- **Simulation** is the manipulation of a model in such a way that it operates in time or space to summarize it.
- **Simulation** make enable one to perceive the interactions that would otherwise be apparent because of their separation in time or space.

Advantages of M&S

- Choose correctly:
  - M&S lets you test every aspect of a proposed change or addition without committing resources to their acquisition.
- Compress and expand time:
  - M&S allows you to speed up or slow down phenomena so that you can investigate them better.
- Understand why:
  - Managers often want to know why certain phenomena occur in a real system.
  - M&S lets you determine answers to "why" questions by reconstructing (replaying) the scene and taking a closer look at what has happend during the run.
- Explore possibilities:
  - You can explore new policies, operating procedures or methods without the need of experimenting with the real world systems.
- Diagnose problems:
  - Some systems are so complex that it is impossible to consider all the interactions taking place in a given moment.
  - With M&S, you can better understand the interactions among the variables that make up the complex system.
- Identify constraints:
  - Bottlenecks in a system is an effect rather than a cause.
  - Doing bottleneck analysis with M&S, you can discover the cause of the delays in work process, information, material or other processes.
- Develop understanding:
  - M&S provides understanding about how a system really operates rather than indicating someone's predictions about how a system will operate.
- Visualize the plan:

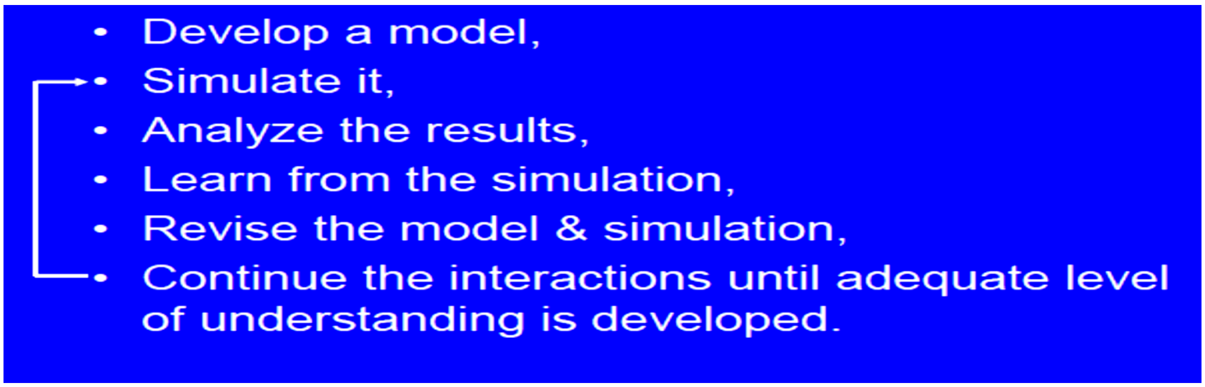
  - M&S lets you see your system actually running.
  - That allows you to detect design flaws that appear credible.
- Build consensus:
  - Instead of saying one person's opinion about a system, you actually show how the system works, so provide an objective opinion.
- Prepare for change:
  - Using M&S, you can ask what-if questions for determining future improvements and new designs on a system.
- Invest wisely:
  - M&S is a wise investment since
- Typical cost of a simulation study is substantially less than generally 1% of the total amount being expended for the implementation of a design or redesign.
- Train the team:
  - M&S can provide excellent training when design for that purpose.
  - In training, team provides decision inputs to the simulation as it progress, and observes the outputs.
  - After simulation ends, further evaluation can be provided by after action review (AAR).
- Specify requirements:
  - M&S can be used to determine requirements for a system design by simulating different possible configurations of a system.

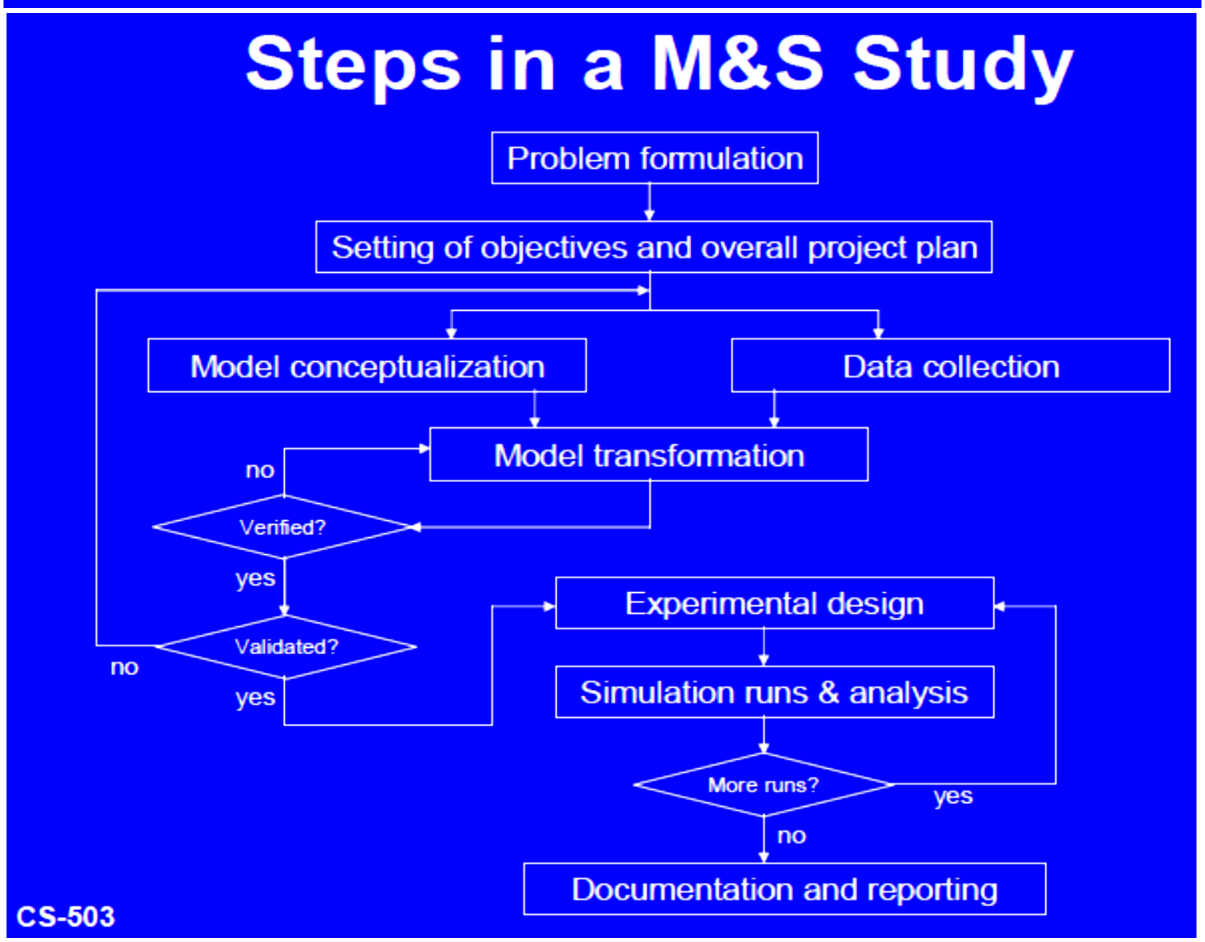
Disadvantages of M&S

- Model building requires special training:
  - M&S is an art that is learned over time and through experience.
  - Two models of the same system developed by two different individuals may have similarities, but it is unlikely be the same.
  - Building a realistic model may require domain knowledge that can only be acquired from a subject matter expert.
- Simulation results may be difficult to interpret:
  - Since most simulation results are essentially random variables,
- It may be hard to determine whether an observation is a result of system interrelationships or just randomness.

- Simulation modeling and analysis can be time consuming and expensive:
  - Economizing on resources for modeling and analysis may result in a simulation not sufficient enough for the problem, and may consume time, effort and money for nothing.
- Simulation may be used inappropriately:
  - Simulation is used in some cases when analitical solution is possible, or even preferable.

❖ How to Use a Simulation ?





❖ Some Application Areas

- Medical research, training & support
- Industrial engineering designs & presentations (Factory process design, manufacturing, ...)
- Civil engineering designs & presentations (Building design, city & infrastructure planning, ...)
- Mechanical engineering designs & presentations (Engine designs, aerodynamic design, ...)
- Nature sciences (Physic, chemistry, biology, meteorology, astronomy, ...)
- Geographic Information Systems (Earth modeling, ...)
- Military Decision Support (War modeling, ...)
- Training (Simulators, games, ...)
- Entertainment (Games, ...)

❖ Practical Focus

- Modeling & Simulation in;
  - Defense Industry, and
  - Game Programming.
- Includes:
  - Earth modeling,
  - Entity modeling,
  - Behavior modeling,
  - Sensor & weapon systems modeling,
  - Distributed simulations,
  - Simulation based optimization and analysis.

❖ Complexity Types

- Detail Complexity (Associated with systems which have many component parts).
- Dynamic Complexity (Associated with systems which have cause and effect separated by time and space.
- Great difficulty dealing with (Unable to readily see the connections between parts of the systems and their interactions).

❖ Simulation Types (WRT Entities Involved)

- Live
- Virtual
- Constructive

▪ Live Simulations

- Real systems & actors
- Real environment

▪ Possible results:

- Resource Waste
- Time Waste
- Possible Damages

▪ Virtual Simulations

- Real/Virtual systems & actors
- Real/Virtual environment

Usually used for training within simulators

▪ Constructive Simulations

- Virtual systems & actors
- Virtual environment

▪ Objectives:

- Doing measurement, comparison, forcasting & concept analysis,
- Producing statistics

❖ Simulation Types (WRT Time Advance)

- Discrete
- Continuous

▪ Discrete (Event) Simulations

- Time is advanced from event time to event time rather than using a continuously advancing time clock.

▪ Continuous Simulations

- Something that can only really be accomplished with an analog computer.

- An approximation for continuous simulations (combined discrete continuous sim.) is;
  - Making the time step of the simulation sufficiently small so there are no transitions within the system between time steps.
  - So the simulation is stepped in time increments.

Simulation Types (WRT Results)

- Deterministic
- Stochastic

Deterministic Simulations

- A model that does not contain probability.
- Every run will result the same.
- Single run is enough to evaluate the result.

Stochastic Simulations

- A model that contains probability.
- Units, process, events or their parameters are initiated randomly using random numbers.
- If different runs are initiated with different random number seeds,
  - Every run will result differently.
- Multiple runs are required to evaluate the results.
- Statistics such as averages, standard deviations are used for evaluation.

Simulation Types (WRT Design)

- Traditional
- Agent-Based

Traditional Simulations

- Simulations where the characteristics of a population are averaged together, and
- The model attempts to simulate changes in these averaged characteristics for the whole population.

Traditional Simulations (Screen shoot of a GPSS Program)

- GPSS is a traditional computer simulation language that stands for general-purpose simulation systems.

Agent-Based Simulations

- Differs from traditional kinds of simulations in that some or all of the simulated entities are modeled in terms of agents.
- Explicitly attempts to model specific behaviors of specific individuals.
- Contrasted to methods where the characteristics of a population are averaged together.
- Supports structure preserving modeling of the simulated reality.

Agent-Based Simulations (Domain Examples)

- Vehicles and pedestrians in traffic situations.
- Actors in financial markets.
- Consumer behavior.
- Humans and machines in battlefields.
- People in crowds.
- Animals and/or plants in eco-systems.
- Artificial creatures in computer games.

Agent-Based Simulations (Advantages)

- Distributed control, supporting parallel computations on separate machines.
- Supports simulation of pro-active behaviour.
- Ability to add or delete entities during a simulation.
- Easy to swap (exchange) an agent with the corresponding simulated entity,
  - i.e., a real person or a physical machine, (even during a simulation) making the simulation scenarios very dynamic.
- Facilitates simulation of group behavior in highly dynamic situations,
  - Thereby allowing the study of "emergent behavior" that is hard to grasp with traditional methods.

- Well-suited for the simulation of situations where there are a large number of hetereogenous individuals who may behave somewhat differently.

❖ Verification & Validation

- Real-world system under investigation is abstracted by a conceptual model.
- Conceptual model is then coded into operational model.
- Hopefully, operation model is a correct representation of real-world system.
- We need more than hope.
- To ensure correctness, we have to perform verification and validation.

▪ Verification

- Determination of whether the computer implementation of the conceptual model is correct.
- Question:
  - Does the operational model accurately reflects the conceptual model?
- To get an answer:
  - Examine the simulation program in details and compare to the conceptual model.
- Commonsense ways to perform verification:
  - Follow the principles of structured programming (detailed plans, top-down design, flow charts, etc.).
  - Make operational model as self- documenting as possible (comments, graphical software).
  - Have computer code checked by more than one person.
- Commonsense ways to perform verification:
  - Check to see that values of input data are being used appropriately (e.g. units).
  - For a variety of input-data values, ensure that outputs are reasonable.
  - Use an interactive run controller or debugger to check that program operates as intended (e.g. execute model step by step).
  - Visualization is a very useful verification tool (e.g. detect actions that are illogical).

▪ Validation

- Determination of whether the conceptual model can be substituded for the real system for the purpose of experimentation.

- A variety of subjective and objective techniques can be used to validate the conceptual model.
- Subjective techniques to perform validation:
  - Face validation: Model must appear reasonable to the subject matter experts.
  - Sensitivity analysis: When model input is changed, output should change in a predictable direction.
  - Extreme condition test: Check whether model behaves properly when input data are at the extremes.
- Subjective techniques to perform validation:
  - Validation of conceptual model assumptions:
- Check structural and data assumptions with appropriate personnel (experts, consultants).
- No one person knows everything about the entire system.
- So, many people are required.
- Subjective techniques to perform validation:
  - Consistency checks:
- Continue to examine operation model over time.
- Detect significant changes in real-system that would effect correctness of simulation model.
- Subjective techniques to perform validation:
  - Turing tests:
- Experimentally compare model outputs to system outputs with experts.
- Make experts distinguish the ones that are simulated.
- If a substantial number of simulated ones are identified, simulation model is inadequate.
- Objective techniques to perform validation:
  - Validating input-output transformations:
- Compare model output to the output of real-system if possible (e.g. using t-test).
  - Validation using historical input data:
- Drive operational model with historical records.
- Output should stay within acceptable statistical error of those observed from real-world system.