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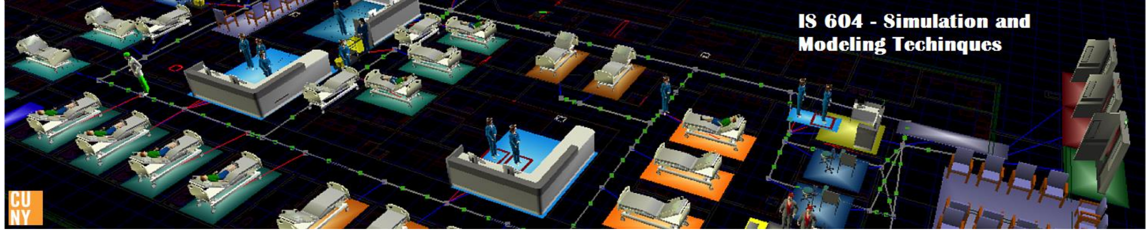


Week #1:

Introduction to Simulation

Graduate Program in Data Analytics (MSDA)
CUNY School of Professional Studies
The City University of New York

IS 604 – Simulation and Modeling Techniques

Assignment

- **Reading:** Ch. 1 (SCR), Ch. 1 (DES)

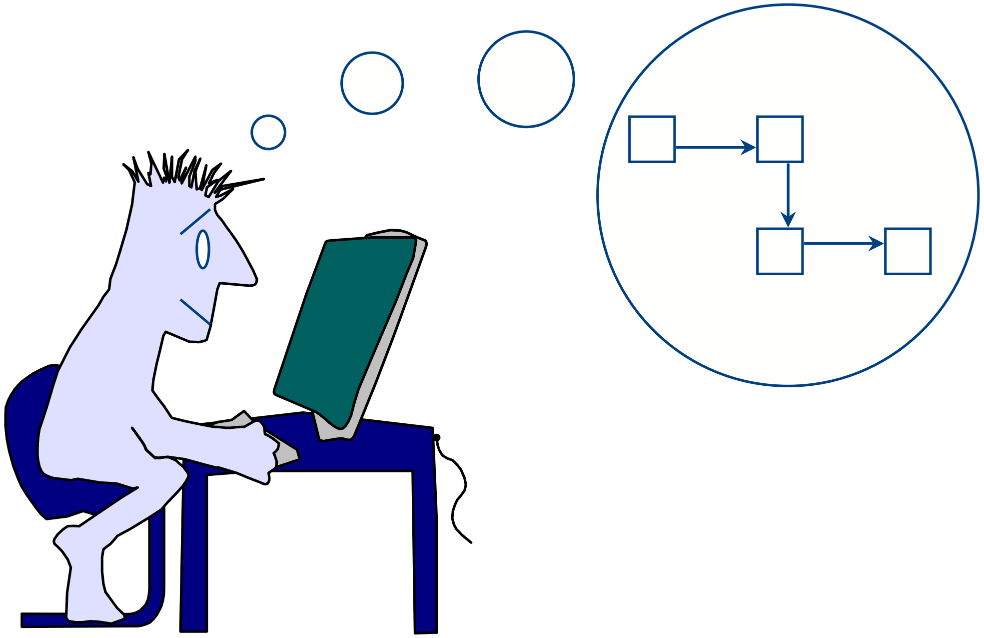
- **Activity:** Week #1 Quiz, Discussion #1

Learning Outcomes

- Understand the basic foundations of systems, models, and simulation.
- Know the different types of simulation.
- Learn the advantages and disadvantages of simulation.

What is simulation?

- **Simulation** is the imitation of a dynamic system using a computer model in order to evaluate and improve system performance.



What is simulation? (cont'd)

- ***Simulation***: Imitate the operations of a facility or process, usually via computer.
  - What's being simulated is the ***system***
  - To study system, often make assumptions or approximations, both logical and mathematical, about how it works
  - These assumptions form a ***model*** of the system
  - If model structure is simple enough, could use mathematical methods to get exact information on questions of interest — ***analytical solution***

System vs. State

- ***System***: A collection of entities (people, parts, messages, machines, servers, …) that act and interact together toward some end
  - In practice, depends on objectives of study
  - Might limit the boundaries (physical and logical) of the system
  - Judgment call: level of detail (e.g., what is an entity?)
  - Usually assume a time element – *dynamic* system

- ***State of a system***: Collection of variables and their values necessary to describe the system at that time
  - Might depend on desired objectives, output performance measures
  - Bank model: Could include number of busy tellers, time of arrival of each customer, etc.

Discrete vs. Continuous

- **Types of systems**
  - *Discrete*
    - State variables change instantaneously at separated points in time
    - Bank model: State changes occur only when a customer arrives or departs
  - *Continuous*
    - State variables change continuously as a function of time
    - Airplane flight: State variables like position, velocity change continuously
- Many systems are partly discrete, partly continuous

Examples of Systems

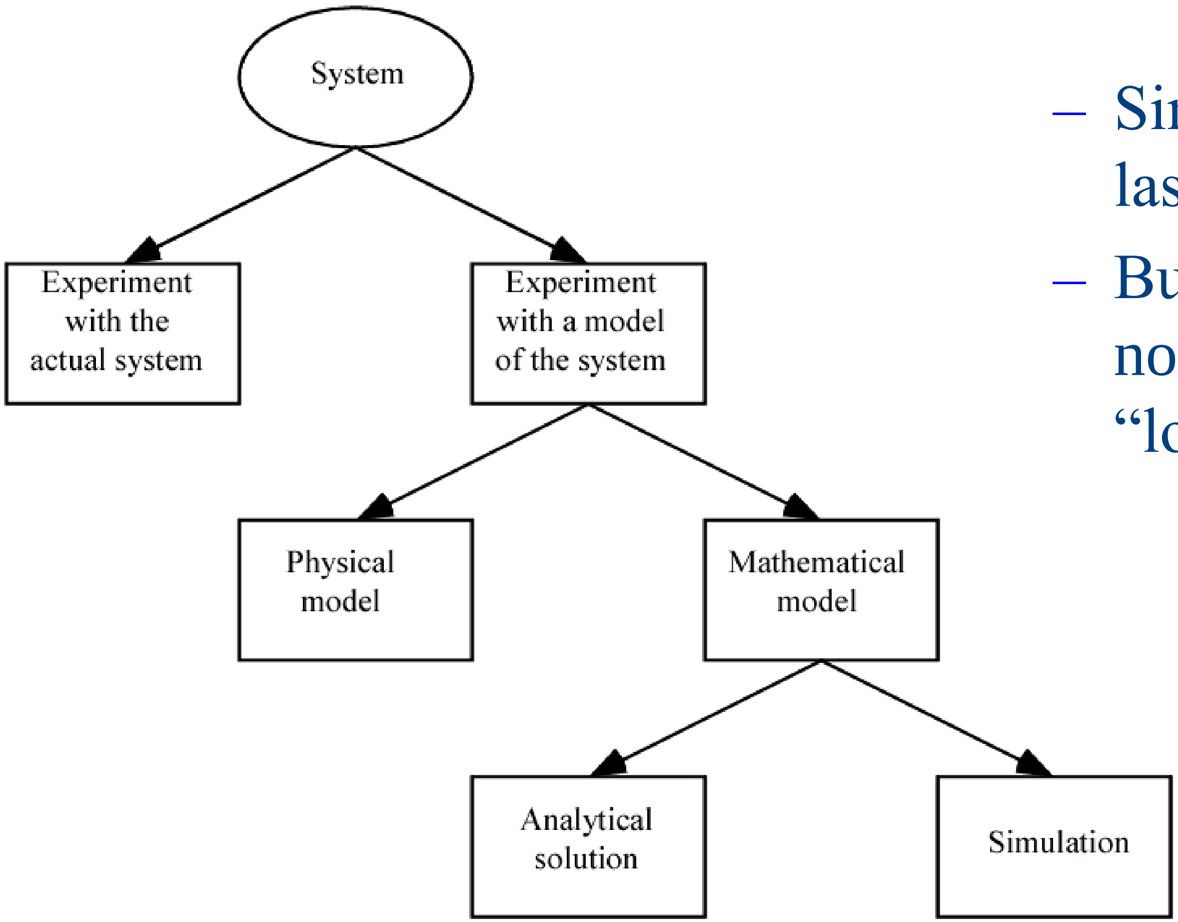
- ***System*** – facility or process, actual or planned
  - Examples abound …
    - Manufacturing facility
    - Bank operation
    - Airport operations (passengers, security, planes, crews, baggage)
    - Transportation/logistics/distribution operation
    - Hospital facilities (emergency room, operating room, admissions)
    - Computer network
    - Freeway system
    - Business process (insurance office)
    - Criminal justice system
    - Chemical plant
    - Fast-food restaurant
    - Supermarket
    - Theme park
    - Emergency-response system

Knowing the System

- **Study the system – measure, improve, design, control**
  - Maybe just play with the actual system
    - Advantage — unquestionably looking at the right thing
  - But it's often impossible to do so in reality with the actual system
    - System doesn't exist
    - Would be disruptive, expensive, or dangerous

Studying a System

- **Ways to study a system**



  - Simulation is "method of last resort?" Maybe …
  - But with simulation there's no need (or less need) to "look where the light is"

What is a model?

- ***Model*** – set of assumptions/approximations about how the system works
  - Study the model instead of the real system … usually much easier, faster, cheaper, safer
  - Can try wide-ranging ideas with the model
    - Make your mistakes on the computer where they *don't* count, rather than for real where they *do* count
  - Often, just *building* the model is instructive – regardless of results
  - Model *validity* (any kind of model … not just simulation)
    - Care in building to mimic reality faithfully
    - Level of detail
    - Get same conclusions from the model as you would from system

Physical vs. Logical

- ***Physical*** **(*iconic*) models**
  - Tabletop material-handling models
  - Mock-ups of fast-food restaurants
  - Flight simulators
- ***Logical*** **(*mathematical*) models**
  - Approximations and assumptions about a system's operation
  - Often represented via computer program in appropriate software
  - Exercise the program to try things, get results, learn about model behavior

More on Models

- If the model is simple enough, use traditional mathematical analysis … get exact results, lots of insight into model
  - Queueing theory
  - Differential equations
  - Linear programming
- But complex systems can seldom be *validly* represented by a simple analytic model
  - Danger of over-simplifying assumptions … model validity?
  - Type III error – working on the wrong problem
- Often, a complex system requires a complex model, and analytical methods don't apply … what to do?

Modeling Complexity

- But most complex systems require models that are also complex (to be valid)
  - Must be studied via simulation — evaluate model numerically and collect data to estimate model characteristics
- **Example:** Manufacturing company considering extending its plant
  - Build it and see if it works out?
  - Simulate current, expanded operations — could also investigate many other issues along the way, quickly and cheaply

Simulation Applications

- **Some (not all) application areas**
  - Designing and analyzing manufacturing systems
  - Evaluating military weapons systems or their logistics requirements
  - Determining hardware requirements or protocols for communications networks
  - Determining hardware and software requirements for a computer system
  - Designing and operating transportation systems such as airports, freeways, ports, and subways
  - Evaluating designs for service organizations such as call centers, fast-food restaurants, hospitals, and post offices
  - Reengineering of business processes
  - Determining ordering policies for an inventory system
  - Analyzing financial or economic systems

Computer Simulation

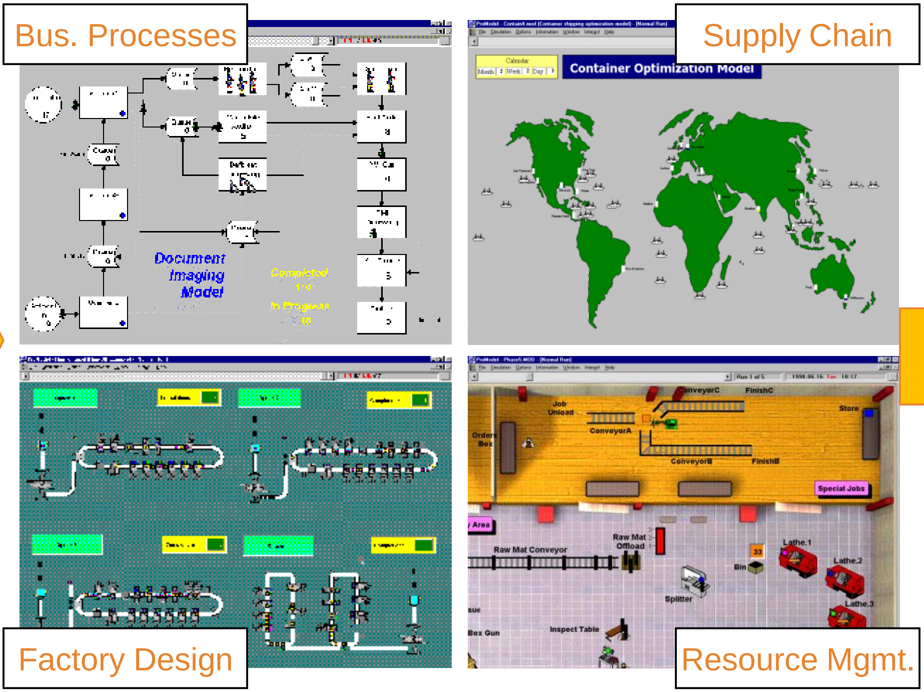
- Broadly interpreted, ***computer simulation*** refers to methods for studying a wide variety of models of systems
  - Numerically evaluate on a computer
  - Use software to imitate the system’s operations and characteristics, often over time
- Can be used to study simple models but should not use it if an analytical solution is available
- Real power of simulation is in studying complex models
- Simulation can tolerate complex models since we don’t even aspire to an analytical solution

Simulation Input/Output

INPUT

Operating Information

- Product/customer Mix
- Routings
- Schedules
- Operating Rules



OUTPUT

Performance Metrics

- Flow Times
- Resource Utilizations
- Inventory levels
- Output rates

More on Simulation

- **Like a flight simulator, simulation….**
  - Improves one's ability to make skilled decisions.
  - Reduces the time and cost associated with experimenting on the real system.
  - Minimizes the risk of making mistakes on the actual system.

Types of Simulation

- **Static vs. *Dynamic***
  - Does time have a role in the model?
- **Continuous-change vs. *Discrete-change***
  - Can the “state” change continuously or only at discrete points in time?
- **Deterministic vs. *Stochastic***
  - Is everything for sure or is there uncertainty?
- **Most operational models:**
  - *Dynamic*, *Discrete-change*, *Stochastic*

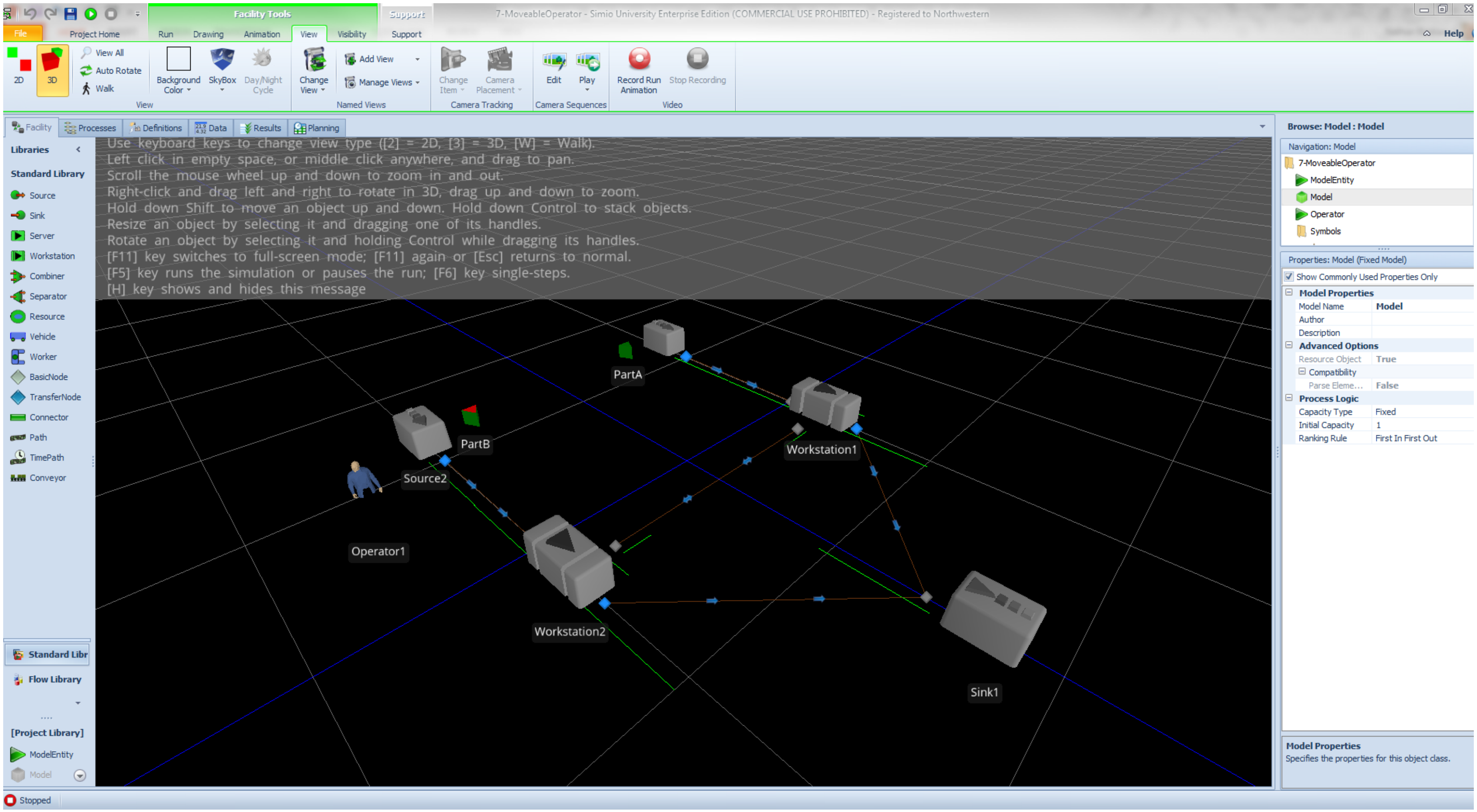
Impediments to Simulation

- **Impediments to acceptance, use of simulation**
  - Models of large systems are usually very complex
    - But now have better modeling software … more general, flexible, but still (relatively) easy to use
  - Can consume a lot of computer time
    - But now have faster, bigger, cheaper hardware to allow for much better studies than just a few years ago … this trend will continue
    - However, simulation will also continue to push the envelope on computing power in that we ask more and more of our simulation models
  - Impression that simulation is "just programming"
    - There's a lot more to a simulation study than just "coding" a model in some software and running it to get "the answer"
    - Need careful design and analysis of simulation models – simulation methodology

Benefits of Simulation

- Quick and easy to use.
- Versatile enough to model any system.
- Captures system dynamics and variation.
- Shows system behavior over time.
- Animation provides effective communication.
- Forces one to think through the operational details of a system.

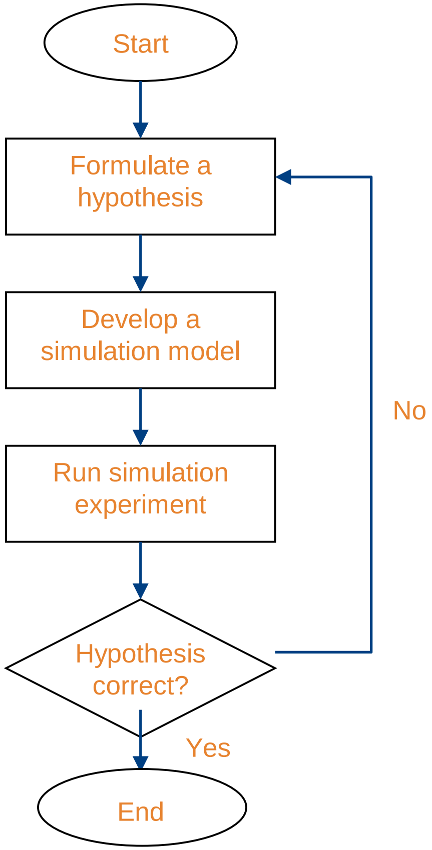
Simulation as a Visualization Tool



Simulation Animation

- Visually shows system behavior
- Stimulates interest
- Sparks creative thinking

Simulation as an Experimentation Tool



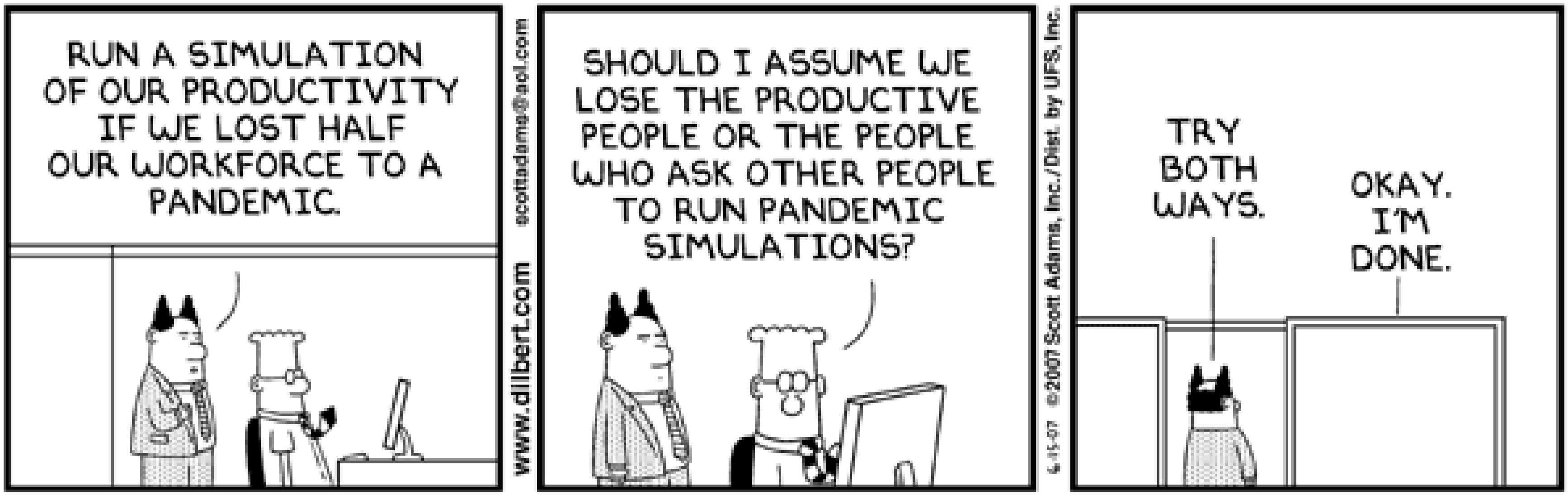
Reasons for Doing Simulation

1. Analyze a problem (why is this problem happening?)
2. Facilitate innovation (what solutions should I consider?)
3. Evaluate one or more scenarios (how do different solutions compare?)
4. Find the optimum solution (what solution settings give the best desired performance?)
5. Assess the robustness of the solution (how does the solution perform under extreme conditions?)
6. Communicate a concept/solution (how can I show the benefits of the solution?)

When to Simulate…

- An operational (logical or quantitative) decision is being made.
- The process being analyzed is well defined and repetitive.
- Activities and events are interdependent and variable.
- The cost impact of the decision is greater than the cost of doing the simulation.
- The cost to experiment on the actual system is greater than the cost of simulation.

Or, if required by management.



Knowledge and Skills for Doing Simulation

- Project management
- Communication
- Systems engineering
- Statistical analysis and design of experiments
- Modeling principles and concepts
- Basic programming and computer skills
- Training on one or more simulation products
- Familiarity with the system being modeled

Steps In Simulation and Model Building

1. Define an achievable goal
2. Put together a complete mix of skills on the team
3. Involve the end-user
4. Choose the appropriate simulation tools
5. Model the appropriate level(s) of detail
6. Start early to collect the necessary input data

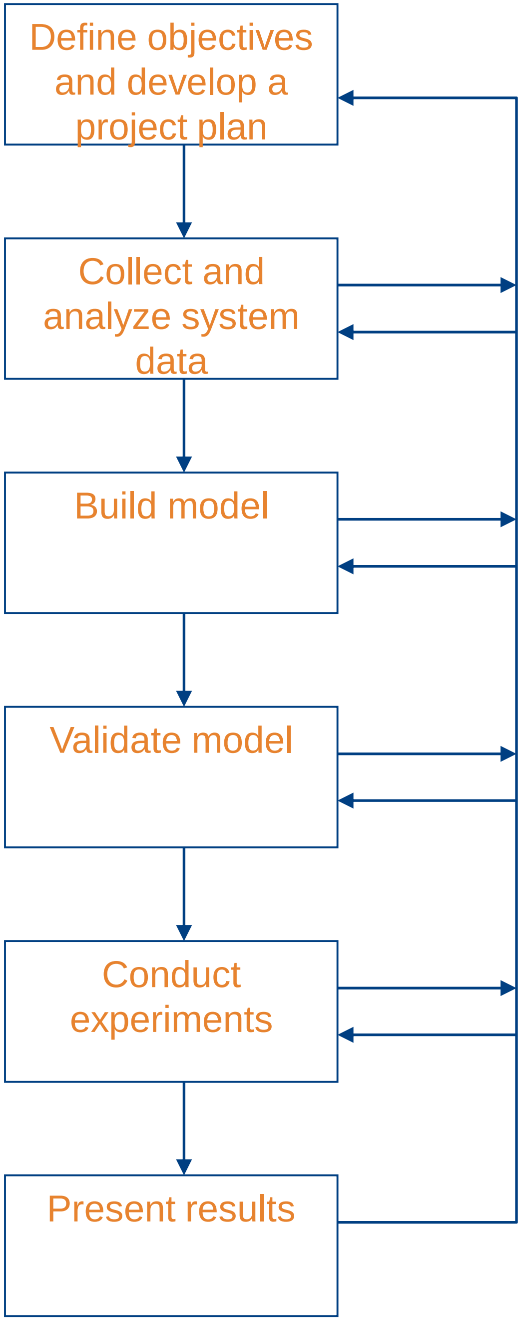
Steps In Simulation and Model Building (cont'd)

7. Provide adequate and on-going documentation
8. Develop a plan for adequate model verification

   (Did we get the "right answers ?")
9. Develop a plan for model validation

   (Did we ask the "right questions ?")
10. Develop a plan for statistical output analysis

These steps are iterative rather than sequential.



Define An Achievable Goal

"To model the…" is NOT a goal!

"To model the…in order to select/determine feasibility/…is a goal.

Goal selection is not cast in concrete

Goals change with increasing insight

Put together a complete mix of skills on the team

We Need:

-Knowledge of the system under investigation

-System analyst skills (model formulation)

-Model building skills (model Programming)

-Data collection skills

-Statistical skills (input data representation)

Put together a complete mix of skills on the team (cont'd)

We Need:

-More statistical skills (output data analysis)

-Even more statistical skills (design of experiments)

-Management skills (to get everyone pulling in the same direction)

Involve the End User

-Modeling is a selling job!

-Does anyone believe the results?

-Will anyone put the results into action?

-The End-user (your customer) can (and must) do all of the above BUT, first he must be convinced!

-He must believe it is HIS Model!

Choose the Appropriate Simulation Tools

Assuming Simulation is the appropriate means, three alternatives exist:

1. Build Model in a General Purpose Language

2. Build Model in a General Simulation Language

3. Use a Special Purpose Simulation Package

Model the Appropriate Level(s) Of Detail

- Define the boundaries of the system to be modeled.
- Some characteristics of “the environment” (outside the boundaries) may need to be included in the model.
- Not all subsystems will require the same level of detail.
- Control the tendency to model in great detail those elements of the system which are well understood, while skimming over other, less well - understood sections.

Start Early to Collect the Necessary Input Data

Data comes in two quantities:

TOO MUCH!!

TOO LITTLE!!

With too much data, we need techniques for reducing it to a form usable in our model.

With too little data, we need information which can be represented by statistical distributions.

Provide Adequate and On-going Documentation

In general, programmers hate to document. (They love to program!)

Documentation is always their lowest priority item. (Usually scheduled for just after the budget runs out!)

They believe that "only wimps read manuals."

What can we do?

- Use self-documenting languages
- Insist on built-in user instructions(help screens)
- Set (or insist on) standards for coding style

Develop Plan for Adequate Model Verification

Did we get the “right answers?”

(No such thing!!)

Simulation provides something that no other technique does:

Step by step tracing of the model execution.

This provides a very natural way of checking the internal consistency of the model.

Develop a Plan for Model Validation

VALIDATION: "Doing the right thing"

Or "Asking the right questions"

How do we know our model represents the

system under investigation?

- Compare to existing system?
- Deterministic Case?

Develop a Plan for Statistical Output Analysis

- How much is enough?

  Long runs versus Replications

- Techniques for Analysis

Simulation in Systems Design

- Flow Analysis
- Resource and Equipment Selection
- Methods analysis (e.g. automation vs manual)
- Optimization (e.g. right number of resources)
- Capacity/Throughput Analysis
- Control Logic Design

Simulation in Systems Management

- Production/Customer Scheduling
- Resource Scheduling
- Maintenance Scheduling
- Work Prioritization
- Flow Management
- Delay/Inventory management
- Quality Management

Drawbacks to Simulation

- It can be expensive and time consuming to get started.
- Sometimes easier and better solutions get overlooked.
- Qualitative and human factors may get ignored.
- Results can be misinterpreted.
- It can be difficult to prove model validity.
- Too much confidence can be placed in results.

Advantages of Simulation

- **Advantages**
  - Simulation allows great flexibility in modeling complex systems, so simulation models can be highly valid
  - Easy to compare alternatives
  - Control experimental conditions
  - Can study system with a very long time frame

Disadvantages of Simulation

- **Disadvantages**
  - Stochastic simulations produce only estimates – with noise
  - Simulation models can be expensive to develop
  - Simulations usually produce large volumes of output – need to summarize, statistically analyze appropriately

- **Pitfalls**
  - Failure to identify objectives clearly up front
  - In appropriate level of detail (both ways)
  - Inadequate design and analysis of simulation experiments
  - Inadequate education, training