverted to another resource, ejected from the system). (Other terms for queues include files, chains, buffers, and waiting lines.) If permitted to capture the resource, the entity remains for a time, then releases the resource.
- There are many possible states of the resource:idle and busy (may include failed, blocked, or starved).

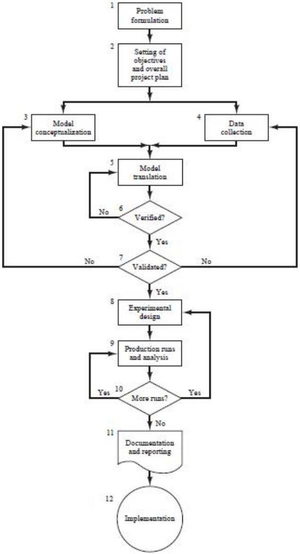
Modeling concepts V

- *List Processing*: Entities are managed by allocating them to resources that provide service, by attaching them to event notices thereby suspending their activity into the future, or by placing them into an ordered list. Lists are used to represent queues.
- An *activity* is a duration of time whose duration is known prior to commencement of the activity. Thus, when the duration begins, its end can be scheduled. The duration can be a constant, a random value from a statistical distribution, the result of an equation, input from a file, or computed based on the event state.
- A *delay* is an indefinite duration that is caused by some combination of system conditions. When an entity joins a queue for a resource, the time that it will remain in the queue may be unknown initially since that time may depend on other events that may occur. An example of another event would be the arrival of a rush order that preempts the resource. When the preempt occurs, the entity using the resource relinquishes its control instantaneously. Another example is a failure necessitating repair of the resource.

Discrete-Event Simulation Model

- Discrete-event simulations contain activities that cause time to advance. Most discrete-event simulations also contain delays as entities wait. The beginning and ending of an activity or delay is an event.
- A *discrete-event simulation model* can be defined as one in which the state variables change only at those discrete points in time at which events occur. Events occur as a consequence of activity times and delays. Entities may compete for system resources, possibly joining queues while waiting for an available resource. Activity and delay times may "hold" entities for durations of time.
- A discrete-event simulation model is conducted over time ("run") by a mechanism that moves simulated time forward. The system state is updated at each event along with capturing and freeing of resources that may occur at that time.

Steps in a simulation study flowchart



Steps in a simulation study I

1. **Problem formulation** – Every simulation study begins with a statement of the problem. If the statement is provided by those that have the problem (client), the simulation analyst must take extreme care to insure that the problem is clearly understood. If a problem statement is prepared by the simulation analyst, it is important that the client understand and agree with the formulation. It is suggested that a set of assumptions be prepared by the simulation analyst and agreed to by the client. Even with all of these precautions, it is possible that the problem will need to be reformulated as the simulation study progresses.

Steps in a simulation study II

2. **Setting of objectives and overall project plan** – Another way to state this step is "prepare a proposal." This step should be accomplished regardless of location of the analyst and client, viz., as an external or internal consultant. The objectives indicate the questions that are to be answered by the simulation study. The project plan should include a statement of the various scenarios that will be investigated. The plans for the study should be indicated in terms of time that will be required, personnel that will be used, hardware and software requirements if the client wants to run the model and conduct the analysis, stages in the investigation, output at each stage, cost of the study and billing procedures, if any.

3. **Model conceptualization** – The real-world system under investigation is abstracted by a conceptual model, a series of mathematical and logical relationships concerning the components and the structure of the system. It is recommended that modeling begin simply and that the model grow until a model of appropriate complexity has been developed. For example, consider the model of a manufacturing and material handling system. The basic model with the arrivals, queues and servers is constructed. Then, add the failures and shift schedules. Next, add the material-handling capabilities. Finally, add the special features. Constructing an unduly complex model will add to the cost of the study and the time for its completion without increasing the quality of the output. Maintaining client involvement will enhance the quality of the resulting model and increase the client's confidence in its use.

Steps in a simulation study IV

4. **Data collection** – Shortly after the proposal is "accepted" a schedule of data requirements should be submitted to the client. In the best of circumstances, the client has been collecting the kind of data needed in the format required, and can submit these data to the simulation analyst in electronic format. Oftentimes, the client indicates that the required data are indeed available. However, when the data are delivered they are found to be quite different than anticipated. For example, in the simulation of an airline-reservation system, the simulation analyst was told "we have every bit of data that you want over the last five years." When the study commenced, the data delivered were the average "talk time" of the reservationist for each of the years. Individual values were needed, not summary measures. Model building and data collection are shown as contemporaneous in Figure 1. This is to indicate that the simulation analyst can readily construct the model while the data collection is progressing.

Steps in a simulation study V

5. **Model translation** – The conceptual model constructed in Step 3 is coded into a computer recognizable form, an operational model.
6. **Verified?** – Verification concerns the operational model. Is it performing properly? Even with small textbook sized models, it is quite possible that they have verification difficulties. These models are orders of magnitude smaller than real models (say 50 lines of computer code versus 2,000 lines of computer code). It is highly advisable that verification take place as a continuing process. It is ill advised for the simulation analyst to wait until the entire model is complete to begin the verification process. Also, use of an interactive run controller, or debugger, is highly encouraged as an aid to the verification process.

Steps in a simulation study VI

7. **Validated?** – Validation is the determination that the conceptual model is an accurate representation of the real system. Can the model be substituted for the real system for the purposes of experimentation? If there is an existing system, call it the base system, then an ideal way to validate the model is to compare its output to that of the base system. Unfortunately, there is not always a base system. There are many methods for performing validation.
8. **Experimental design** – For each scenario that is to be simulated, decisions need to be made concerning the length of the simulation run, the number of runs (also called replications), and the manner of initialization, as required.
9. **Production runs and analysis** – Production runs, and their subsequent analysis, are used to estimate measures of performance for the scenarios that are being simulated.

Steps in a simulation study VII

10. **More runs?** – Based on the analysis of runs that have been completed, the simulation analyst determines if additional runs are needed and if any additional scenarios need to be simulated.
11. **Documentation and reporting** – Documentation is necessary for numerous reasons. If the simulation model is going to be used again by the same or different analysts, it may be necessary to understand how the simulation model operates. This will enable confidence in the simulation model so that the client can make decisions based on the analysis. Also, if the model is to be modified, this can be greatly facilitated by adequate documentation. The result of all the analysis should be reported clearly and concisely. This will enable the client to review the final formulation, the alternatives that were addressed, the criterion by which the alternative systems were compared, the results of the experiments, and analyst recommendations, if any.

Steps in a simulation study VIII

12. **Implementation** – The simulation analyst acts as a reporter rather than an advocate. The report prepared in step 11 stands on its merits, and is just additional information that the client uses to make a decision. If the client has been involved throughout the study period, and the simulation analyst has followed all of the steps rigorously, then the likelihood of a successful implementation is increased.

References

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- Sheldon M. Ross, *Simulation*, Fourth Edition, Elsevier, 2006