

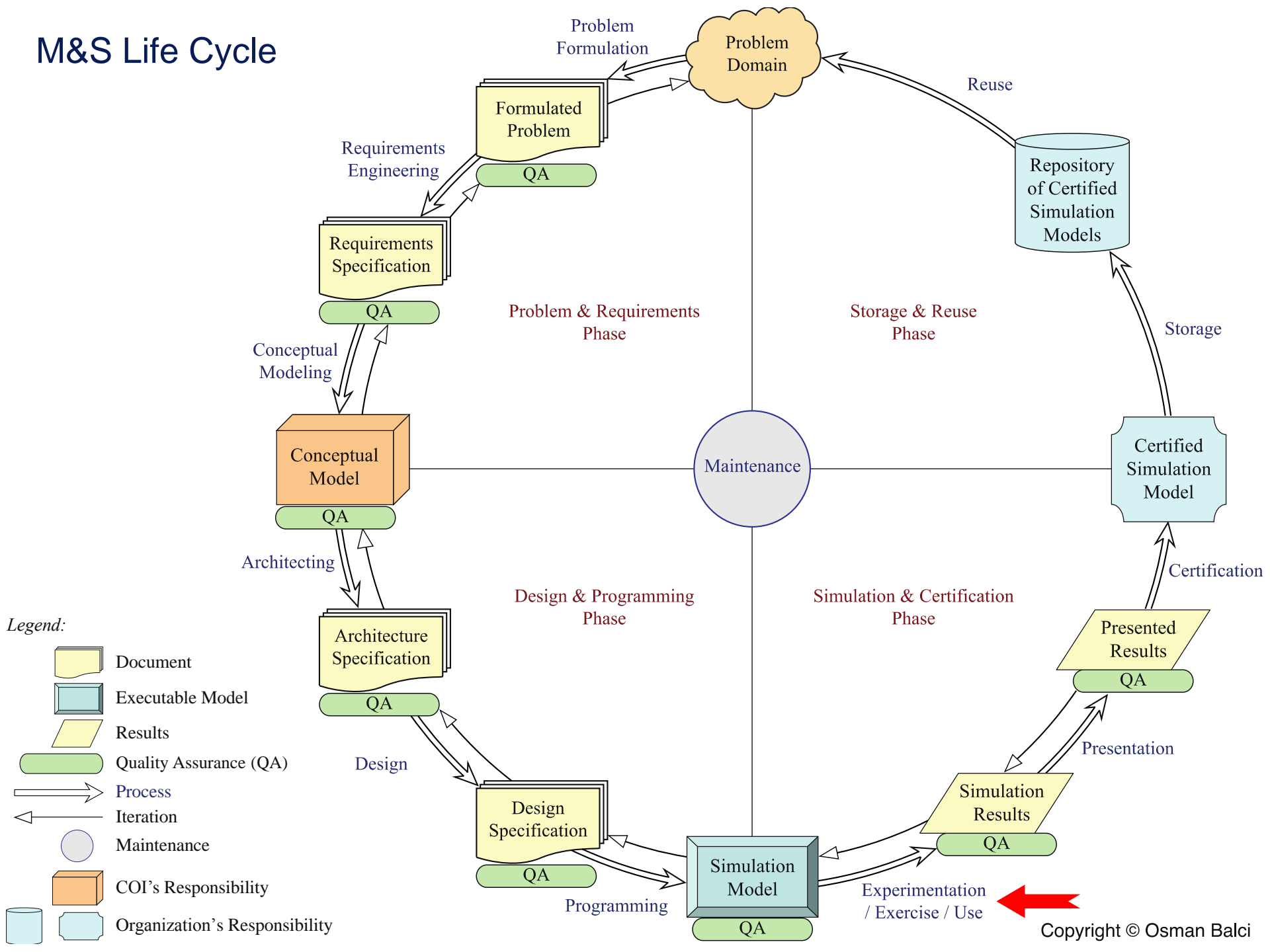
Experimentation / Exercise / Use

OSMAN BALCI
Professor

Department of Computer Science
Virginia Polytechnic Institute and State University (Virginia Tech)
Blacksburg, VA 24061, USA

<https://manta.cs.vt.edu/balci>

M&S Life Cycle



Experimentation / Exercise / Use

■ Experimentation / Exercise / Use

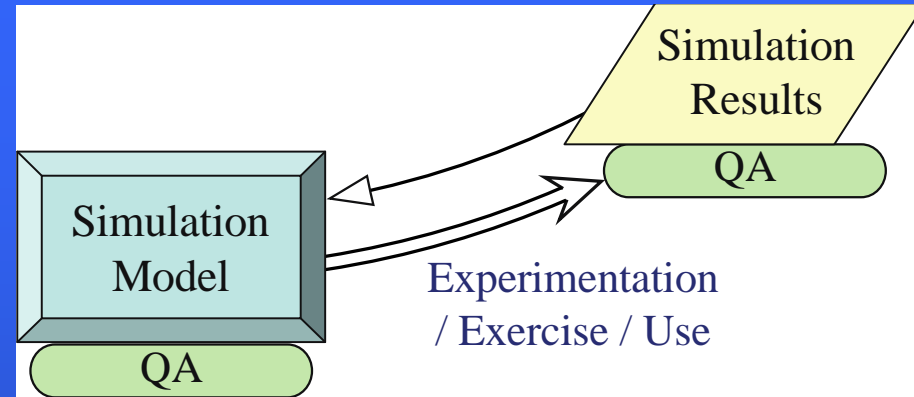
is the process in which the finished simulation model is

- **experimented with** (for **problem solving**),
- **exercised** (for **training purposes**), or
- otherwise **used**.

■ This process produces the simulation results based on the experimentation, exercise or use.

■ The simulation results

- make up the solution to the problem (for problem solving)
- show effectiveness of training (for training purposes), or
- indicate some benefit in using the simulation model (e.g., for research).

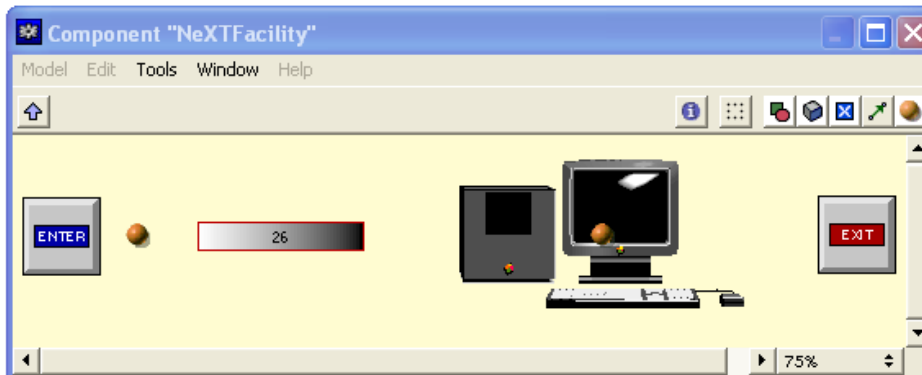
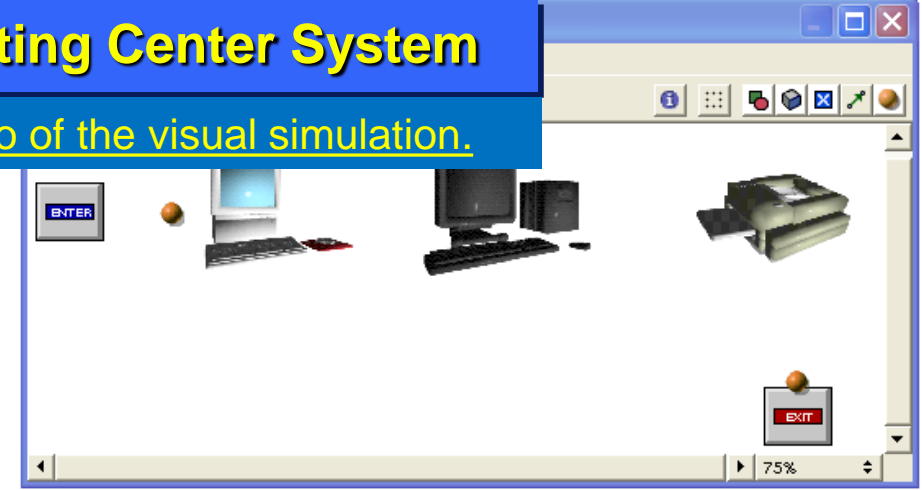
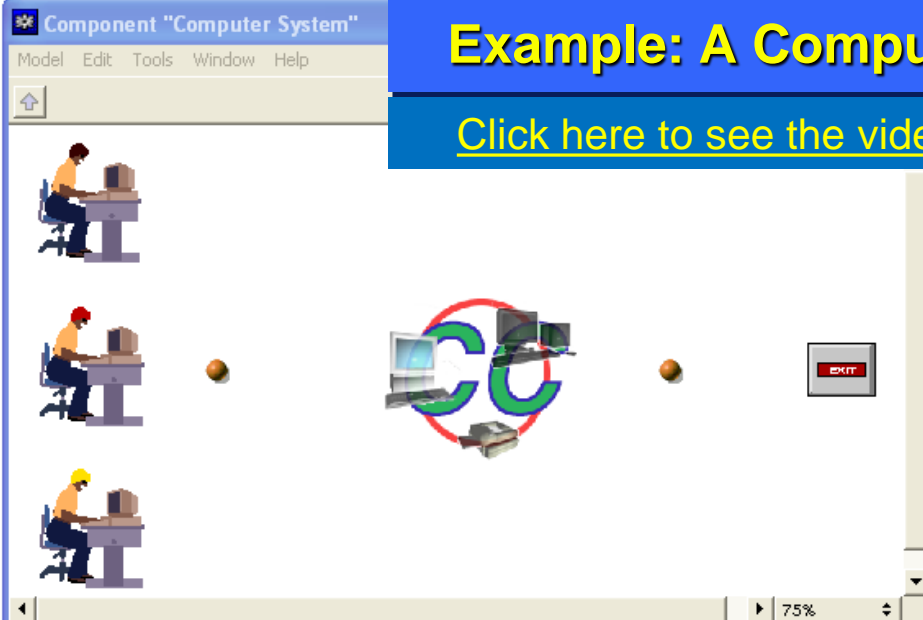


Example Purposes of Experimentation

- **Evaluation:** e.g., Evaluation of the proposed system design for the purpose of assessing its quality characteristics such as operational effectiveness, integrated system effectiveness, deployment readiness, performance, interoperability, and security.
- **Comparison:** Comparing competitive systems designed to carry out a specified function, or comparing several proposed operating policies or procedures.
- **Prediction:** Forecasting the behavior of a system under some projected set of conditions.
- **Sensitivity Analysis:** Determining which of many factors are the most significant in affecting overall system behavior.
- **Optimization:** Determining exactly which combination of factor levels will produce the optimal overall behavior of the system.
- **Ranking and Selection:** Ranking N number of alternatives (e.g., operating policies) and selecting the best one.

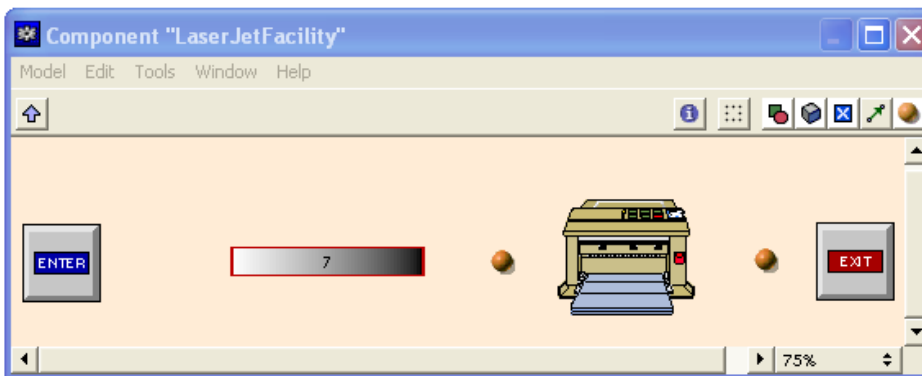
Example: A Computing Center System

[Click here to see the video of the visual simulation.](#)



Simulation Control window. It features playback controls (stop, play, pause) and status information: Replication Number: 1, Simulation Clock: 1052.4, Number of DynObjs Departed: 100. Animation mode is set to Periodic. Below is a table of experiment data.

Experiment name	Replications	Warm-up	Steady-state	Value set
Experiment for Evaluation	30	3000	15000	My Experiment
Model Validation Test	30	3000	15000	Model Validation Test



Problem to Solve

- **Estimate the following performance measures:**
 1. **Average Number of Jobs in the Computing Center**
 2. **Average Waiting Time of Jobs in the Computing Center**
 3. **Average Number of Jobs in the LaserJet Facility**
 4. **Average Number of Jobs in the Macintosh Facility**
 5. **Average Number of Jobs in the NeXT Facility**
 6. **Average Number of Jobs in the LaserJet Waiting Line**
 7. **Average Number of Jobs in the Macintosh Waiting Line**
 8. **Average Number of Jobs in the NeXT Waiting Line**
 9. **Utilization of the LaserJet Printer**
 10. **Utilization of the Macintosh Computer**
 11. **Utilization of the NeXT Computer**
 12. **Average Waiting Time of Jobs in the LaserJet Facility**
 13. **Average Waiting Time of Jobs in the Macintosh Facility**
 14. **Average Waiting Time of Jobs in the NeXT Facility**
 15. **Average Waiting Time of Jobs in the LaserJet Waiting Line**
 16. **Average Waiting Time of Jobs in the Macintosh Waiting Line**
 17. **Average Waiting Time of Jobs in the NeXT Waiting Line**

Input Variables and Parameters

Input Data

Model Edit Tools Window Help

Type	Name	My Experiment	Model Validation T
integer	CAPACITY	10	10
real	TRANSMISSIONTIME	3.0	3.0
VStream ref	interArrivalTimesOfJobsFromUsers 1	(VExponentialRVStream 13 15)	(VExponentialRVStream 13 15)
VStream ref	interArrivalTimesOfJobsFromUsers2	(VExponentialRVStream 13 16)	(VExponentialRVStream 13 16)
VStream ref	interArrivalTimesOfJobsFromUsers3	(VExponentialRVStream 13 17)	(VExponentialRVStream 13 17)
VStream ref	jobExecutionTimesOnMac	(VExponentialRVStream 13 18)	(VExponentialRVStream 13 18)
VStream ref	jobExecutionTimesOnNeXT	(VExponentialRVStream 13 19)	(VExponentialRVStream 13 19)
VStream ref	jobPrintingTimesOnLaserJet	(VExponentialRVStream 13 20)	(VExponentialRVStream 13 20)

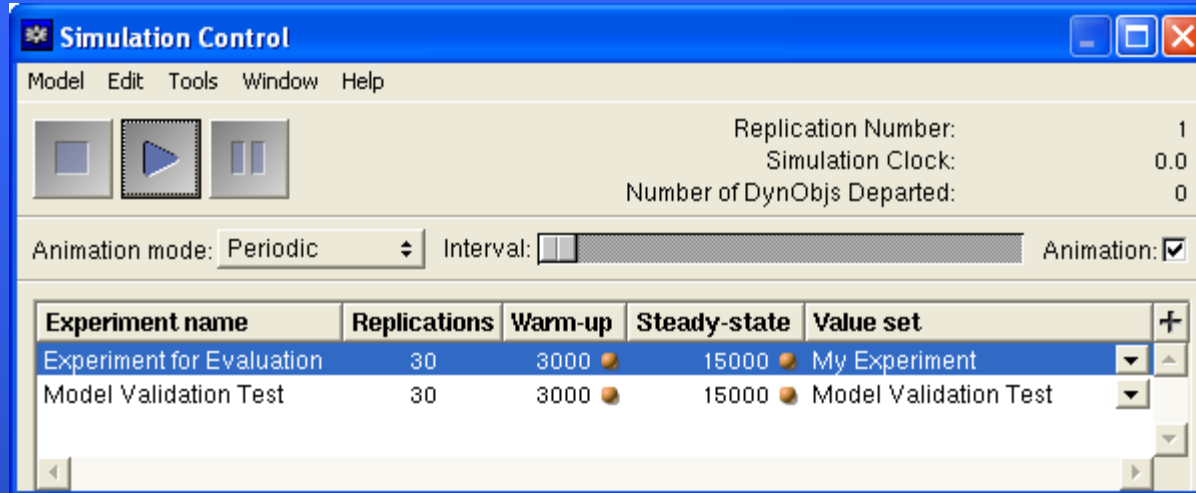
Object: (VExponentialRVStream 13 16)

seed	9752
location	0.0
scale	40.0

Interarrival times of jobs from PC Users Group 2:

This random variable characterizes the time between the arrivals of two jobs from the PC Users Group 2.

Experiment Design



- **Method of Replications** is used for experimenting with the model.
- 30 simulation runs (replications) are performed.
- Each replication consists of
 - 3,000 jobs leaving the computer system to warm up the model; and
 - 15,000 jobs leaving the computer system to collect data in steady state for constructing confidence intervals for the performance measures to be estimated.

Experimentation Results

AvgNoOfJobsInSystem.vseout -- C:\Program Files\WSE\Samples\...

File Edit Format Tools Window Help

// Average Number of Jobs in the Computing Center

9.137216
9.519452
9.362068
9.673683
8.904831
10.087507
10.261262
9.960460
9.396043

Compute Compute All Save Results... Save

Confidence Intervals General Statistics

	90%	95%	97.5%	99%	99.5%
Upper limit:	9.671013	9.703022	9.730798	9.763072	9.785117
Lower limit:	9.444923	9.412914	9.385138	9.352864	9.330820

AvgWTimeInSystem.vseout -- C:\Program Files\WSE\Samples\Sa...

File Edit Format Tools Window Help

// Average Waiting Time of Jobs in the Computing Center

60.712267
62.520243
61.745375
63.507749
59.576186
65.897476
66.785915
65.415337
62.631401

Compute Compute All Save Results... Save All Results...

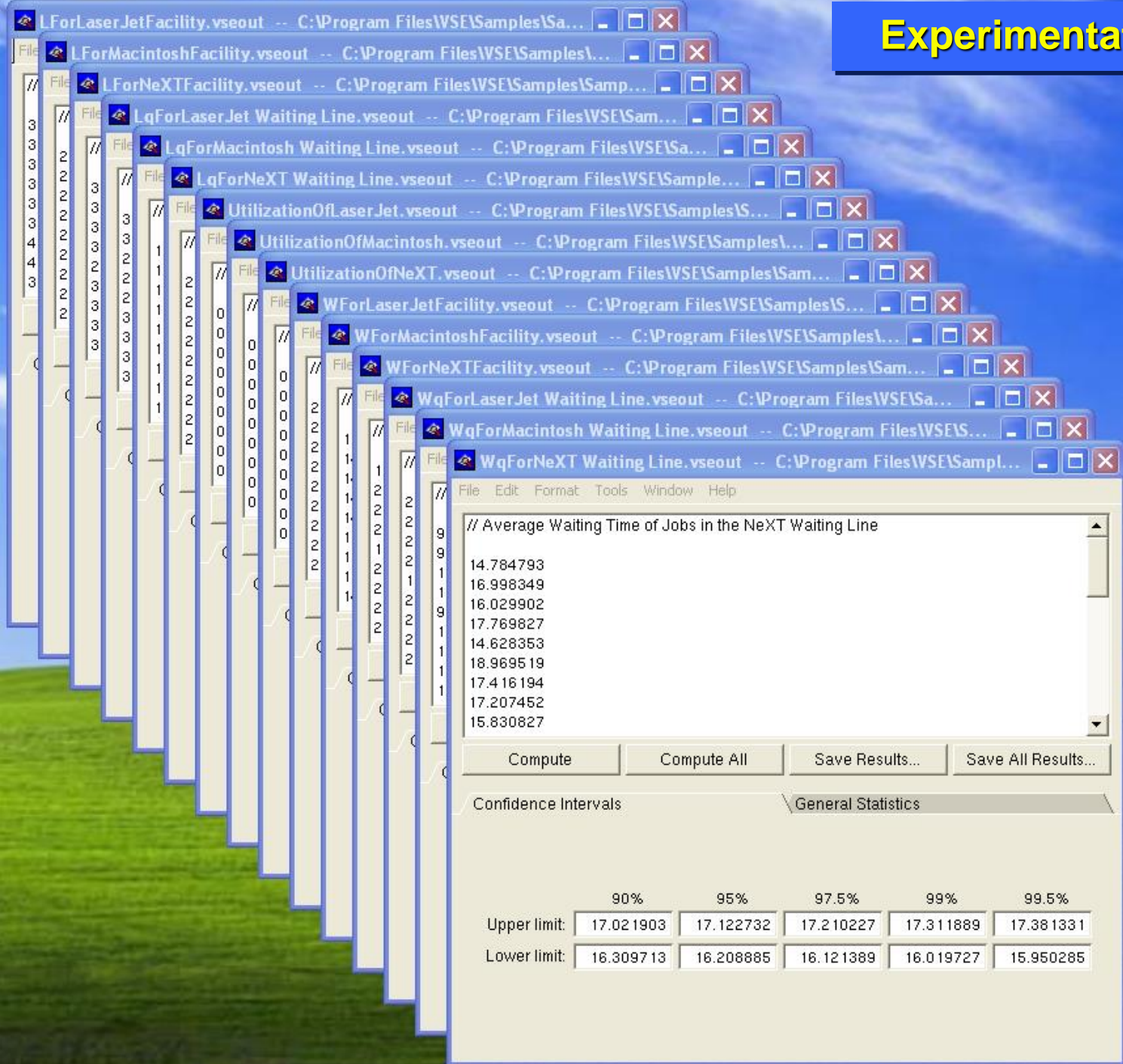
Confidence Intervals General Statistics

	90%	95%	97.5%	99%	99.5%
Upper limit:	63.915789	64.091707	64.244362	64.421734	64.542889
Lower limit:	62.673221	62.497303	62.344648	62.167276	62.046121

Confidence Intervals General Statistics

	90%	95%	97.5%	99%	99.5%
Upper limit:	63.915789	64.091707	64.244362	64.421734	64.542889
Lower limit:	62.673221	62.497303	62.344648	62.167276	62.046121

Experimentation Results



Design of Experiments

- **Design of Experiments** (for problem solving/analysis) is the process of formulating a plan to gather the desired information at minimal cost and to enable the analyst to draw valid inferences.
- Some of the techniques used for the design of experiments:
 - **Response-surface methodologies** can be used to find the optimal combination of parameter values which maximize or minimize the value of a response variable.
 - **Factorial designs** can be employed to determine the effect of various input variables on a response variable.
 - **Variance reduction techniques** can be implemented to obtain greater statistical accuracy for the same amount of simulation.
 - **Ranking and selection techniques** can be utilized for comparing alternative systems.
 - **Method of replications, method of batch means, regenerative method**, and others can be used for statistical analysis of simulation output data.

Example Indicators for Assessing Experimental Design

- Are the algorithms used for random variate generation theoretically accurate?
- Are the random variate generation algorithms translated into executable code accurately?
- How well is the random number generator tested?
- Are appropriate statistical techniques implemented to design and analyze the simulation experiments?
- How well are the underlying assumptions satisfied?
- Is the problem of the initial transient (or the start-up problem) appropriately addressed?
- For comparison studies, are identical experimental conditions replicated correctly for each of the alternative operating policies compared?