HALMSTAD UNIVERSITY

Quantitative methods: Simulation and modeling

Lecture 1 and Lecture 2

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INTRODUCTION TO COMPUTER SIMULATION

Outline Simulation and modeling

- The Nature of Simulations
- Application Areas of Computer Simulation
- Advantages with Computer Simulation
- Drawbacks with Computer Simulation
- Pitfalls with Computer Simulation
- Systems, Models and Simulation
- Elements of Simulation Analysis

The Nature of Simulations

“The process of designing a mathematical or logical model of a real system and then conduct computer-based experiments with the model to describe, explain, and predict the behavior of the real system”

T. H. Naylor et al., *Computer Simulation Techniques*, John Wiley and Sons, 1966.

The Nature of Simulations

- A computer simulation ***imitates the operation*** of various kinds of real-world ***facilities*** or ***physical* processes**.

- The ***facility*** or ***process*** is usually referred to as a ***system***.

- In order to study it scientifically one have to make a set of assumptions about how the system works. These assumptions usually take the form of ***mathematical*** or ***logical relationships*** that constitutes a ***model*** of the ***real-world system***.

The Nature of Simulations

- If the ***relationships***, that compose the ***model***, are simple enough, it may be possible to use ***analytic methods*** to obtain an exact answer on questions of interest.

- However, most ***real-world systems*** are ***too complex*** to be evaluated analytically (only a very limited set of algebraic equations can be solved analytically) and these must be studied by means of ***simulation***.

- In a simulation a computer is used to ***evaluate a model numerically*** where data is gathered to ***estimate*** the ***characteristics*** of the ***model***.

Application Areas of Computer Simulation

- Designing and analyzing manufacturing systems
- Designing and evaluating electronic circuits.
- Construction modeling
- Evaluate military systems or logistics requirements.
- Determining requirements or evaluating protocols for communication protocols.
- Determining hardware and software requirements for a computer systems.
- Designing and operating transportation systems such as airports, freeways, ports and subways.

Application Areas of Computer Simulation

- Evaluating designs for service organizations such as contact centers, fast-food restaurants, hospitals, post offices.
- Reengineering of business processes
- Analyzing supply chains
- Determining ordering policies for inventory systems
- Analyzing mining operations

Advantages with Computer Simulation

- Most complex, real world systems with stochastic elements cannot be accurately described by a mathematical model that can be evaluated analytically, simulation (numerical) methods is the only available type of evaluation.
- Simulation allow one to estimate the performance of an existing system under some projected set of operation conditions.
- Alternative proposed system designs can be pre-evaluated via simulation to see which design that meets the system requirements best.
- Much better control over experimental conditions can be maintained in a simulation than experimenting with a real system.

Drawbacks with Computer Simulation

- Models to study large-scale systems tend to be very complex, writing computer programs that execute these models can be a very tedious and hard task.

- A second problem is that the ***computational complexity*** of large scale simulations, extremely large amount of computer time is sometimes required.

- Verification of the ***correctness*** of the simulation model and its implementation can be hard to accomplish.

Drawbacks with Computer Simulation

- There exist an impression that simulation is just an exercise in computer programming (a complicated one).
  - Consequently, many simulation studies have been composed of ad hoc models, ad hoc implementation and just run the simulator once to obtain the answer, attitude.
  - This attitude, which neglects the important issue of how a properly coded model should be used, has doubtless led to that erroneous conclusions have been drawn in many simulation studies.

- Stochastic simulation models produce output that is itself random, and must therefore be treated as only an estimate of the true characteristics of the model. This is one of the disadvantages of simulation.

Pitfalls with Computer Simulation

- Failure to have a well-defined set of objectives at the beginning of the simulation.
- Failure to have the entire project team involved at the beginning of the study.
- Inappropriate level of model detail.
- Failure to communicate with management throughout the course of the simulation study.
- Misunderstanding of simulation by the management.
- Treating simulation as if it were primarily an exercise in computer programming.
- Failure to have people with a knowledge of simulation methodology and statistics on the modeling team.

Pitfalls with Computer Simulation

- Failure to collect good system data, e.g. not enough data to create a good model.
- Inappropriate simulation software.
- Belief that easy-to-use simulation tools require a significantly lower level of technical competence.
- Failure to account correctly for sources of randomness in the system under consideration.
- Using arbitrary random distributions as input to the simulation.
- Analyzing the output from the simulation using formulas that assumes independence.

Pitfalls with Computer Simulation

- Making single replication of a particular system design and treating the output statistics as true answers.
- Failure to have warm up period, if the steady state behavior of a system is of interest.
- Comparing alternative system designs on the basis of one replica for each design.
- Using wrong performance measures.

Systems, Models and Simulation

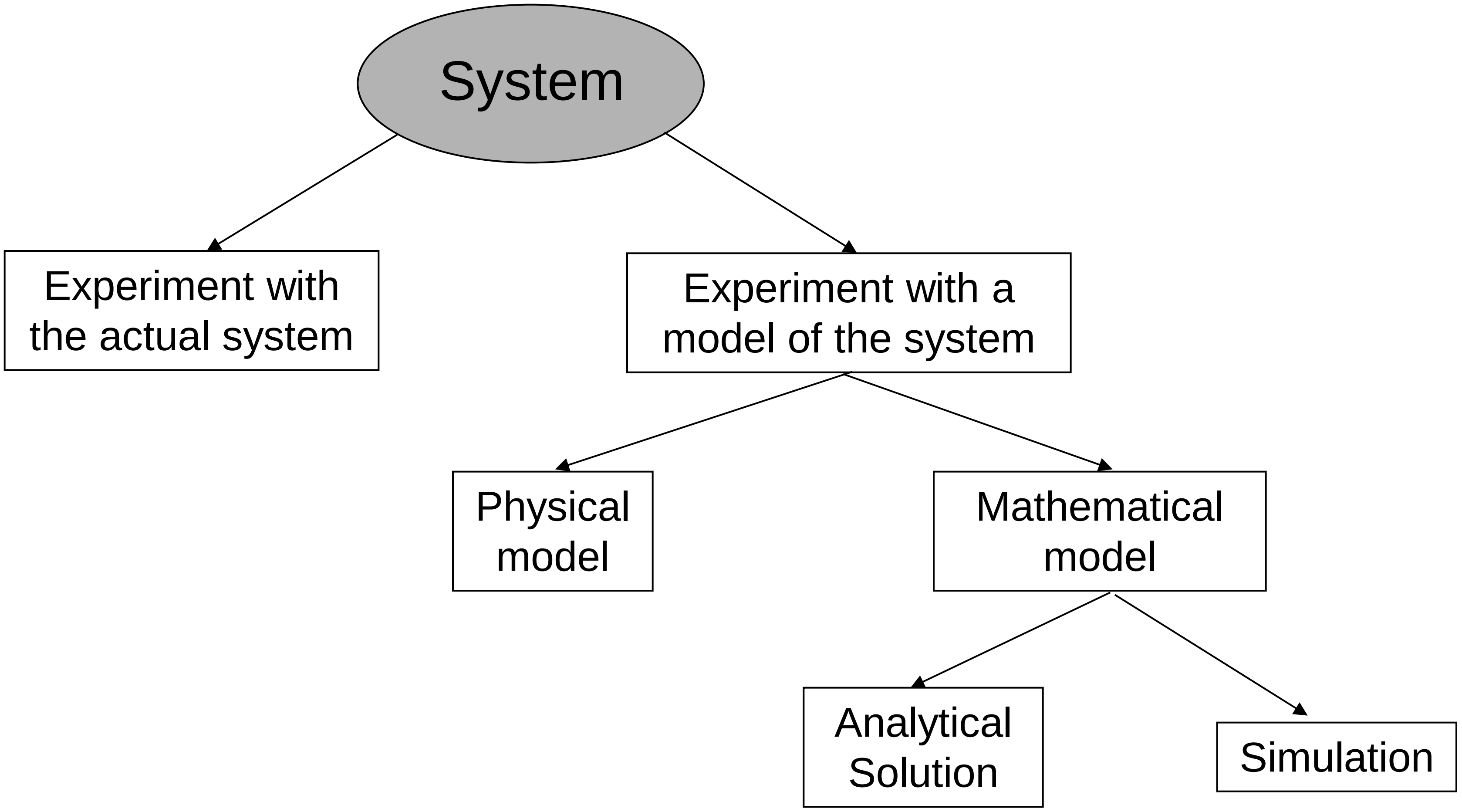
- A ***system*** is defined as collection of ***entities***, (e.g. people or machines) that ***acts*** and ***interacts*** towards the accomplishment of some ***logical end***.
  - In practice what is meant by the system depends on the objectives of a particular study.

- The ***state*** of a system is defined as the collection of variables necessary to describe a system at a particular time, relative to the objectives of a study.

Systems, Models and Simulation

- Systems can be categorized in to two types: ***discrete*** and ***continuous***.
  - A ***discrete system*** is one for which the state variables change instantaneously at separated point in time.
  - A ***continuous system*** is one for which the state variables change continuously with respect to time.

Systems, Models and Simulation



Systems, Models and Simulation

Experiment with the actual system
versus
Experiment with a model of the system

- If it is possible to alter an existing system physically and then let it operate under the new conditions it is probably desirable to do so. However, it is rarely feasible to do so caused by that:
  - The system may not exist
  - The stimulus may not exist
  - High cost to alter a existing system
  - Dangerous elaborate with a existing system
  - ………….

Systems, Models and Simulation

Physical model versus Mathematical model

- Sometimes small scale physical models are used to evaluate constructions, e.g. air plane or car models in wind tunnels, ship models in swimming pools etc.

- The vast majority of used models are mathematical, representing a system in terms of logical and quantitative relationships that are possible to manipulate and change to see how the model reacts.

- Faster, lower cost, etc…..

Analytic solution versus Simulation

- The vast majority of used models are mathematical, e.g. $d=rt$, where r is the rate of travel, t is the time spent traveling, and d is the distance traveled, the closed form solution of this model is very simple to find.
- However, a closed form solution can become extraordinary complex to find, e.g. inverting a large non-sparse matrix is a well known example. The formula is well known, but obtaining the solution is far from trivial.
- Many systems are highly complex, so that valid mathematical models of them are themselves complex precluding any possibility of analytical solutions.
- In these cases the model must be studied by means of simulation, i.e. numerically exercising the model for the inputs in question to see how they affect the output measures of performance.

Systems, Models and Simulation

- Given that there exist a mathematical (numerical) model, we must then look for a particular ***tool*** to do this.

- For this purpose it useful to classify models along three different ***dimensions***:

  - Static versus Dynamic models
  - Deterministic versus Stochastic models
  - Continuous versus Discrete models

Systems, Models and Simulation

Static versus dynamic model

- A ***static model*** is a representation of a system at a particular time, or a model that may be used to represent a system in which time have no role.

- A ***dynamic model*** evolves over time, i.e. the state variables are time dependent.

Systems, Models and Simulation

Deterministic versus Stochastic models

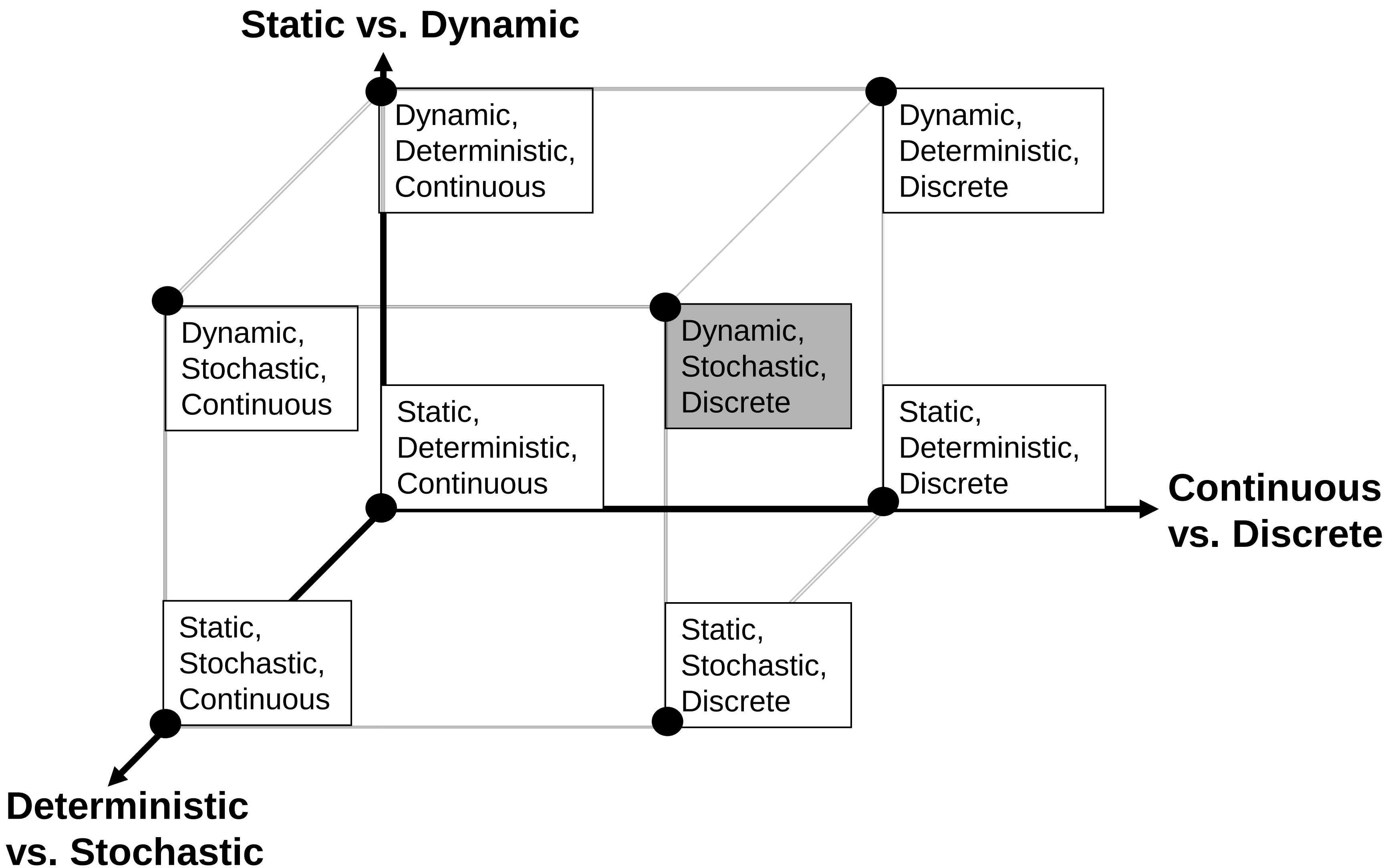
- If a model does not contain any probabilistic components, it is called deterministic, often a complicated system of differential equation (analytically intractable).
- Many systems must however be modeled as having at least some random input component, and these gives rise to stochastic models, e.g. communication, queuing and inventory systems are modeled stochastically.
- Stochastic models produce output that is itself random, and must therefore be treated as only an estimate of the true characteristics of the model.

Systems, Models and Simulation

Continuous versus Discrete models

- Discrete and continuous models analogously to the way discrete and continuous systems.
  - A ***discrete model*** is one for which the state variables change instantaneously at separated point in time.
  - A ***continuous model*** is one for which the state variables change continuously with respect to time.

Systems, Models and Simulation



Elements of Simulation Analysis – Introduction

- Simulation analysis is a descriptive modeling technique.
- As such, simulation analysis does not provide the explicit problem formulation and solution steps.
- Consequently, one must specify in detail a procedure for the development and use of simulation models to assure successful outcome from a simulation study.

Elements of Simulation Analysis – Introduction

- **Problem Formulation**: questions for which answer are sought, the variables involved and measures of system performance to be used

- **Data Collection and Analysis**: assembling the information necessary to further refine our understanding of the problem.

- **Model Development**: building and testing the model of the real system, selecting simulation tool (programming language), coding the model and debugging it.

Elements of Simulation Analysis – Introduction

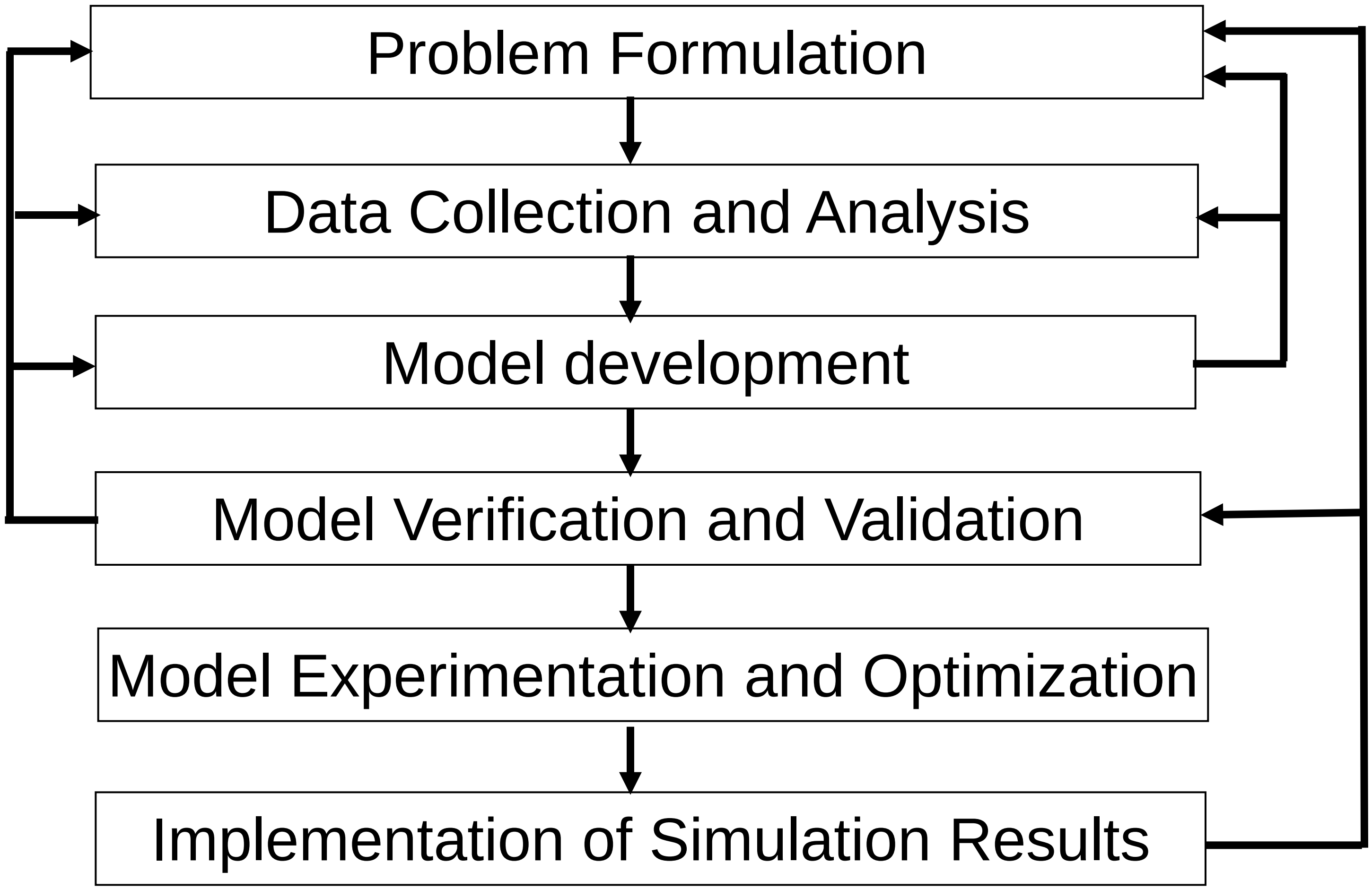
- **Model Verification and Validation**: establish that the model is an appropriate accurate representation of the real system.

- **Model Experimentation and Optimization**: precision issues, how large sample (simulation time) is necessary to estimate the performance of the system. The design of effective experiments with which to answer the question asked in the problem formulation.

- **Implementation and Simulation result:** acceptance of the result by the users and improved decision making stemming from the analysis.

Elements of Simulation Analysis – Introduction

Major Iterative Loops in a Simulation Study



Elements of Simulation Analysis – Problem Formulation

- Problem formulation is the most important step in a simulation study.

- Problem formulation often include:
  - Technical aspects
  - Economical aspects
  - Political aspects

- The problem formulation can have a significant impact on the success of the simulation study.

Elements of Simulation Analysis – Problem Formulation

But let us concentrate on the required tasks from a technical perspective !!!!!

- Four fundamental design issues must be addressed in the problem formulation phase.

  - Identify **decision** and **uncontrolled** variable
  - Specify **constraints** on the decision variable
  - Define **measures** of the system performance and their **objectives**
  - Develop a preliminary **model structure** to interrelate the system variable and the measure of performance

Elements of Simulation Analysis – Problem Formulation

- The first step is the specification of variables that define the system and its outputs. Variables may be classified as ***exogenous*** or ***endogenous***.
  - ***Exogenous*** (input variables) are external to the model and exist independently of the model.
  - ***Endogenous*** are internal to the model and are a function of the exogenous variables and the model structure.

- Exogenous variables can be further classified as ***controllable*** and ***uncontrollable***.
  - ***Exogenous controllable variables*** (decision variables) can be manipulated within some limit by the decision maker.
  - ***Exogenous uncontrollable variable*** (parameters) is beyond the control of the decision maker.

Elements of Simulation Analysis – Problem Formulation

- To evaluate the effectiveness of a system, we must identify a measure (or measures) of performance by which to judge it.

- Performance measure (or measures) of the system are selected from the ***endogenous variables***.

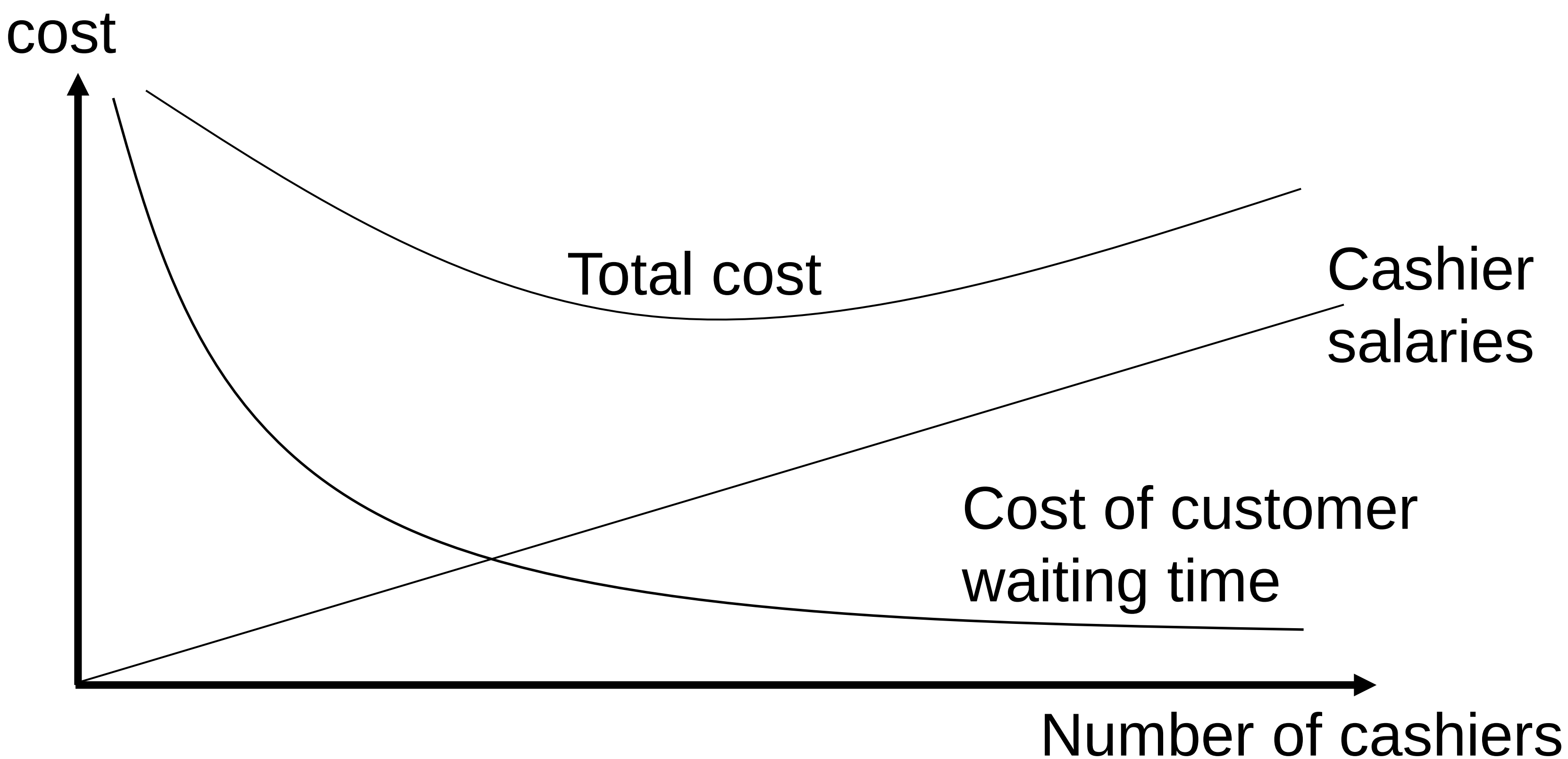
- The measure (or measures) which we chose to optimize on, ***minimize/maximize,*** in a simulation are referred to as the ***objective function***.

Elements of Simulation Analysis – Problem Formulation

- If multiple measures of performance are identified it is hard to optimize on several of them simultaneously since minimizing one tends to produce large value for the other.
- There exist two approaches to this dilemma:
  - Make explicit trade-offs among the measures by combining several measures using some common dimension, e.g., cost.
  - Select the measure of most concern to optimize while constraining the others to be at a constant value or within some minimal range.
- If one is fortune, one measure will dominate the performance for all other alternatives.
- When dominance cannot be shown, one must deal with the problem of combining several measures into one common dimension for all measures.

Elements of Simulation Analysis – Problem Formulation

A simple example: combining several measures in a simulation of a supermarket multi-lane checkout system.



Elements of Simulation Analysis – Problem Formulation

- Developing the model is often a trade off between the level of detail the simulation model should include and the understandability of the measures, i.e. too many variable to optimize on.

- But how much detail to be included in the model of a system?

- It depends upon the purpose for which the model is being developed and the marginal contribution of the additional detail.

Elements of Simulation Analysis – Problem Formulation

- The level of detail must be based on a subjective trial and error derived assessment of the marginal cost of obtaining the necessary data and including the required relationship in the model, versus the additional accuracy with which estimates of system performance can be made.

- The ultimate goal of any simulation is to assist in decision making, and this must dictate the problem formulation.

Elements of Simulation Analysis – Data collection and analysis

- Data collection methods are as varied as the problems to which they are applied, manual approaches to very sophisticated high technology techniques.
- The data collection method should be tail ordered to the particular system model that should be derived.
- Following issues can be considered:
  - Ability to record the data, achieving the desired level of accuracy
  - Impact of the data collection process on the system under observation
  - Ease of conversion of the sampled data to a computer processable form
  - Cost of the method

Elements of Simulation Analysis – Data collection and analysis

- Some of the data that defines simulation models are deterministic, that is, known with certainty, but much of it is often probabilistic.
- Given a set of probabilistic data, there are two main ways to include it in a simulation mode:
  - Use the actual sample data to represent the probabilistic distribution
  - Determine a theoretical probability distribution which is similar to the sample data.
- If possible, it is often better to use a theoretical distribution. It provides a better understanding of the simulation model and most often a more efficient execution of the simulation model.

Elements of Simulation Analysis – Model development

- In the model development step the description of the system being modeled by *quantifying the relationships among all of the variable and the performance measures*.
- In order to develop an accurate computer program which implements our model, we must *fully understand the system and all of its intricacies*.
- Acquiring this understanding of the system to develop an appropriate model is one of the most difficult tasks in simulation studies.
- Very often any specific approach or clear description of how to do it is lacking, or it is very hard to communicate the used approach.

Elements of Simulation Analysis – Model development

There exist two commonly used approaches:

- ***The physical flow approach***
- ***State change approach***

Elements of Simulation Analysis – Model development

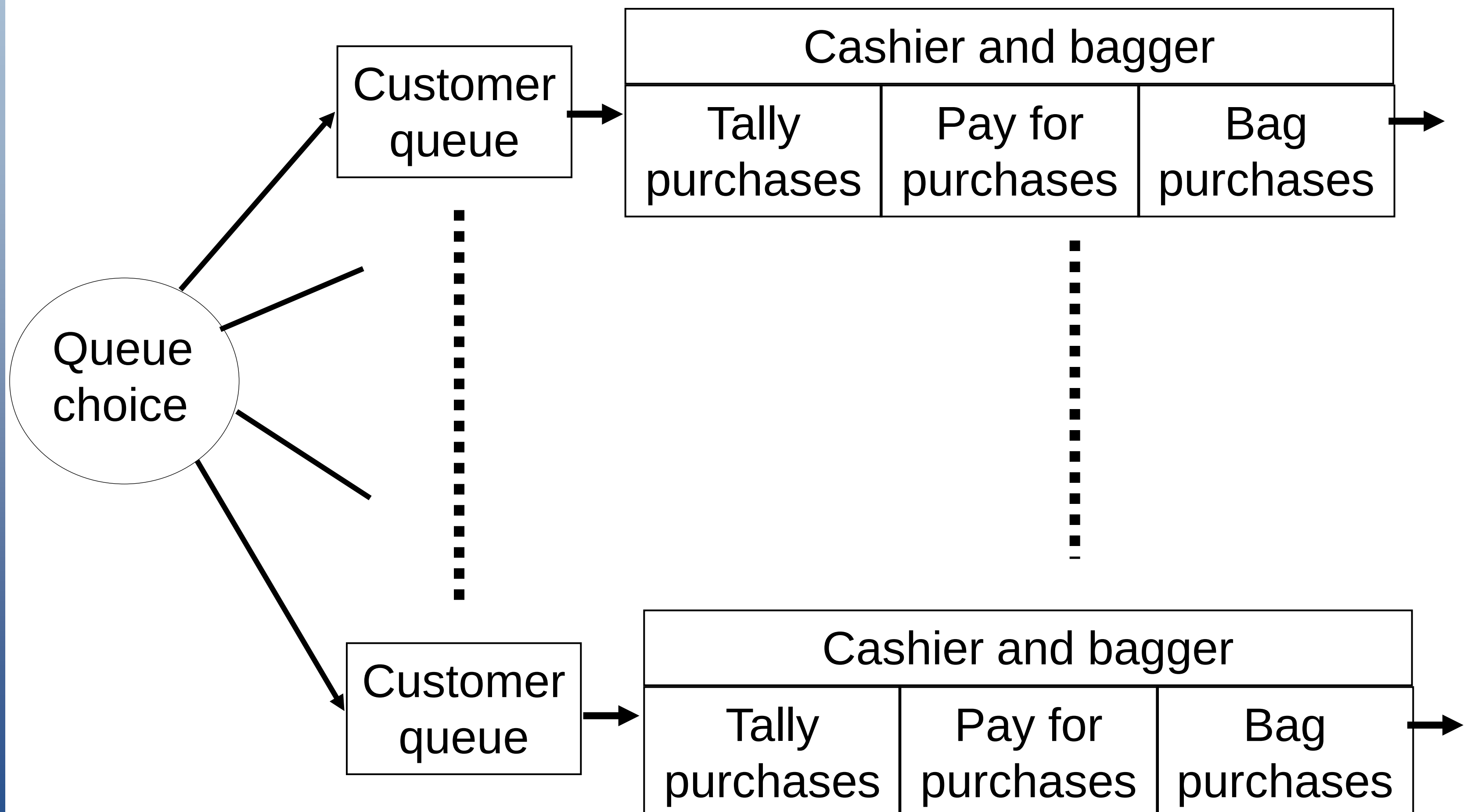
- To use the ***physical flow approach***, one identifies the physical entities for which processing or transformation constitutes the main purpose of the system.

- These entities are then tracked through the system, noting points of processing and branching decision rules that determine their route.

- A diagram of the entity flow and the system processing elements then provides the representation of the system from which the model and its associated computer program can be developed.

Elements of Simulation Analysis – Model development

Physical flow chart for supermarket checkout system



Elements of Simulation Analysis – Model development

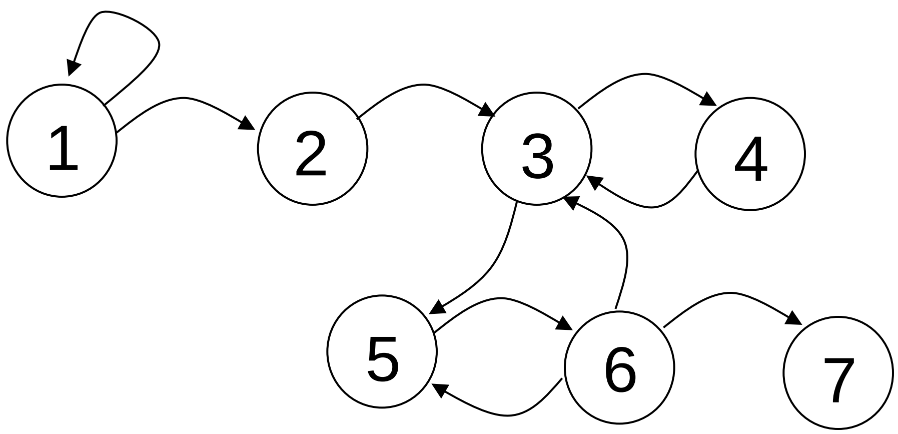
- In order to describe the ***state change approach*** it is necessary to define additional endogenous variable classification ***state variable*** and introduce the concept of an ***event***.
- ***State variable*** describes the present status of the system e.g. number of people in a queue, number of people presently served etc.
- Event is the particular point in time when a person arrives and joins a queue etc.
- By incorporating into the model the ability to update state variables as time advances and events occur we can describe the system behavior.

Elements of Simulation Analysis – Model development

- A useful approach for the ***state change approach*** is to represent this as an event graph.

- Events are represented as nodes and progression from event to event as arrows.

Event graph for the supermarket checkout system



Events

1. Customer arrives
2. Customer selects cashier
3. Cashier begins checkout
4. Cashier finish checkout
5. Bagger begins packing
6. Bagger Finish packing
7. Customers leaves

Elements of Simulation Analysis – Model development

- With an understanding of the type of model that is to be developed the next step is to do the actual model construction.

- The major tasks in this step are:
  - Developing a computer program flow chart for the simulation model.
  - Selecting programming language or simulation tool
  - Providing entities for the generation of random numbers and random distributions.
  - Writing and debugging program code.

Elements of Simulation Analysis – Model development

- The first step is to produce a logic flow chart of the computer program.
- If the physical flow approach was followed, the previous flow chart can more or less be used but one other factors must be considered.