<u>**SYSTEM MODELING AND SIMULATION(15CS834)**</u>

<u>**SOLUTIONS : VTU JUNE 2019**</u>

1.a) Simulation is the imitation of the real world or system over time

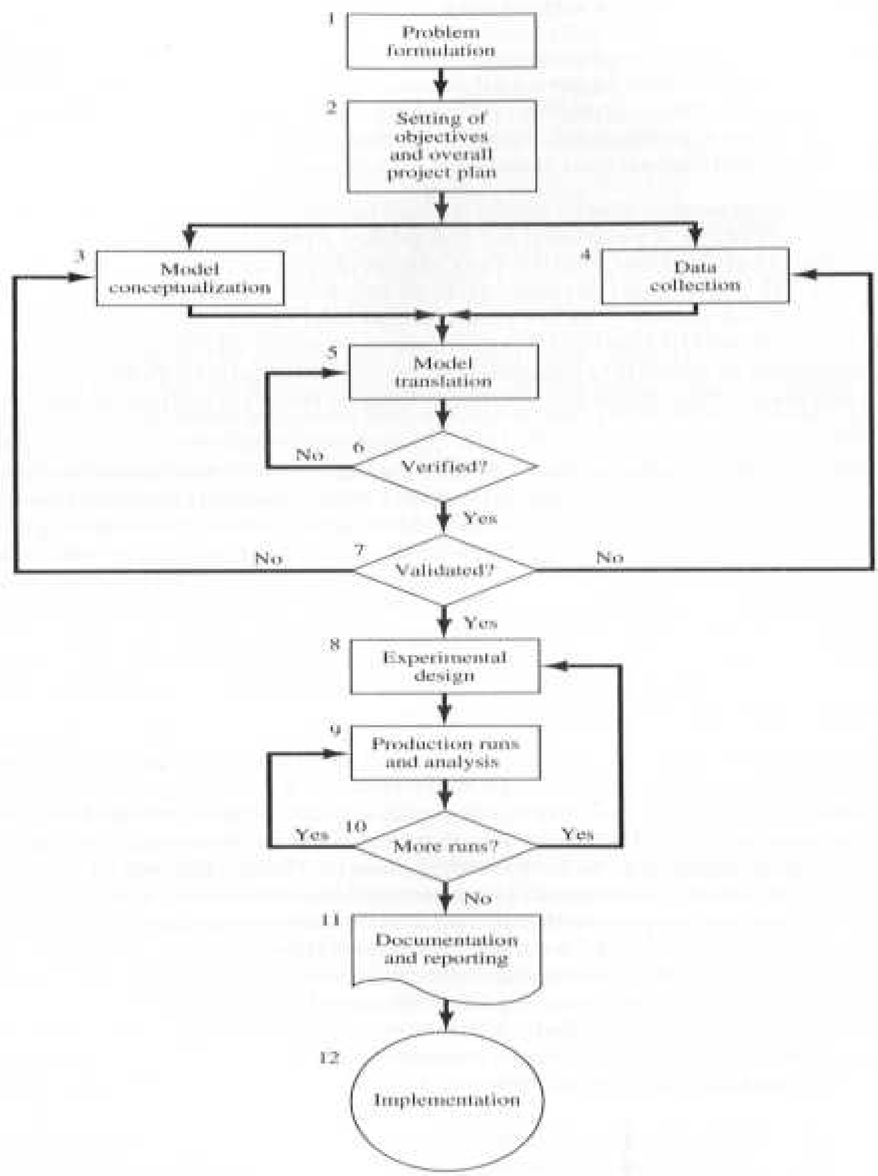

Figure 1.3. Steps in a simulation study.

- **Four phases according to Figure 1.3**
  - **First phase : a period of discovery or orientation (step 1, step2)**
  - **Second phase : a model building and data collection (step 3, step 4, step 5, step 6, step 7)**
  - **Third phase : running the model (step 8, step 9, step 10)**
  - **Fourth phase : an implementation (step 11, step 12)**

1.b)

Inter-Arrival time	Probability	Cumulative Probability	Random No Assessment
1	0.25	0.25	1-25
2	0.40	0.65	26-65
3	0.20	0.85	66-85
4	0.15	1.00	86-00

ST of Able	Probability	Cumulative Probability	Random No Assessment	ST of Baker	Probability	Cumulative Probability	Random No Assessment
2	0.30	0.30	1-30	3	0.35	0.35	1-35
3	0.28	0.58	31-58	4	0.25	0.60	36-60
4	0.25	0.87	59-87	5	0.20	0.80	61-80
5	0.17	1.00	88-00	6	0.20	1.00	81-100

Caller ID	IAT	AT	Server Choosen	ST	Time Service Begins	Time Service Ends		Caller Delay	Time customer Spend in system
						Able	Baker		
1	-	0	Able	5	0	5	-	0	5
2	2	2	Baker	3	2	-	5	0	3
3	4	6	Able	3	6	9	-	0	3
4	4	10	Able	5	10	15	-	0	5
5	2	12	Baker	6	12	-	18	0	6
6	2	14	Able	3	15	18	-	1	4
7	3	17	Able	2	18	20	-	1	3
8	3	20	Able	4	20	24	-	0	4
9	3	23	Baker	4	23	-	27	0	4
10	1	24	Able	3	24	27	-	0	3
Total	24							2	40

- For finding the following times – 1 Mark

Avg IAT = 24/9
Avg ST of able = 118/10

Avg ST of baker = 50/10

2.a. Components of Discrete event simulation

1. System: A collection of entities (e.g., people and machines) that together over time to accomplish one or more goals.
2. Model: An abstract representation of a system, usually containing structural, logical, or mathematical relationships which describe a system in terms of state, entities and their attributes, sets, processes, events, activities, and delays.
3. System state: A collection of variables that contain all the information necessary to describe the system at any time.
4. Entity: Any object or component in the system which requires explicit representation in the model (e.g., a server, a customer, a machine).
5. Attributes: The properties of a given entity (e.g., the priority of a v customer, the routing of a job through a job shop).
6. List: A collection of (permanently or temporarily) associated entities ordered in some logical fashion (such as all customers currently in a waiting line, ordered by first come, first served, or by priority).
7. Event: An instantaneous occurrence that changes the state of a system as an arrival of a new customer).
8. Event notice: A record of an event to occur at the current or some future time, along with any associated data necessary to execute the event; at a minimum, the record includes the event type and the event time.
9. Event list: A list of event notices for future events, ordered by time of occurrence; also known as the future event list (FEL).
10. Activity: A duration of time of specified length (e.g., a service time or arrival time), which is known when it begins (although it may be defined in terms of a statistical distribution).
11. Delay: A duration of time of unspecified indefinite length, which is not known until it ends (e.g., a customer's delay in a last-in, first-out waiting line which, when it begins, depends on future arrivals).
12. Clock: A variable representing simulated time.

2.b) C1-AT:0, DT-5
C2-AT:4,DT-8
C3-AT:9,DT-13
C4-AT-11,DT-19
C5-AT:19,DT-21
C6-AT:22,DT-29

Clock	System State		Future Event List	Comments	Cumulative Statistics	
	LQ(t)	LS(t)			B	MQ
0	0	1	(A,4)(D,5)(E,30)	1st Customer arrived	0	0
4	1	1	(D,5)(A,9)(E,30)	2nd Customer arrived	4	1
5	0	1	(D,8)(A,9)(E,30)	1st Customer departured	5	1
8	0	0	(A,9)(E,30)	2nd Customer Departured	8	1
9	0	1	(A,11)(D,13)(E,30)		8	1
11	1	1	(A,19)(D,13)(E,30)	4th Customer Arrived	10	1
13	0	1	(D,19)(A,19)(E,30)	3rd Customer Departured	12	1
19	0	1	(D,21)(A,22)(E,30)	4th Customer Departured 5th Customer Arrived	18	1
21	0	0	(A,22)(D,29)(E,30)	5th Customer Departured	20	1

22	0	1	(A,29)(D,29)(E,30)	6^{th} Customer arrived	20	1
29	0	1	(E,30)	6^{th} Customer Departured End of simulation time	27	1

3.a) Explain the following distributions.

i) Binomial distribution ii) Uniform distribution

i)Binomial Distribution

The no of successes in n Bernoulli trials is said to follow binomial distribution.

$P(x) = (n)\ p^x q^{n-x}$ for x=0,1,2,….n

Mean: E(x) = np

Variance : V(x) = npq

ii)Uniform Distribution

In probability theory and statistics, the **continuous uniform distribution** or **rectangular distribution** is a family of symmetric probability distributions such that for each member of the family, all intervals of the same length on the distribution's support are equally probable. The support is defined by the two parameters, a and b, which are its minimum and maximum values.

Pdf : f(x) = 1/b-a , $a<x<b$

Cdf : F(x) = x-a/b-a , $a<x<b$

Mean: E(x) = a+b/2

Variance: $v(x) = (b-a)^2/12$

4.a) List and explain the characteristics of queuing system. Briefly explain queuing notations.

characteristics of Queuing system

The key elements of queuing system are the customers and servers.

customers :— refers to people, m/c, trucks, mechanics, patients airplanes, email etc.

servers :— refers to receptionists, repair person, cpu, any resource that provides requested service

the following table gives few examples of queuing system

system	customer	server
Airport	Airplanes	Runway
Hospital	patients	Nurses, doctor
Reception desk	people	Receptionist
~~theatre~~		

The term customer means anything that arrives at a facility and requires service.

→ the characteristics of queuing system are

- calling population
- system capacity
- Arrival process
- Queue behaviour and queue discipline
- service time and service mechanism

The calling population

the population of potential customers is referred as calling population.

→ the calling population can be either finite (or) infinite

→ the main difference b/n finite and infinite is based on how arrival rate is defined.

4) Queue behaviour and Queue discipline

Queue behaviour refers to the action of customer while in queue waiting for service to begin.

Queue behaviour are

→ Balk — leave when they see that the line is too long.

→ Renege — leave after being in the line when they see that the line is moving too slowly.

→ Jockey — move from one line to another if they think they have choosen a slowline.

— Queue discipline refers to how the customers are severed in the queue

- FIFO, LIFO,
- SIRO — service in random

5) service times and service mechanism

service times are denoted by $s_1, s_2, s_3, \ldots$

They may be constant (or) of random duration.

the exponential, weibull, gamma, lognormal distributions are used to model the service times.

A queuing system consists of no of service centers and interconnecting queues each service center consists of no of servers c working in parallel. parallel service mechanisms are either single server ($c=1$), multiple server (or) unlimited servers.

→ In infinite population the arrival rate is not affected by the no of customers who have left the calling population and Joining the queuing system.

Ex :- Hotel

→ In finite population the arrival rate depends on the number of customers being served and waiting.

Ex :- ~~Bo~~ In a ~~bank~~ hospital where there are prior appointments the customers are patients here and the arrival rate of patients depends on finite arrivals.

2. System capacity :-

System capacity is defined as the maximum no of customers allowed in system (or) in waiting queue.

Ex :- An automatic car wash might have room for only 10 cars to wait in line to enter the mechanism. An arriving customer who finds the system full does not enter but returns immediately to the calling population.

— Some systems such as concert ticket sales for students may be considered to have unlimited capacity

3. The arrival Process :-

Arrival process describe how customer arrival, how the arrival are distributed in time and whether there is finite population model (or) infinite population model.

→ Arrivals may occur at scheduled times (or) random times.

→ The most important model for random arrivals is the poisson arrival process.

↳ If A_n represents IAT b/n customer $n-1$ and customer n then for poisson arrival process A_n is exponentially distributed with mean $1/\lambda$ time units.

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Queuing notation

Kendall proposed a queuing notation as follows.

A/B/c/N/K

A represents Inter arrival time distribution

B represents service time distrn

C represents no of parallel servers

N represents system capacity

K represents size of calling population

– common symbols for A and B includes M (exponential (or) markov), D (constant (or) deterministic), Ek (erlang of order K), G (arbitrary, general)

Ex:- M/M/1/∞/∞

↳ A single server system that has unlimited queue capacity and an infinite population of potential arrivals.

→ when N and K are infinite then they may be dropped from the notation

M/M/1/∞/∞ is shortened to M/M/1

5.a) **Sol:** The sequence of Xi and subsequent Ri values is computed as follows:

X0 = 27

- X1 = (a.X0+c) mod m = (17.27 + 43) mod 100 = 502 mod 100 = 2
- R1=X1/m = 2⁄100=0. 02
- X2 = (17 • 2 + 43) mod 100 = 77 mod 100 = 77
- R2=77⁄100=0. 77
- X3 = (17•77+ 43) mod 100 = 1352 mod 100 = 52
- R3=52⁄100=0. 52

<u>Finding the Period :</u>

1. For m a power of 2, say m =2b and c ≠ 0, the longest possible period is P = m = 2b, which is achieved provided that c is relatively prime to m (that is, the greatest common factor of c and m i s l), and =a = l+4k, where k is an integer.
2. For m a power of 2, say m =2b and c = 0, the longest possible period is P = m⁄4 = 2b-2, which is achieved provided that the seed X0 is odd and the multiplier ,a, is given by a=3+8K , for some k=0,1..
3. For m a prime number and c=0, the longest possible period is P=m-1, which is achieved provided that the multiplier , a, has the property that the smallest integer k such that a k - 1is divisible by m is k= m-1.

5.b.)

- Rank the data from smallest to largest.Finding the R_i
  - i.e. R_i 0.11 0.54 0.68 0.73 0.98
- Finding the D^+ and D^- values
  - i.e. D^+= i/N-R_i = 0.09

- $D^- = R_i-(i-1)/N = 0.34$
- Finding D value
  - i.e. $D = \max(D^+,D^-) = 0.34$
- Justification of the data accept or reject
  - i.e. The tabular value $D_{\alpha,n}= 0.565$.Since $D < D_\alpha$ i.e $0.34 < 0.565$ the sequence of numbers given are accepted.

6.a)

exponential distribution

1. compute the cdf of the desired random variable x

$$cdf: F(x) = 1-e^{-\lambda x}$$

2. Set $F(x) = R$ on the range of x

$$1-e^{-\lambda x} = R$$

3. Solve $F(x) = R$ in terms of x

$$1-e^{-\lambda x} = R$$

$$e^{-\lambda x} = 1-R$$

$$-\lambda x = \ln(1-R) \Rightarrow \boxed{x = \frac{-1}{\lambda}\ln(1-R)}$$

x is called as random variate

1) Given random no 0.1306, 0.0422, 0.6597, 0.7965, 0.7696.
mean $\lambda=1$ find random variates.

$$x_i = \frac{-1}{\lambda}\ln(1-R_i)$$

$$x_1 = \frac{-1}{1}\ln(1-0.1306) = 1.592$$

$$x_2 = \frac{-1}{1}\ln(1-0.0422) = 1.468$$

6.b.) i.e. 1. Set n=0,p=1.

2. R1=0.4357,P=1*0.4357 = 0.4357
3. Since P=0.4357 < $e^{-0.2}$ = 0.8187, accept N=0

Steps 1-3.(R1=0.4146 leads to N=0),accept N=0

- 1.Set n=0,P=1
- 2. R1=0.8353,P=1*0.8353=0.8353
- 3.Since 0.8353 >0.8187,reject n=0 and return to step 2 with n=1
- Step 2. R2= 0.9952,P=R1R2=0.8353*0.9952 = 0.8313
- 3.Since 0.8313 > 0.8187,reject n=1 and return to step 2 with n=2
- Step 2. R3=0.8004,P=R1R2R3 = 0.8313 * 0.8004 = 0.6654
- 3. Since 0.6654 < 0.8187 accept N=2.
- The three Poisson Variates are 0.4357, 0.4146, 0.6654

7.a)

sol:- There are 4 steps in the ... useful model of input data.

1) collect data from the real system of interest.

— this requires a substantial time and resource. In some cases it is not possible to collect data for ex when time is limited (or) when the i/p process does not exist.

— when data are not available expert opinion and knowledge of the process must be used.

2) Identify a probability distribution to represent the input process

— when data are available this step begins with the development of frequency distrn (or) histogram of the data.

3) choose parameters that determine a specific instance of the distrn family.

4) Evaluate the choosen distribution and the associated parameters for goodness of fit.

— chi-square and kolmogorov-smirnov tests are goodness of fit tests. If the choosen distrn is not satisfied from these tests then the analyst returns to second step and chooses a different family of distributions

Data collection :- (Q) Explain data collection in detail.

Data collection is very important but hard to achieve there are 2 approaches

1. classical approach

7.b). Explain Chi–square goodness of fit test. Apply it to Poisson assumption with α=3.64.Data size=100 and observed frequency Oi=12,10,19,17,10,8,7,5,5,3,3,1.Consider tabular value as 11.1.

Sol: For Poisson distribution $P(x) = e^{-\alpha}\alpha^{x} / x!$ for x=0,1,2,…..

Compute P(0),P(1),P(2),……P(11) as follows

$P(0)= e^{-3.64}(3.64)^{0} / 0! = 0.026$

$P(1)= e^{-3.64}(3.64)^{1} / 1! = 0.096$

$P(2)= e^{-3.64}(3.64)^{2} / 2! = 0.174$

$P(3)= e^{-3.64}(3.64)^{3} / 3! = 0.211$

……till P(11) as follows

$$P(4) = \frac{e^{-3.64}(3.64)^4}{4!} = 0.192$$

$$P(5) = \frac{e^{-3.64}(3.64)^5}{5!} = 0.140$$

$$P(6) = \frac{e^{-3.64}(3.64)^6}{6!} = 0.085$$

$$P(7) = \frac{e^{-3.64}(3.64)^7}{7!} = 0.044$$

$$P(8) = \frac{e^{-3.64}(3.64)^8}{8!} = 0.020$$

$$P(9) = \frac{e^{-3.64}(3.64)^9}{9!} = 0.008$$

$$P(10) = \frac{e^{-3.64}(3.64)^{10}}{10!} = 0.003$$

$$P(11) = \frac{e^{-3.64}(3.64)^{11}}{11!} = 0.001$$

Chi-square test table

x_i	observed frequency O_i		expected frequency E_i $(n \times p_i)$		$\frac{(O_i-E_i)^2}{E_i}$
0	12	22	$100 \times 0.026 = 2.6$	12.2	7.87
1	10		$100 \times 0.096 = 9.6$		
2	19		$100 \times 0.174 = 17.4$		0.15
3	17		$100 \times 0.211 = 21.1$		0.80
4	10		$100 \times 0.192 = 19.2$		4.41
5	8		$100 \times 0.140 = 14.0$		2.57
6	7		$100 \times 0.085 = 8.5$		0.26
7	5	17	$100 \times 0.044 = 4.4$	7.6	11.62
8	5		$100 \times 0.020 = 2.0$		
9	3		$100 \times 0.008 = 0.8$		
10	3		$100 \times 0.003 = 0.3$		
11	1		$100 \times 0.001 = 0.1$		
					27.68

— Always we have to see that the expected freq values should be >5. If not then combine with previous (or) next value until it becomes >5.

8.a)

b) :- engineering data :-

- often a product (or) process has performance ratings provided by the manufacturer.

Ex :- mean time to failure of a disk drive is 10000 hrs a laser printer can produce 8 pages/min etc.

- company rules might specify time (or) production standards.

- Expert option :-

- Talk to people who are experienced with the process. they can provide optimistic, pessimistic and most likely times.

- they might also able to say whether the process is nearly constant (or) highly variable and they can define the source of variability.

- physical or conventional limitations :-

- most real processes have physical limits on performance

Ex :- computer data entry cannot be faster than a person can type.

- Because of company policies there could be upper limits on how long a process may take and do not ignore it.

- the nature of the process :-

when data are not available then uniform, triangular, and beta distributions are often used as i/p models.

- uniform distn - poor choice bcz upper and lower bounds are likely as central values in real process.

- Triangular distn - In addition to upper and lower bounds a most likely value is given then use triangular distn.

- Beta distn - density function has to be plotted

8.b)

Types of simulations with respect to output analysis

there are 2 types of simulations

1. Terminating simulations
2. steady state simulations

A terminating simulation is one that runs for some duration of time T_E where E is the specified event that stops the simulation.

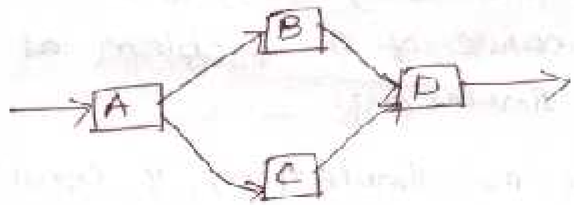
Ex:- A retail shop closes every evening from which it opens from 9am to 5 pm.

L Here E = atleast 7 hours of time has been used

2)- A company which sells a product would like to decide how many items to have in inventory during planning for 100 months.

L Here E = 100 months

3) A communication system consists of several components plus several backup components, as in fig.



Here E = consider the system over a period of time T_E until system fails.

E = {A fails, (or) D fails (or) B and C fails}

- In this case we cannot predict E in advance bcz we do not know when the component fails.

9.b)

Output analysis for terminating simulations

A terminating simulation runs over a simulated time interval $[0, T_E]$

- A common goal is to estimate

$$\theta = E\left[\frac{1}{n}\sum_{i=1}^{n} Y_i\right] \quad \text{for discrete output}$$

$$\phi = E\left[\frac{1}{T_E}\int_0^{T_E} Y(t)\,dt\right] \quad \text{for continuous o/p } Y(t),\ 0 \le t \le T_E.$$

- In general independent replications are used. each run using a different random no stream and independently choosen initial conditions.

Statistical background :-

the most confusing aspect among simulation o/p analysis is distinguishing within-replication data from across-replication data.

- For ex simulation of a manufacturing system
  - Two performance measures of that system
    - cycle time for parts (time from release into the factory until completion)
    - work in process (WIP) - the total no of parts in the factory at any time.
  - Let Y_{ij} be the cycle time for the j^{th} part produced in the i^{th} replication
  - Across-replication data are formed by summerizing within-replication data

$\bar{Y}_i$ — sample mean of the n_i cycle times from i^{th} replication

S_i^2 — sample variance of the same data.

and $H_i = t_{\alpha/2, n_i - 1} \frac{s_i}{\sqrt{n_i}}$ is a confidence interval half-width based on this data set.

within rep data	Across-Rep data
$Y_{11}\ Y_{12}\ \cdots\ Y_{1n_1}$	$\overline{Y}_1, \ldots S_1^2, H_1$
$Y_{21}\ Y_{22}\ \cdots\ Y_{2n_2}$	$\overline{Y}_2, \ldots S_2^2, \ldots H_2$
$\vdots$	$\vdots$
$Y_{R1}\ Y_{R2}\ \cdots\ Y_{Rn_R}$	$\overline{Y}_R, \ldots S_R^2 \ldots H_R$
	$\overline{Y} \ldots S^2, H$

within and across-rep data for cycle-time

- From the across-replication data we compute the overall statistics the avg of the daily cycle time averages

$$\overline{Y} = \frac{1}{R} \sum_{i=1}^{R} \overline{Y_i}$$

the sample variance of the daily cycle time averages $S^2 = \frac{1}{R-1} \sum_{i=1}^{R} \left(\overline{Y_i} - \overline{Y}\right)^2$

the confidence interval half width

$$H = t_{\alpha/2, R-1} \frac{S}{\sqrt{R}}$$

- the quantity $S/\sqrt{R}$ is the standard error

within-replication

work in process is a continuous time o/p. denoted by $Y_i(t)$. the stopping time for i^{th} replication T_{E_i} could be a random variable

Within-Rep data	Across-rep data
$Y_1(t)$, $0 \le t \le T_{E_1}$	$\bar{Y}_1$, S_1^2, H_1
$Y_2(t)$, $0 \le t \le T_{E_2}$	$\bar{Y}_2$, S_2^2, H_2
$\vdots$	$\vdots$
$Y_R(t)$, $0 \le t \le T_{E_R}$	$\bar{Y}_R$, S_R^2, H_R
	$\bar{Y}$, S^2, H

Within-Rep and Across replication WIP data

– The within-replication sample mean and variance are defined as

$$\bar{Y}_i = \frac{1}{T_{E_i}} \int_0^{T_{E_i}} Y_i(t)\, dt$$

$$S_i^2 = \frac{1}{T_{E_i}} \int_0^{T_{E_i}} \left(Y_i(t) - \bar{Y}_i\right)^2 dt$$

$$H_i = Z_{\alpha/2} \frac{S_i}{\sqrt{T_{E_i}}}$$

Confidence intervals with specified precision

The half length H of a $100(1-\alpha)\%$ confidence interval for a mean θ based on the t distribution is given by

$$H = t_{\alpha/2, R-1} \frac{S}{\sqrt{R}}$$

S^2 is the sample variance

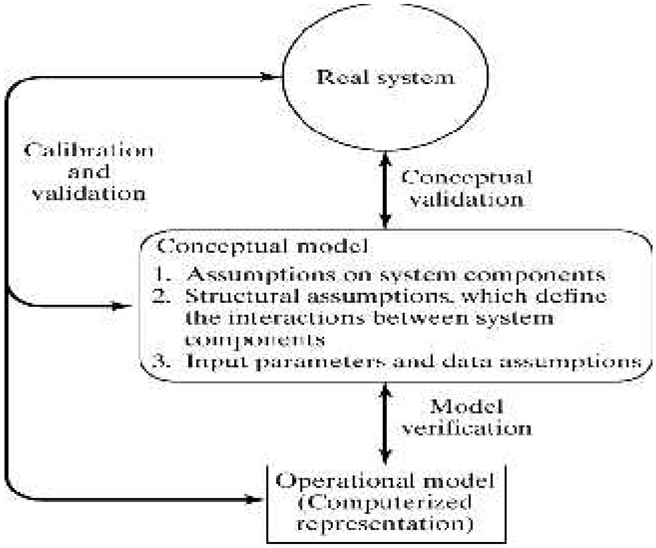
R is the no of replications

– Suppose that an error criterion ϵ is specified with probability $1-\alpha$ a sufficiently large sample size should satisfy

$$P(|\bar{Y} - \theta| < \epsilon) \geq 1-\alpha$$

– Assume that an initial sample size of R_0 replications has been observed

10.a)



The first step in model building consists of observing the real system and the interactions among their various components and of collecting data on their behavior. But observation alone seldom yields sufficient understanding of system behavior. Persons familiar with the system, or any subsystem, should be questioned to take advantage of their special knowledge. Operators, technicians, repair and maintenance personnel, engineers, supervisors, and managers understand certain aspects of the system that might be unfamiliar to others. As model development proceeds, new questions may arise and the model developers will return to this step of learning true system structure and behavior.

The second step in model building is the construction of a conceptual model-a collection of assumptions about the components and the structure of the system, plus hypotheses about the values of model input parameters. As is illustrated by Figure, conceptual validation is the comparison of the real system to the conceptual model.

The third step is the implementation of an operational model, usually by using simulation software and incorporating the assumptions of the conceptual model into the worldview and concepts of the simulation software. In actuality, model building is not a linear process with three steps. Instead; the model builder will return to each of these steps many times while building, verifying, and validating the model.

The above figure, depicts the ongoing model building process, in which the need for· verification and validation causes continual comparison of the real system to the conceptual model and to the operational model and induces repeated modification of the model to improve its accuracy.

10.b)Naylor and Finger formulated a **three step approach** which has been widely followed:-

1. Build a model that has high face validity.

2. Validate model assumptions.

3. Compare the model input-output transformations to corresponding input-output transformations for the real system.

1. Face Validity

• The first goal of the simulation modeler is to construct a model that appears reasonable on its face to model users and others who are knowledgeable about the real system being simulated.

• The users of a model should be involved in model construction from its conceptualization to its implementation to ensure that a high degree of realism is built into the model through reasonable assumptions regarding system structure, and reliable data.

• Another advantage of user involvement is the increase in the models perceived validity or credibility without which manager will not be willing to trust simulation results as the basis for decision making.

• Sensitivity analysis can also be used to check model's face validity.

• The model user is asked if the model behaves in the expected way when one or more input variables is changed.

• Based on experience and observations on the real system the model user and model builder would probably have some notion at least of the direction of change in model output when an input variable is increased or decreased.

• The model builder must attempt to choose the most critical input variables for testing if it is too expensive or time consuming to: vary all input variables.

2. Validation of Model Assumptions

• Model assumptions fall into two general classes: structural assumptions and data assumptions.

Structural assumptions involve questions of how the system operates and usually involve simplification and abstractions of reality.

• For example, consider the customer queuing and service facility in a bank. Customers may form one line, or there may be an individual line for each teller. If there are many lines, customers may be served strictly on a first-come, first-served basis, or some customers may change lines if one is moving faster. The number of tellers may be fixed or variable. These structural assumptions should be verified by actual observation during appropriate time periods together with discussions with managers and tellers regarding bank policies and actual implementation of these policies.

• Data assumptions should be based on the collection of reliable data and correct statistical analysis of the data.

3. Validating Input-Output Transformation

In this phase of validation process the model is viewed as input –output transformation : That is, the model accepts the values of input parameters and transforms these inputs into output measure of performance. It is this correspondence that is being validated.

• Using historical input data : Instead of validating the model input-output transformation by predicting the future, the modeler may use past historical data which has been served for validation purposes that is, if one set has been used to develop calibrate the model, its recommended that a separate data test be used as final validation test.

- Using Turing test: When no statistical test is readily applicable then persons knowledgeable about system behavior can be used to compare model output with system output. This type of test is called Turing test used in detecting model inadequacies and to increase the model credibility.