Simulation and Modeling

Module-1: Introduction- When simulation is appropriate and when not, advantages and disadvantages of simulation, application areas in communication, computer and software design, systems and systems environment, components of a system, discrete and continuous systems, model of a system, types of models, discrete-event simulation, steps in a simulation study. Simulation Examples- Simulation of queuing systems, on-demand and inventory systems, simulation for reliability analysis etc.

Simulation (imitation of a situation or process) is the re-creation of a real world process in a controlled environment. A **simulation** is an approximate imitation of the operation of a process or system that represents its operation over time. It uses something called modeling to figure out the result of the simulation. A **model** is a representation of an object or process that describes and explains that phenomenon when it can't be experienced directly. Briefly we can say that Simulation is

- Simulated system imitates operation of actual system over time
- Artificial history of system can be generated and observed
- Internal (perhaps unobservable) behavior of system can be studied
- Time scale can be altered as needed
- Conclusions about actual system characteristics can be inferred in Figure , actual system (real system) is compared with simulation

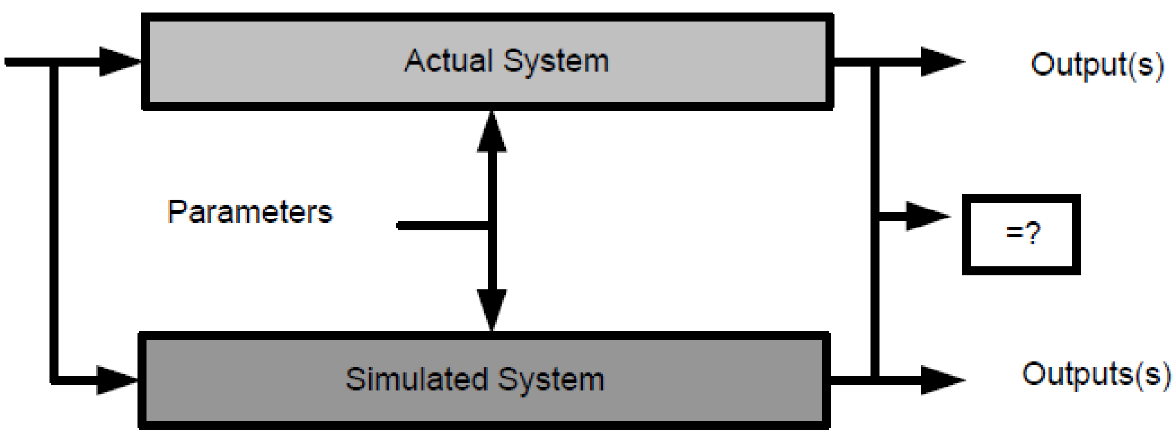


Figure 2: Simulation vs Actual System

For Example: The Life long journey of a famous personality is described in movies or book. Life journey= simulation and movies or book=modeling

A simulator is a device, computer program, or system that performs simulation. A simulation is a method for implementing a model over time. There are three (3) types of commonly uses simulations:

1. **Live:** Simulation involving real people operating real systems
   - Involve individuals or groups
   - May use actual equipment
   - Should provide a similar area of operations
   - Should be close to replicating the actual activity
2. **Virtual:** Simulation involving real people operating simulated systems. Virtual simulations inject Human-In-The-Loop in a central role by exercising:
   - Motor control skills (e.g., flying an airplane)
   - Decision skills (e.g., committing fire control resources to action)
   - Communication skills (e.g., members of a C4I team)
3. **Constructive:** Simulation involving simulated people operating simulated systems. Real people can stimulate (make inputs) but are not involved in determining outcomes. Constructive simulations offer the ability to:
   - Analyze concepts
   - Predict possible outcomes
   - Stress large organizations
   - Make measurements
   - Generate statistics
   - Perform analysis

Human-In-The-Loop simulations, also known as simulators, are a special class of simulations.

History of Simulation

The historical perspective of simulation is as enumerated in a chronological order.

- **1940** − A method named 'Monte Carlo' was developed by researchers (John von Neumann, Stanislaw Ulan, Edward Teller, Herman Kahn) and physicists working on a Manhattan project to study neutron scattering.
- **1960** − The first special-purpose simulation languages were developed, such as SIMSCRIPT by Harry Markowitz at the RAND Corporation.
- **1970** − During this period, research was initiated on mathematical foundations of simulation.
- **1980** − During this period, PC-based simulation software, graphical user interfaces and object-oriented programming were developed.
- **1990** − During this period, web-based simulation, fancy animated graphics, simulation-based optimization, Markov-chain Monte Carlo methods were developed.

Modelling & Simulation – Advantages

Following are the advantages of using Modelling and Simulation −

- **Easy to understand** − Allows to understand how the system really operates without working on real-time systems.
- **Easy to test** − Allows to make changes into the system and their effect on the output without working on real-time systems.
- **Easy to upgrade** − Allows to determine the system requirements by applying different configurations.
- **Easy to identifying constraints** − Allows to perform bottleneck analysis that causes delay in the work process, information, etc.
- **Easy to diagnose problems** − Certain systems are so complex that it is not easy to understand their interaction at a time. However, Modeling & Simulation allows to understand all the interactions and analyze their effect. Additionally, new policies, operations, and procedures can be explored without affecting the real system.

Modelling & Simulation – Disadvantages

Following are the disadvantages of using Modelling and Simulation −

- Designing a model is an art which requires domain knowledge, training and experience.
- Operations are performed on the system using random number, hence difficult to predict the result.
- Simulation requires manpower and it is a time-consuming process.
- Simulation results are difficult to translate. It requires experts to understand.
- Simulation process is expensive.

Modelling & Simulation – Application Areas

✓ **Manufacturing Applications**

1. Analysis of electronics assembly operations
2. Design and evaluation of a selective assembly station for high precision scroll compressor shells.
3. Comparison of dispatching rules for semiconductor manufacturing using large facility models.
4. Evaluation of cluster tool throughput for thin-film head production.
5. Determining optimal lot size for a semiconductor backend factory.
6. Optimization of cycle time and utilization in semiconductor test manufacturing.
7. Analysis of storage and retrieval strategies in a warehouse.
8. Investigation of dynamics in a service oriented supply chain.
9. Model for an Army chemical munitions disposal facility.

✓ **Semiconductor Manufacturing**

1. Comparison of dispatching rules using large-facility models.
2. The corrupting influence of variability.

3. A new lot-release rule for wafer fabs.
4. Assessment of potential gains in productivity due to proactive retied management.
5. Comparison of a 200 mm and 300 mm X-ray lithography cell.
6. Capacity planning with time constraints between operations.
7. 300 mm logistic system risk reduction.

- ✓ **Construction Engineering**

1. Construction of a dam embankment.
2. Trench less renewal of underground urban infrastructures.
3. Activity scheduling in a dynamic, multi project setting.
4. Investigation of the structural steel erection process.
5. Special purpose template for utility tunnel construction.

- ✓ **Military Applications**

1. Modeling leadership effects and recruit type in a Army recruiting station.
2. Design and test of an intelligent controller for autonomous underwater vehicles.
3. Modeling military requirements for non war fighting operations.
4. Multi trajectory performance for varying scenario sizes.
5. Using adaptive agents in U.S. Air Force retention.

- ✓ **Logistics, Transportation and Distribution Applications**

1. Evaluating the potential benefits of a rail-traffic planning algorithm.
2. Evaluating strategies to improve railroad performance.
3. Parametric Modeling in rail-capacity planning.
4. Analysis of passenger flows in an airport terminal.
5. Proactive flight-schedule evaluation.
6. Logistic issues in autonomous food production systems for extended duration space exploration.
7. Sizing industrial rail-car fleets.
8. Production distribution in newspaper industry.
9. Design of a toll plaza
10. Choosing between rental-car locations.
11. Quick response replenishment.

- ✓ **Business Process Simulation**

1. Impact of connection bank redesign on airport gate assignment.
2. Product development program planning.
3. Reconciliation of business and system modeling.
4. Personal forecasting and strategic workforce planning.

- ✓ **Human Systems**

1. Modeling human performance in complex systems.
2. Studying the human element in out traffic control.

When Simulation is the appropriate tool?

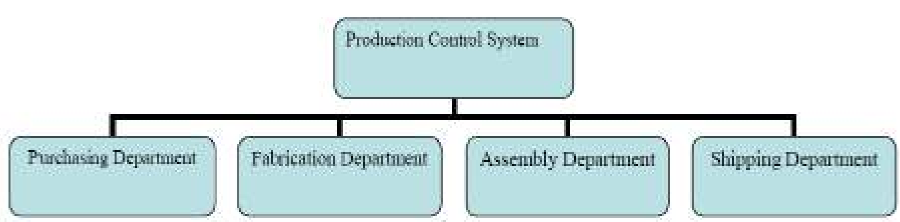
1. It enables one to study internal interactions of a complex system or of a subsystem within a complex system.
2. The effect of information, organization and environmental changes on the model's behavior can be simulated and observed.
3. The performance of the system under investigation can be improved by knowledge gained from simulations.
4. Simulation results can help to find which variables are the most important ones and how variables interact.
5. It can be used as a learning tool.
6. It can be used to verify analytical solutions.
7. By simulating diff. capabilities for m/c, re. can be determined.
8. Simulation models designed for training allow learning without any cast.
9. simulation in the form of animation can show the system in action, so that the plan can be visualized.
10. The interactions in modern complex system like factory, water fabrication, etc. can be treated only through simulation.

When Simulation is not appropriate?

- Simulation is not appropriate when the problem can be solved by common sense.
- Simulation should not be used if the problem can be solved analytically.
- Simulation should not be used if it is easier to perform direct implementations.
- Simulation should not be used if the cost exceeds the savings.
- Simulation should not be done if the resources and time are not available.
- Simulation cannot be done if no data is available.
- Simulation is not preferred if the system behavior is too complex to be defined.

Systems and System Environment

A system is defined as groups of objects that are joined together in some regular interaction toward the accomplishment of some purpose.



An automobile factory: Machines, components parts and workers operate jointly along assembly line. A system is often affected by changes occurring outside the system: system environment.

… Factory : Arrival orders

Effect of supply on demand: relationship between factory

Components of system

•„ **Entity**: An entity is an object of interest in a system. Ex: In the factory system, departments, orders, parts and products are The entities.

•„ **Attribute**: An attribute denotes the property of an entity. Ex: Quantities for each order, type of part, or number of machines in a Department are attributes of factory system.

•„ **Activity**: Any process causing changes in a system is called as an activity. Ex: Manufacturing process of the department.

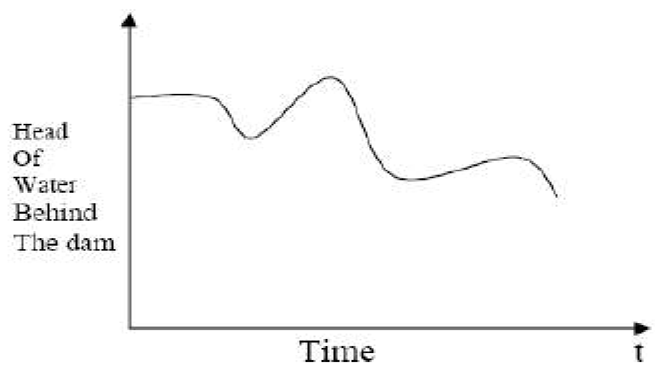
•„ **State:**The state of a system is defined as the collection of variables necessary to describe a system at any time, relative to the objective of study. In other words, state of the system mean a description of all the entities, attributes and activities as they exist at one point in time

.•„ Event: An event is define as an instaneous occurrence that may change the state of the system.

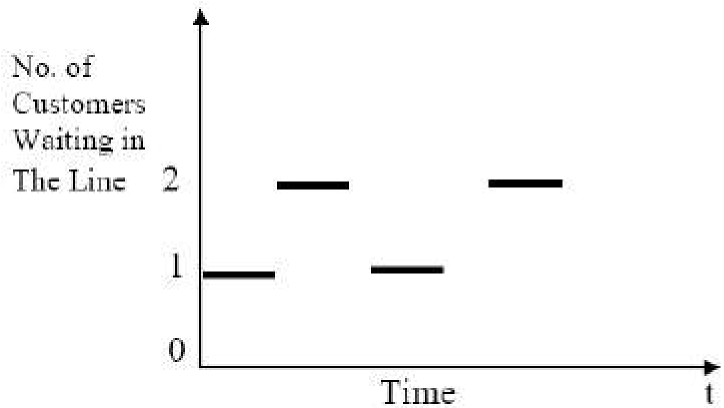
•„ **Endogenous**:… The term endogenous is used to describe activities and events occurring within a system. Ex: Drawing cash in a bank.

•„ **Exogenous** the term exogenous is used to describe activities and events in the environment that affect the system. Ex: Arrival of customers.

- ✓ **Closed System:** A system for which there is no exogenous activity and event is said to be a closed. Ex: Water in an insulated flask.
- ✓ **Open system:** A system for which there is exogenous activity and event is said to be a open. Ex: Bank system.
- ✓ **Continuous Systems :**Systems in which the changes are predominantly smooth are called continuous system.Ex: Head of a water behind a dam.

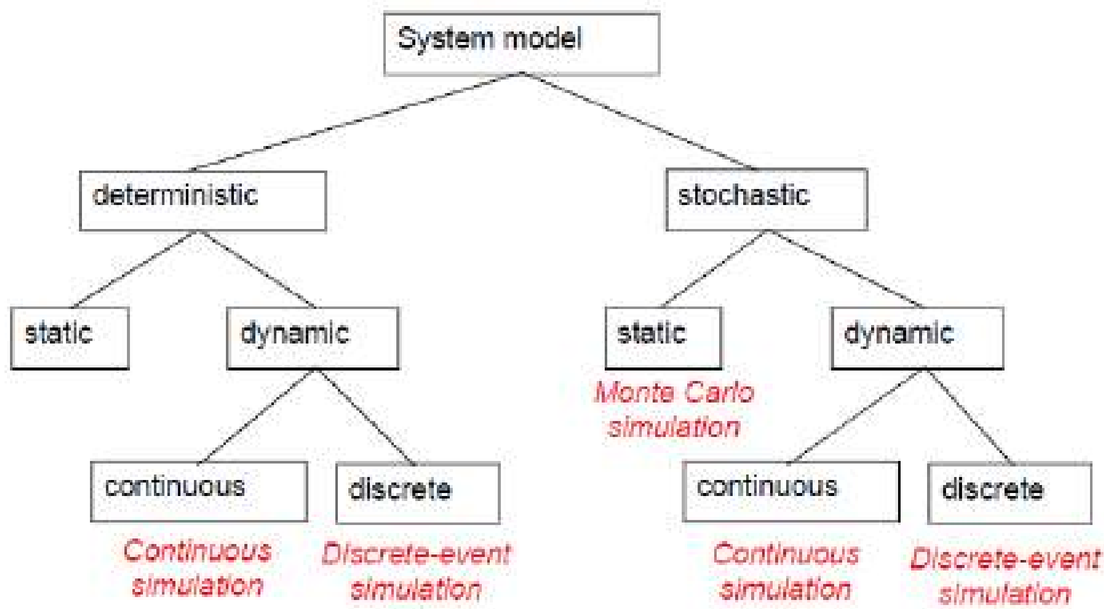


- ✓ **Discrete Systems:** Systems in which the changes are predominantly discontinuous are called discrete systems. Ex: Bank – the number of customer's changes only when a customer arrives or when the service provided a customer is completed.



Model of a system

A model is defined as a representation of a system for the purpose of studying the system. It is necessary to consider only those aspects of the system that affect the problem under investigation. These aspects are represented in a model, and by definition it is a simplification of the system.



Deterministic Model

It contains no random variables. They have a known set of inputs which will result in a unique set of outputs. Ex: Arrival of patients to the Dentist at the scheduled appointment time.

Static Model

It represents a system at a particular point of time and also known as Monte-Carlo simulation.

Dynamic Model

It represents systems as they change over time. Ex: Simulation of a bank

Discrete and Continuous Model

Used in an analogous manner. Simulation models may be mixed both with discrete and continuous. The choice is based on the characteristics of the system and the objective of the study.

Discrete-Event System Simulation

System in which the state of the system changes continuously with time are called continuous systems while the systems in which the state changes abruptly at discrete points in time called discrete systems.

Stochastic Model

Has one or more random variable as inputs. Random inputs leads to random outputs. Ex: Simulation of a bank involves random inter arrival and service times.

Differences between static modeling and dynamic modeling

Sr No.	Static modeling	Dynamic modeling
1	Model of the system not during runtime.	runtime model of the system
2	No use of differential equations	use of differential equations
3	static models are at equilibrium of in a steady state.	keep changing with reference to time
4	Static model is more structural than behavioral	dynamic model is a representation of the behavior of the static components of the system
5	Static modeling includes class diagram and object diagrams and help in depicting static constituents of the system	Dynamic modeling on the other hand consists of sequence of operations, state changes, activities, interactions and memory.
6	Static modeling is more rigid than dynamic modeling as it is a time independent view of a system.	Less rigid
7	It cannot be changed in real time and this is why it is referred to as static modeling.	Dynamic modeling is flexible as it can change with time as it shows what an object does with many possibilities that might arise in time.

Developing Simulation Models

Simulation models consist of the following components: system entities, input variables, performance measures, and functional relationships. Following are the steps to develop a simulation model.

- **Step 1** − Identify the problem with an existing system or set requirements of a proposed system.
- **Step 2** − Design the problem while taking care of the existing system factors and limitations.

- **Step 3** − Collect and start processing the system data, observing its performance and result.
- **Step 4** − Develop the model using network diagrams and verify it using various verifications techniques.
- **Step 5** − Validate the model by comparing its performance under various conditions with the real system.
- **Step 6** − Create a document of the model for future use, which includes objectives, assumptions, input variables and performance in detail.
- **Step 7** − Select an appropriate experimental design as per requirement.
- **Step 8** − Induce experimental conditions on the model and observe the result.

Performing Simulation Analysis

Following are the steps to perform simulation analysis.

- **Step 1** − Prepare a problem statement.
- **Step 2** − Choose input variables and create entities for the simulation process. There are two types of variables - decision variables and uncontrollable variables. Decision variables are controlled by the programmer, whereas uncontrollable variables are the random variables.
- **Step 3** − Create constraints on the decision variables by assigning it to the simulation process.
- **Step 4** − Determine the output variables.
- **Step 5** − Collect data from the real-life system to input into the simulation.
- **Step 6** − Develop a flowchart showing the progress of the simulation process.
- **Step 7** − Choose an appropriate simulation software to run the model.
- **Step 8** − Verify the simulation model by comparing its result with the real-time system.
- **Step 9** − Perform an experiment on the model by changing the variable values to find the best solution.
- **Step 10** − Finally, apply these results into the real-time system.

Steps in Simulation Study

1. **Problem Formulation**
- To begin any study, there must be statement of problem.
- Problem statement is formulated either by policy makers or analysts. Whoever formulates the statement, it must be understood by both.
- Problems formulated at the beginning of the study may not be complete, so this process is further iterated whenever there arises a new problem and needs attention to solve it during other stages of simulation study.

2. **Setting objectives and overall project plan**
- Objectives for the simulation must be formulated.
- It indicates what is to be done by the simulation.
- In this phase, it is decided whether or not the simulation is the appropriate tool.

- If simulation is appropriate tool, then the overall project plan should be formulated with alternative systems to be taken into account and methods to evaluate the effectiveness of the alternatives.
- It should also include time, cost and manpower needed along with the expected results of each stage.

3. **Model Conceptualization**
- Model building is the process of construction of a model of a system.
- There is no necessity of one-to-one mapping between model and real system, only the essential components are used in modeling.
- For modeling, essential features of the system are extracted at first, basic assumptions are made and then the assumptions are modified until approximate results are obtained.
- At initial stage, the model should be simple and over time should develop complexity.
- Excessive complexity should be forbidden to minimize model and computer expenses.

4. **Data Collection**
- Data plays important role in simulation.
- Data collection is very difficult phase as it requires more time, so it should be started as early as possible.
- The data to be collected depends on the study objectives.

5. **Model Translation**
- The model of real world generally requires storage, so model must be entered into a computer recognizable format.
- The model programming must be selected by the modeler, whether a simulation language or to use a special purpose simulation software.
- Simulation languages are more powerful and flexible than softwares. But, the choice depends on model complexity.

6. **Verified?**
- This stage involves verification of the computer program of modeling.
- Verification is successful if the input parameters and the logical structure of the models are correctly represented in the computer.

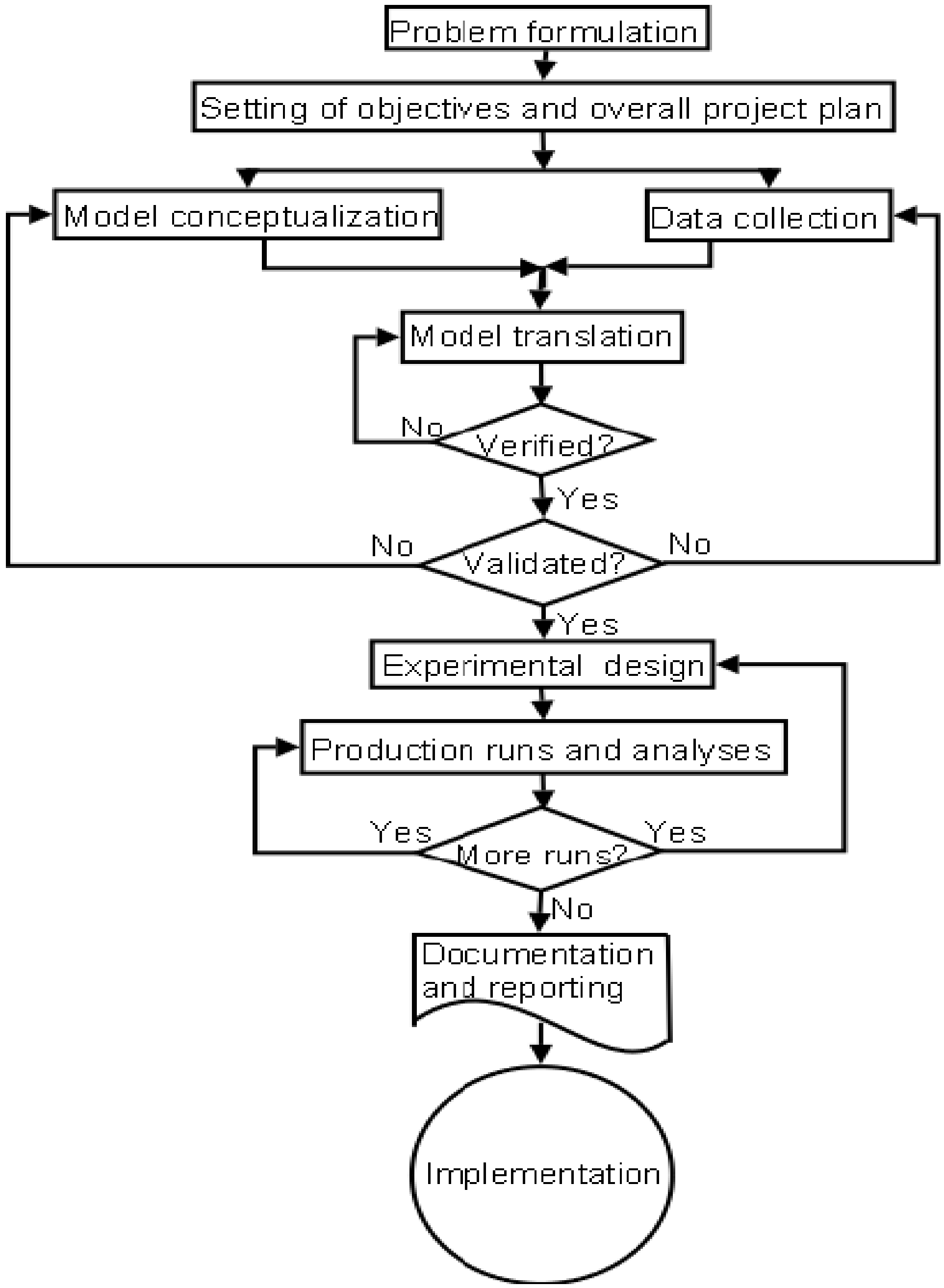
7. **Validated?**
- Validation is performed by calibrating the model against the actual system behavior so as to improve the system model.
- This is iterative process which is successful once the model accuracy is acceptable.

8. **Experimental Design**
- The alternatives to be simulated are determined.
- For each system design, length of initialization period, length of simulation run and number of replications to be made of each run are decided.

9. **Production Runs and Analysis**
- It is used to estimate measures of performance for the system design being simulated.
10. More Runs?
- After the analysis of the runs, it is decided whether or not more runs are needed.

11. **Documentation and Reporting**
- Program documentation is the document stating the operation of the program. It is necessary to understand how the program works. It facilitates easy modification and maintenance of the program.
- Progress documentation provides the chronology of work done and decisions made. It helps in tracking the course of project towards success.
- The result of the analysis should be clearly stated in a final report.

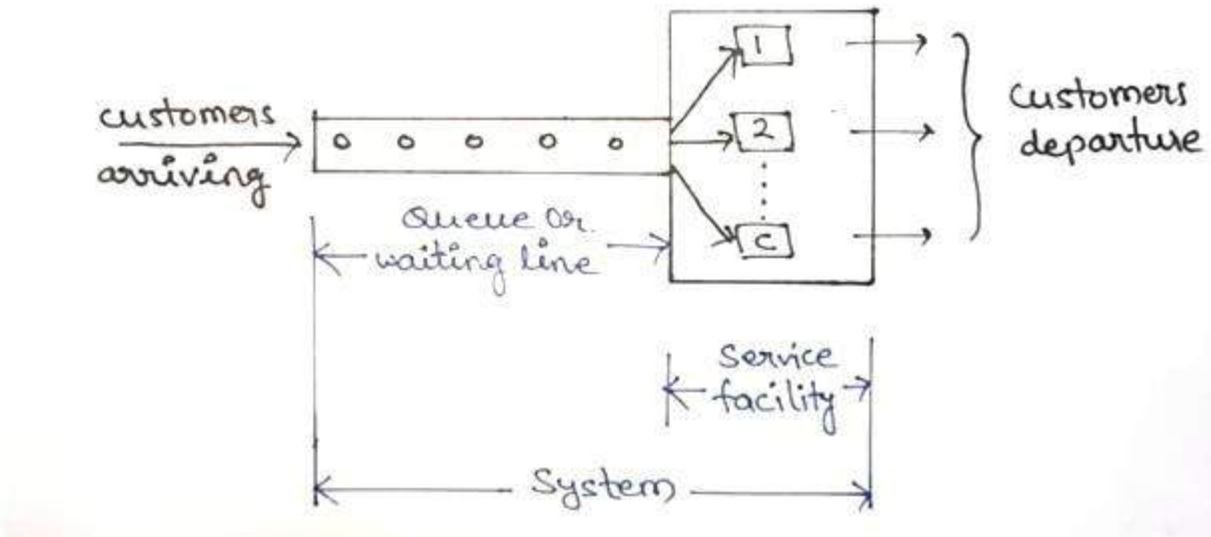
12. **Implementation**
- It involves actual implementation of the model.
- Model implementation depends on how well all the other stages are succeeded.
- Proper success of other stages results in good implementation while improper model on implementation may result in hazards.



Simulation Examples- Simulation of queuing systems

Queuing System/Model (Waiting Line Model)

It is mathematical study of waiting lines or queues and a model or system is constructed so that queue length and waiting time can be predicated. A queue is the combination of all entities in the system being served and those waiting for their turn.



Major Components of Queuing system

1) **Customer:** The arrival unit that requires some service to be performed. The customer may person, vehicles or parts etc.
2) **Queue or Waiting Line:** The number of customer waiting to be served and it does not include service availed customers.
3) **Service Channel:** The process or facility which is performing service to the customer. This may be single or multi channel.

Elements or Structure of Queuing system

1. **Arrival Distribution:** It represents the pattern in which the number of customer arrives at service facility.
2. **Service (Departure) Distribution: :** It represents the pattern in which the number of customer leave at service facility.
3. **Service Channel**: The queuing system may have single or multi server cannels.
4. **Service Discipline**: It is the rule by which customer are selected for service.
   - **a) FIFO**: first in First out
   - **b)** LILO : Last in Last Out
   - **c) SIRO: Service in Random Order**
   - **d)** Priority

5. **Maximum number of customer allowed in the system:** It may be finte or infinte

6. **Calling source or Population**: finite(Few Potential customer) & Infinite(For large Potential customer)
7. Customer behavior: It may be either Patience or Impatience. Impatience customer of type
   a) **Balking customer:** Customer leave the queue without entering in queue system
   b) **Reneging Customer:** Customer leave the queue after entering in queue system for some time
   c) **Jockeying Customer:** Customer leave the one queue and join another queue after entering in queue system for some time

Operating Characteristics of Queuing system

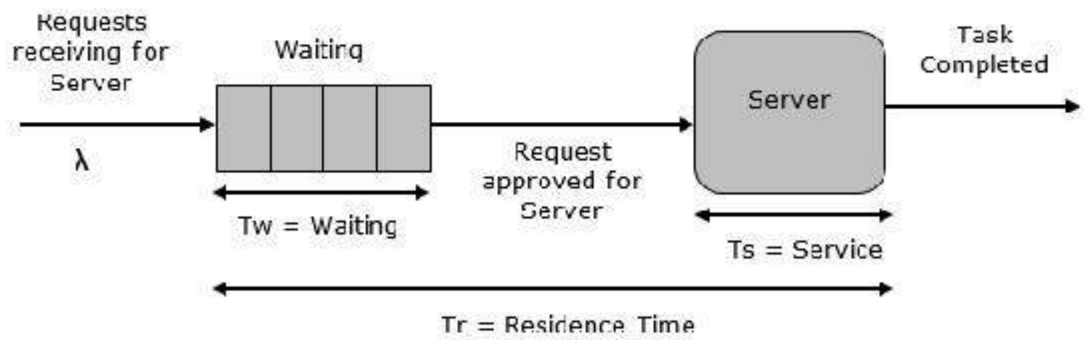
1) **Queue Length(Lq):**The average number of customers in the queue waiting to get services. This excludes the customers that are already served.
2) **System Length (Ls):**The average number of customers in system including waiting customers and customers that are already served in queue system.
3) **Waiting time in the queue (Wq):** The average time for which a customer has to wait in queue to get service.
4) **Total time in the queue (Ws):** The average total time spent by customer in the system when customer enter in queue and leave queue after getting service. It also include waiting time and service time.
5) **Utilization factor (P):** It is the proportion of time a server actually spends with the customer. Its is also called " Traffic Intensity".

Transient and Steady states of the System

- ✓ **Transient State:** It is study of system's behavior over time. If Operating Characteristics (system's behavior) of system with time the it's called Transient State
- ✓ **Steady State:** A system is said to be in steady state if behavior becomes independent of its initial conditions and of elapsed time.
- ✓ **Explosive State:** When arrival rate of customer is more than service rate or when customer are getting slow service as customer are entering swiftly in queue

Single Server Queue

This is the simplest queuing system as represented in the following figure. The central element of the system is a server, which provides service to the connected devices or items. Items request to the system to be served, if the server is idle. Then, it is served immediately, else it joins a waiting queue. After the task is completed by the server, the item departs.

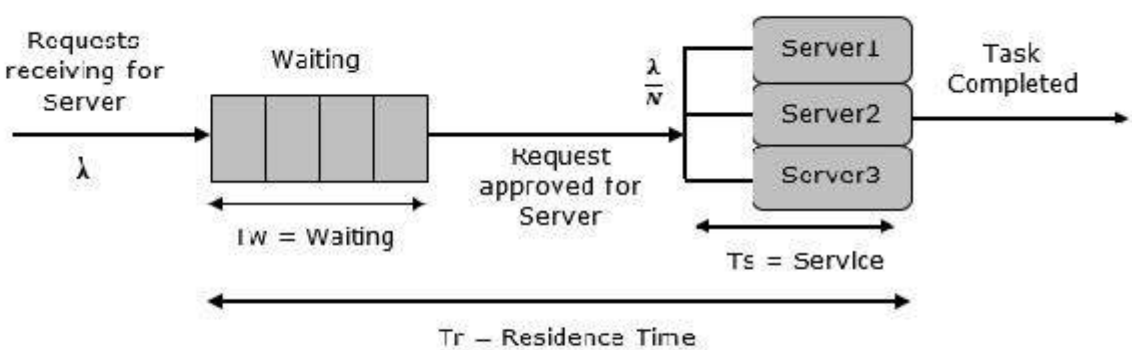


Multi Server Queue

As the name suggests, the system consists of multiple servers and a common queue for all items. When any item requests for the server, it is allocated if at-least one server is available. Else the queue begins to start until the server is free. In this system, we assume that all servers are identical, i.e. there is no difference which server is chosen for which item.

There is an exception of utilization. Let **N** be the identical servers, then **ρ** is the utilization of each server. Consider **Nρ** to be the utilization of the entire system; then the maximum utilization is **N*100%**, and the maximum input rate is −

$\lambda max = \frac{\text{N}}{\text{T}s}$



Simulation Examples- Simulation of on-demand and inventory systems

Simulation of on-demand Cake supply system.

On-demand system is a delivery model in which resources are made available to the user as per requirement. The on-demand model was developed to overcome the common challenge and being able to meet fluctuating demands efficiently because user's demand can vary drastically over the time.

The on-demand system uses cake supply that is not fixed. To use the on-demand service, Baker provided us 50 days data for processing. In the simulation users may decide whether to take cake, to call the on-demand service, and, if none of these options is satisfactory, to use other baker.

Monte Carlo Method: The '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 (observations) using random numbers. If a system cannot be described by a standard probability distribution such as normal, Poisson, exponential, etc, an empirical probability distribution can be constructed. The Monte Carlo simulation technique consists of the following 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 and then assigning an appropriate set of random numbers to represent value or range (interval) of values for each random variable.

(4) Conducting the simulation experiment using random sampling.

(5) Repeating Step – 4 until the required number of simulation runs has been generated.

(6) Designing and implementing a course of action and maintaining control.

Case/Problem: Demand(in '00 Cakes per day): 0 5 10 15 20 25
No. of Days: 2 11 8 21 5 3

Using the following sequence of random numbers, simulate the demand for the next 10 days and find out the average demand: 35, 52, 90, 13, 23, 73, 74, 57, 35, 83

Simulation-Monte Carlo Method

Demand Per Day	Frequency [f] (No. of Days)	Probability	Commutative Probability	Random Number Range
0	2	2/50=0.04	0.04	00-03
5	11	11/50=0.22	0.04+0.22=0.26	04-25
10	8	8/50=0.16	0.16+0.26=0.42	26-41
15	21	21/50=0.42	0.42+0.42=0.84	42-83
20	5	5/50=0.10	0.10+0.84=0.94	84-93
25	3	3/50=0.06	0.06+.0.94=1.00	94-99
	N=∑f= 50	Commutative Probability should end with 1		

Days	Random Number	Range of Random Number	Demand(Cake)
1	35	26-41	10
2	52	42-83	15
3	90	84-93	20
4	13	04-25	5
5	23	04-25	5
6	73	42-83	15
7	74	42-83	15
8	57	42-83	15
9	35	26-41	10
10	83	42-83	15
		Total Demand	**125**

$$\text{Average Demand} = \frac{\text{Total Demand}}{\text{Number of days}} = \frac{125}{10}$$

which means 12.5 or 1250 Cake per days

About Inventory Systems

Inventory is the **stock** of goods, materials or resources that are stored or reserved holds for the ultimate goal of business. Manufacturers will have three or four categories of inventories:

- Raw materials
- Work-in-process
- Finished goods
- Manufacturing and packaging supplies

An inventory management system is the combination of technology (hardware and software) and processes and procedures that oversee the monitoring and maintenance of stocked products, whether those products are company assets, raw materials and supplies, or finished products ready to be sent to vendors or end consumers. A complete inventory management system consists of:

- A system for identifying every inventory item and its associated information, such as barcode labels or asset tags.
- Hardware tools for reading barcode labels, such as handheld barcode scanners or smart phones with barcode scanning apps.
- Inventory management software, which provides a central database and point of reference for all inventory, coupled with the ability to analyze data, generate reports, forecast future demand, and more.
- Processes and policies for labeling, documentation, and reporting. This should include an inventory management technique such as Just in Time, ABC Analysis, First-In First-Out (FIFO), Stock Review, or another proven methodology.
- People who trained to follow these policies and processes.

Overall, a comprehensive inventory management system offers countless benefits to companies including:

- Improved cash flow
- Better reporting and forecasting capabilities
- Reduction in storage costs (overhead)
- Reduced labor costs
- Reduction in dead stock
- Better organization
- Enhanced transparency
- Improved supplier, vendor, and partner relationships

Types of Inventory Models

1) **Fluctuation Inventories**: In real life demand is always vary which affect production so some stock is reserved for this fluctuation and its is called Fluctuation Inventories
2) **Anticipation Inventories**: It is done in advance season for large sale or for emergency
3) **Cycle(Lot size) Inventories:** The rate of consumption is same as rate of production so items are produced in large than they are required which is called Cycle(Lot size) Inventories
4) **Transportation Inventories**: Such inventories exit because materials are required to shift from one place to another.
5) **Decoupling Inventories:** Such inventories are needed to fulfill the demand during stop time of production or purchase.

An inventory Problem

Perform simulation of following inventory system given daily demand is represented by sequence of random numbers 4 3 8 2 5 **Initial Inventory is 4 units**

Demand	0	1	2
Probability	0.2	0.5	0.3

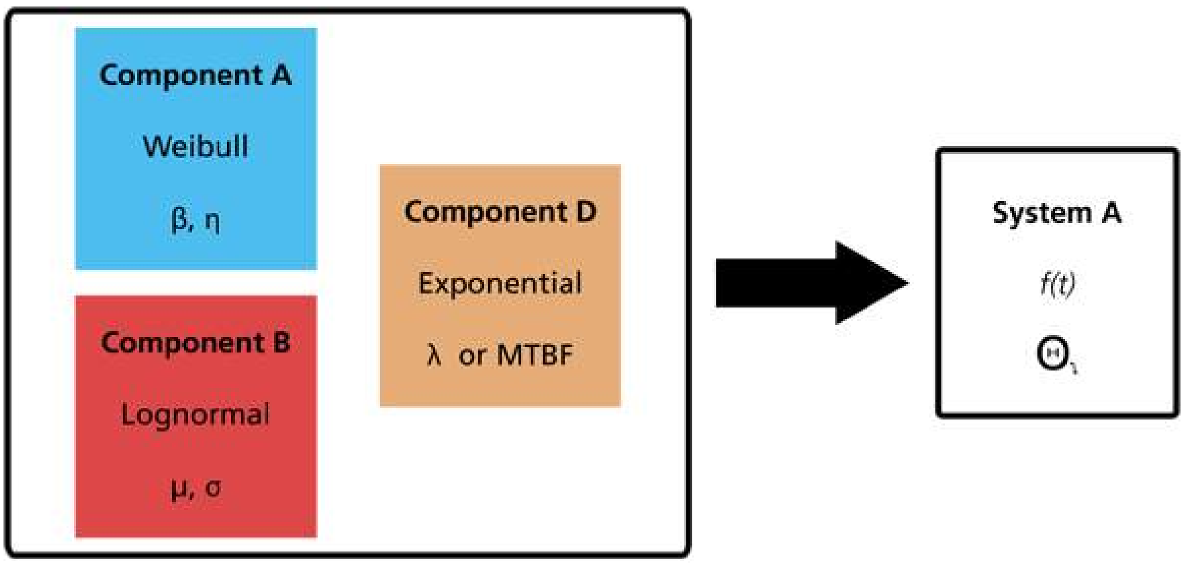
Initial Inventory is 4 units

Demand	Probability	Commutative Probability	Random Digit Assignment
0	0.2	0+0.2=0.2 →	1-2
1	0.5	0.2+0.5=0.7 →	3-7
2	0.3	0.7+0.3=0.1 →	8-0
	Commutative Probability should end with 1		

Days	Starting inventory	Demand (Rand No.)	Demand	End inventory	Shortage
1	4	4	1	4-1=3	0
2	3	3	1	3-1=2	0
3	2	8	2	2-2=0	0
4	0	2	0	0-0=0	0
5	0	5	1	0-1=1	1

Simulation for reliability analysis

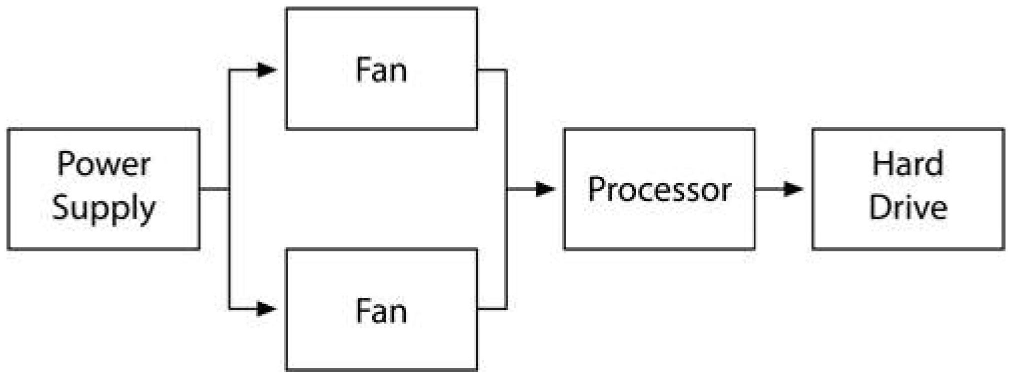
System reliability is an important non-functional requirement whose satisfaction is very crucial for their application or use. In system reliability analysis, "System model" consist of subassemblies and/or assemblies ("black boxes") from which it is composed, as illustrated in the figure below.



A system is a collection of subsystems, assemblies and/or components arranged in a specific design in order to achieve desired functions with acceptable performance and reliability. The types of components, their quantities, their qualities and the manner in which they are arranged within the system have a direct effect on the system's reliability. Therefore, in addition to the reliability of the components, the relationship between these components is also considered to improve or optimize the overall system reliability, maintainability and/or availability. This reliability relationship is usually expressed using logic diagrams, such as reliability block diagrams (RBDs) and/or fault trees

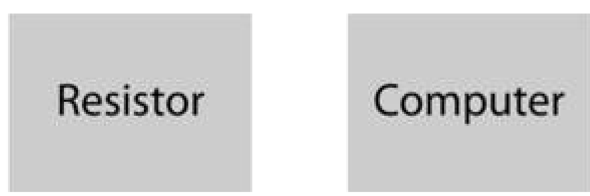
Reliability Block Diagrams (RBDs)

When block diagrams are used to describe the interrelation between the components of system and to define the system then it is referred to as a reliability block diagram (RBD). A reliability block diagram is a graphical representation of the components of the system and how they are reliability-wise related (connected). It should be noted that this may differ from how the components are physically connected. An RBD of a simplified computer system with a redundant fan configuration is shown below.

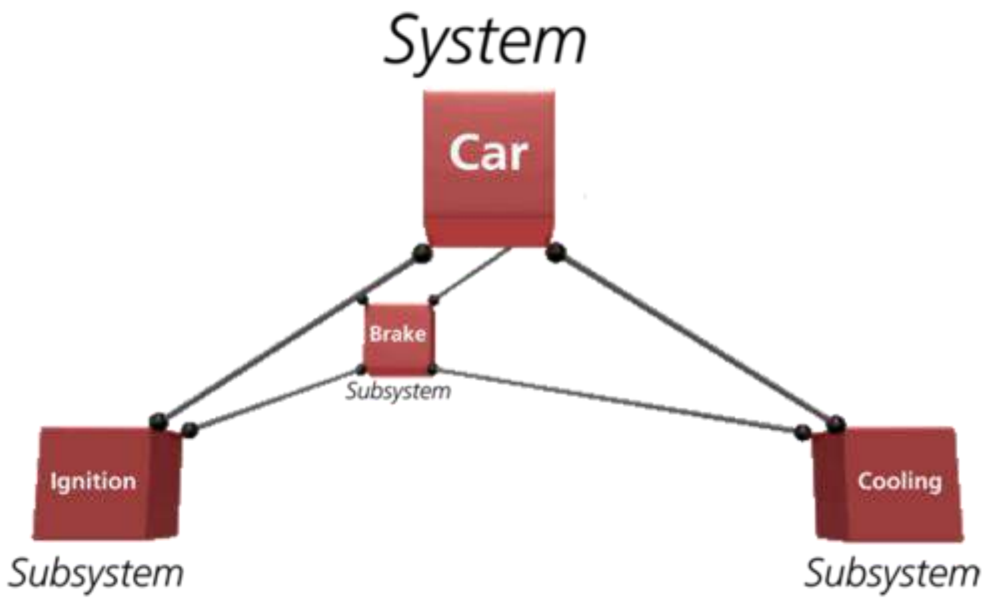


RBDs are constructed out of blocks. The blocks are connected with direction lines that represent the reliability relationship between the blocks.

A block is usually represented in the diagram by a rectangle. In a reliability block diagram, such blocks represent the component, subsystem or assembly at its chosen black box level. The following figure shows two blocks, one representing a resistor and one representing a computer.



It is possible for each block in a particular RBD to be represented by its own reliability block diagram, depending on the level of detail in question. For example, in an RBD of a car, the top level blocks could represent the major systems of the car, as illustrated in the figure below. Each of these systems could have their own RBDs in which the blocks represent the subsystems of that particular system. This could continue down through many levels of detail, all the way down to the level of the most basic components (e.g., fasteners), if so desired.



Analytical Diagrams

The analytical approach involves the determination of a mathematical expression that describes the reliability of the system in terms of the reliabilities of its components. Analytical diagrams are appropriate when one is performing "reliability analysis. In the context of BlockSim, we use the term "reliability analysis" to refer to all analyses that do not include repairs or restorations of the component. When considering only the failure characteristics of the components, the analytical approach can be used. However, when both failure and maintenance characteristics need to be considered, the simulation method must be used to take into account the additional events.

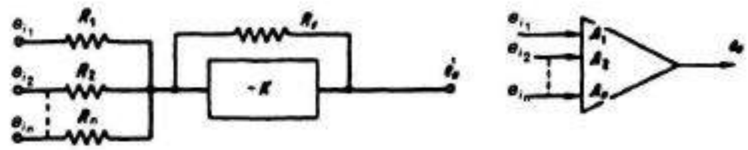
Simulation Diagrams

The simulation diagram can be either a block diagram or a signal-flow graph which is constructed to have a specified transfer function or to model a set of specified differential equations. The resulting simulation diagram is very useful because it can be used to construct either a digital computer or analog computer simulation of the control system.

Addition (case 1):

$$e_o = -\sum_{n=1}^{N} A_n e_{in}$$

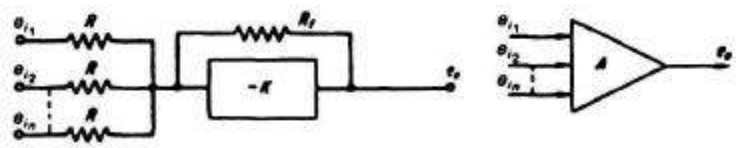
where $A_n = R_f / R_n$

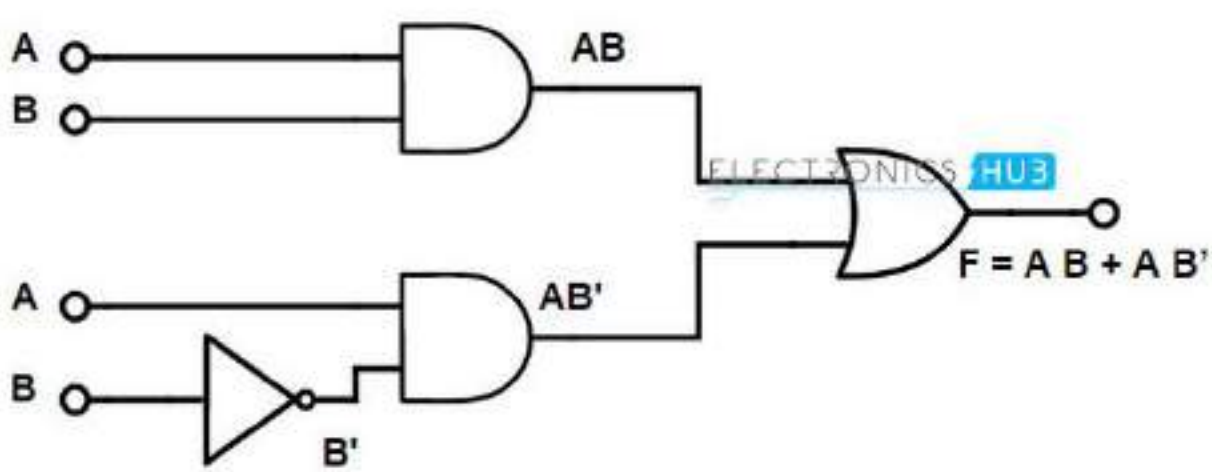


Addition (case 2):

$$e_o = -\sum_{n=1}^{N} A\, e_{in}$$

where $A = R_f / R$



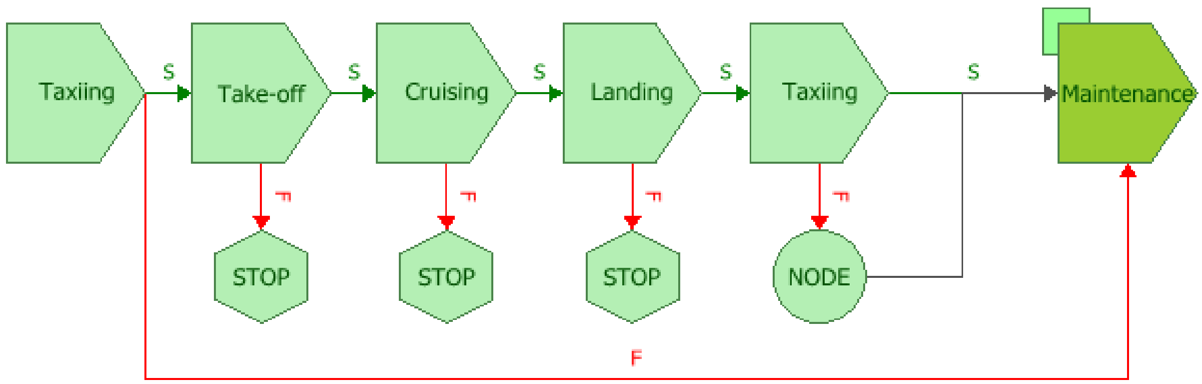


Phase Diagrams

A phase diagram, or more specifically a reliability phase diagram, is an extension of the simulation RBD approach. Phase diagram is a graphical representation of the physical states of a substance under different conditions. A phase diagram can be used to represent scenarios in which a system may undergo changes over time to one or more of the following:

- Its reliability configuration
- The available repair resources
- The failure, maintenance or throughput properties of its individual components.

For example, a manufacturing company's production may be lower during the night shift than during the day shift. Or a system may use different components during different stages of operation, such as an aircraft during taxiing, takeoff, cruising and landing. In these and many other situations, a phase diagram can be configured so that the simulation will account for the differences in the system during different time periods.



The figure below shows an example of a **phase diagram**, which summarizes the effect of temperature and pressure on a substance in a closed container. Every point in this diagram represents a possible combination of temperature and pressure for the system. The diagram is divided into three areas, which represent the solid, liquid, and gaseous states of the substance.