Briefing Document: Modelling and Simulation

Subject: Review of CIT 412 Course Material & "Simulation" Source

Purpose: To provide a concise overview of the core concepts, objectives, and techniques related to modelling and simulation, as covered in the provided source documents.

1. Course Objectives & Structure (CIT 412)

The CIT 412 course aims to equip students with the ability to:

- **Define and Explain Modelling and Simulation:** Understand the fundamental concepts of models, modelling, and simulation.
- "Define a model and modelling."
- "Explain when to and why we use models."
- "Describe the modelling process."
- **Model Types:** Differentiate between different types of models.
- "Describe different types of Models."
- **Random Number Generation:** Grasp the principles and methods of generating random numbers, essential for stochastic simulations.
- "Describe how to generate pseudorandom numbers."
- "Explain properties of good random number generator."
- "Explain the use of Congruential method for generating Random numbers."
- **Practical Application:** Implement random number generation in QBasic and apply the Monte Carlo method.
- "Use QBasic RND function and describe how to simulate randomness."
- "Use different Random number generators."

The course is structured into six modules:

- Unit 1: Basics of Modelling and Simulation
- Unit 2: Random Numbers
- Unit 3: Random Number Generation
- Unit 4: Monte Carlo Method
- Unit 5: Statistical Distribution Functions
- Unit 6: Common Probability Distributions

2. Fundamentals of Modelling & Simulation (CIT 412 & "Simulation" Source)

- **Definitions:**
- The course emphasizes differentiating between Model, Modelling, Simulation, and Computer Models.
- A computer model is "a simulation or model of a situation in the real world or an imaginary world which has parameters that the user can alter." "Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour (within the limits imposed by a criterion or set of criteria) of the operation of the system."
- A "model is the representation of the real world by numbers and other symbols that can be readily be manipulated".
- **Purpose of Modelling:**
- Simulation is a "decision support tool which enable[s] us to evaluate, compare and optimize alternative ways of solving a problem."
- Models allow users to experiment and observe "what if" scenarios, adjusting parameters to simulate real-world uncertainty.
- **Types of Models :**
- **Deterministic:** Uses well-defined procedures to determine outcomes
- **Probabilistic (Stochastic):** incorporates probabilities for certain events, like arrival rates
- **Time Dependent:** Models depend on when events occur
- **Interactive:** decisions made can influence results

3. Random Numbers and Their Generation

- **RND Function in BASIC:** QBasic's RND function generates pseudo-random numbers between 0 and 1.
- "Each time RND is executed, a pseudo random number between 0 and 1 is generated."
- **RANDOMIZE:** The RANDOMIZE statement, especially with TIMER, is crucial for varying the random number seed, preventing predictable sequences.
- "Using RND function at any time will always generate the same sequence of pseudo random numbers unless we vary the random number seed using the BASIC statement: RANDOMIZE"
- **Congruential Method:** This method generates random numbers using a recursive formula:
- $Xn+1 = (aXn + c)(\text{modulo } m)$
- X0 is the seed, and a, c, and m are constants that influence the period and randomness.

- **Properties of a Good Random Number Generator :**
- Uniformity: Numbers should be evenly distributed across the range.
- Independence: Numbers should not be correlated.
- Long Period: The generator should produce a long sequence before repeating.
- Efficiency: The generator should be computationally efficient.
- **Common Generators :**
- Mixed Congruential method
- Multiplicative Congruential Method
- RANECU

4. Monte Carlo Method

- **Concept:** Monte Carlo methods use repeated random sampling to obtain numerical results.
- "Monte Carlo simulation technique involves conducting repetitive experiments on the model of the system under study with some known probability distribution to draw random samples."
- **Crude Monte Carlo Estimator:** A basic method for estimating an integral using random samples.
- **Applications:** Particularly useful for high-dimensional problems where deterministic methods become computationally infeasible.
- Addresses problems that are difficult to solve with direct analytical methods.

Monte Carlo simulation technique steps:

1. Setting up a probability distribution for variables to be analyzed.
2. Building a cumulative probability distribution for each random variable.
3. Generating random numbers
4. Conducting the simulation experiment using random sampling
5. Repeating Step 4

5. Statistical Distributions

Definition: A statistical distribution describes the frequency of each possible outcome in a sample.

- "A statistical distribution describes the numbers of times each possible outcome occurs in a sample."
- **Measures of Central Tendency:** Mean, median, and mode.

- **Measures of Variation:** Range and standard deviation. The standard deviation is the spread of values around the central tendency.
- **Normal Distribution:** A bell-shaped, symmetric distribution defined by its mean (μ) and standard deviation (ζ).
- "In a normal distribution, data are most likely to be at the mean. Data are less likely to be farther away from the mean."
- **Skewness:** A measure of the asymmetry of a distribution.
- **Probability Functions:**Discrete variables - p(x)
- Continuous variable - f(x)

6. Simulation Process

1. **Identify the Problem:** Clearly define the system to be studied.
2. **Identify Decision Variables & Performance Criteria:** Determine key variables and how to measure system performance.
3. **Construct a Simulation Model:** Develop a representation of the system, potentially using influence diagrams.
4. **Validate the Model:** Ensure the model accurately reflects the real system (internal and external validity).
5. **Design Experiments:** Specify values of decision variables to be tested.
6. **Run the Simulation Model:** Execute the model to obtain results.
7. **Evaluate the Results:** Analyse the simulation output and select the best course of action.

7. Advantages and Disadvantages of Simulation

- **Advantages:**
- Suitable for analysing large and complex systems.
- Allows for sensitivity analysis by changing input variables.
- Enables experimentation without risk to the real system (pre-service testing).
- **Disadvantages:**
- Can be time-consuming and expensive.
- May not provide optimal solutions.
- Requires the user to provide all constraints.

8. Types of Simulation Software

- **General Purpose Programming Languages**FORTRAN, BASIC, COBOL, PL/I, Pascal
- **Special Purpose Simulation Languages**GPSS
- SIMSCRIPT

- DYNAMO
- SLAM
- VisSim

9. Applications of Simulation Queuing problems

- Inventory Management
- Project Management
- Financial Analysis

10. Random Walks and Stochastic Processes Stochastic Process: a probabilistic model of a system that evolves randomly in time and space

- **Markov Chain:** Stochastic process that satisfies that the conditional probability distribution of future states depends only on the present state, not on the sequence of events that preceded it
- **Wiener Process:** A continuous-time stochastic process with three properties
- It is a Markov Process
- It has stationary and independent increments
- For every t>0, X(t) is normally distributed with mean 0 and variance ζ 2 t
- **Random Walk:** A mathematical formalization of a path that consists of a succession of random steps.

11. Data Coding and Analysis

- **Data Coding:** The systematic assignment of codes to data to facilitate analysis.
- **When to Code:**
- Deductively (testing a hypothesis): Codes are developed *before* data collection.
- Inductively (generating a theory): Codes are developed *after* examining the data.
- **Steps of Coding (Qualitative Data):**
- Open Coding: Breaking down, comparing, and categorizing data.
- Axial Coding: Making connections between categories.
- Selective Coding: Selecting the core category and relating it to other categories.

This briefing provides a high-level overview of the provided course materials. For a deeper understanding, consult the original sources.