

unit 1:Introduction to simulation

1. Simulation:

- **Simulation is the imitation of the operation of a real world process or system over time.**
- **Simulation models help us to study the behavior of system as it evolves**
- **models keeps the set of assumption concerning the operation of the system**
- **Assumptions are expressed in terms of mathematical, logical and symbolic relationship between the entities or object of interest of the system.**
- **Simulation modeling can be used both as an analysis tools to predict the performance of the new system and also predict the effect of changes to existing system.**
- **simulation can be done by hand or computer its keeps the history of system**
- **Simulation produce the set of data is used to estimate the measures of performance of system.**

1.1 When Simulation is the Appropriate Tool:

- **Study of and experimentation** with the internal interactions of a complex system, or of a subsystem within a complex system.
- Informational, organizational and environmental changes can be simulated and **the model's behavior can be observed**.
- The knowledge gained in designing a simulation model can be of great **value toward suggesting improvement in the system under investigation**.
- By changing simulation inputs and observing the resulting outputs, valuable insight may be obtained into which variables are most important and how variables interact.
- Simulation can be used as a **pedagogical (teaching) device** to reinforce analytic solution methodologies.
- Can be used to experiment **with new designs or policies prior to implementation**, so as to prepare for what may happen.
- Can be used to **verify analytic solutions**.
- By simulating different capabilities for a machine, requirements can be determined.
- Simulation models **designed for training, allow learning without the cost and disruption of on-the-job instructions**.
- **Animation** shows a system in simulated operation so that **the plan can be visualized**.
- **The modern system (factory, water fabrication plant, service organization, etc)** is so **complex** that the interactions can be treated only through simulation

1.2 When Simulation is Not Appropriate

- Ñ Simulation should **not be used when the problem can be solved using common sense**.
- Ñ Simulation should **not be used if the problem can be solved analytically**.
- Ñ Simulation should **not be used if it is easier to perform direct experiments**.
- Ñ Simulation should **not be used, if the costs exceeds savings**.
- Ñ Simulation should **not be used if the resources or time are not available**.
- Ñ No data is available, not even estimate simulation is not advised.

- Ñ If there is not enough time or the people are not available, simulation is not appropriate.
- Ñ If managers have unreasonable expectation say, too much soon – or the power of simulation is over estimated, simulation may not be appropriate.
- Ñ **If system behavior is too complex or cannot be defined**, simulation is not appropriate

1.3Advantages of Simulation

1. **New policies, operating procedures, decision rules, information flow, etc can be explored** without disrupting the ongoing operations of the real system.
2. **New hardware designs, physical layouts, transportation systems** can be tested without committing resources for their acquisition.
3. **Hypotheses** about how or why certain phenomena occur can be **tested for feasibility**.
4. **Time can be compressed or expanded allowing for a speedup or slowdown** of the phenomena under investigation.
5. Insight can be obtained about the **interaction of variables**.
6. Insight can be obtained about **the importance of variables to the performance of the system**.
7. **Bottleneck analysis** can be performed indication where work-in process, information materials and so on are being excessively delayed.
8. A **simulation study can help in understanding how the system operates** rather than how individuals think the system operates.
9. “what-if” questions can be answered. **Useful in the design of new systems**.

1.4Disadvantages of simulation

1. Model building **requires special training**. It is an art **that is learned over time and through experience**.
2. If two models are **constructed by two competent individuals**, they may have similarities, but it is highly unlikely that they will be the same.
3. Simulation results may be **difficult to interpret**. Since most simulation outputs are essentially random variables (they are usually based on random inputs), it may be hard to determine whether an observation is a result of system interrelationships or randomness.
4. Simulation modeling and analysis can be **time consuming and expensive**. Skimping on resources for modeling and analysis may result in a simulation model or analysis that is not sufficient for the task.
5. Simulation is used in some cases when an analytical solution is possible, or even preferable. This might be particularly true in the simulation of some waiting lines where closed-form queueing models are available.

1.5Applications of Simulation

- **Manufacturing application**
- Semiconductor manufacturing
- construction engineering
- military application
- Business process simulation
- Human system

1. Manufacturing Applications

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

2. Semiconductor Manufacturing

- Comparison of dispatching rules using large-facility models
- The corrupting influence of variability
- A new lot-release rule for wafer fabs
- Assessment of potential gains in productivity due to proactive retile management
- Comparison of a 200-mm and 300-mm X-ray lithography cell
- Capacity planning with time constraints between operations
- 300-mm logistic system risk reduction

3. Construction Engineering

- Construction of a dam embankment
- Trenchless renewal of underground urban infrastructures
- Activity scheduling in a dynamic, multi project setting
- Investigation of the structural steel erection process
- Special-purpose template for utility tunnel construction

4. Military Application

- Modeling leadership effects and recruit type in an Army recruiting station
- Design and test of an intelligent controller for autonomous underwater vehicles
- Modeling military requirements for non war fighting operations
- Using adaptive agent in U.S Air Force pilot retention

5. Logistics, Transportation, and Distribution Applications

- Evaluating the potential benefits of a rail-traffic planning algorithm
- Evaluating strategies to improve railroad performance
- Parametric modeling in rail-capacity planning
- Analysis of passenger flows in an airport terminal
- Proactive flight-schedule evaluation
- Logistics issues in autonomous food production systems for extended-duration space exploration
- Sizing industrial rail-car fleets
- Product distribution in the newspaper industry
- Design of a toll plaza

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- Choosing between rental-car locations
- Quick-response replenishment

6. Business Process Simulation

- Impact of connection bank redesign on airport gate assignment
- Product development program planning
- Reconciliation of business and systems modeling
- Personnel forecasting and strategic workforce planning

7. Human Systems and Healthcare

- Modeling human performance in complex systems
- Studying the human element in air traffic control
- Modeling front office and patient care in ambulatory health care practices
- Evaluating hospital operations b/n the emergency department and a medical
- Estimating maximum capacity in an emergency room and reducing length of stay in that room.

1.6 Systems and System Environment

System:

System is defined as a group of object that are joined together in some regular interaction or interdependence toward the accomplishment of same.

System environment:

A system is often affected by changes occurring outside the system, Such changes are said to occur in the system environment.

1.7 Components of a System

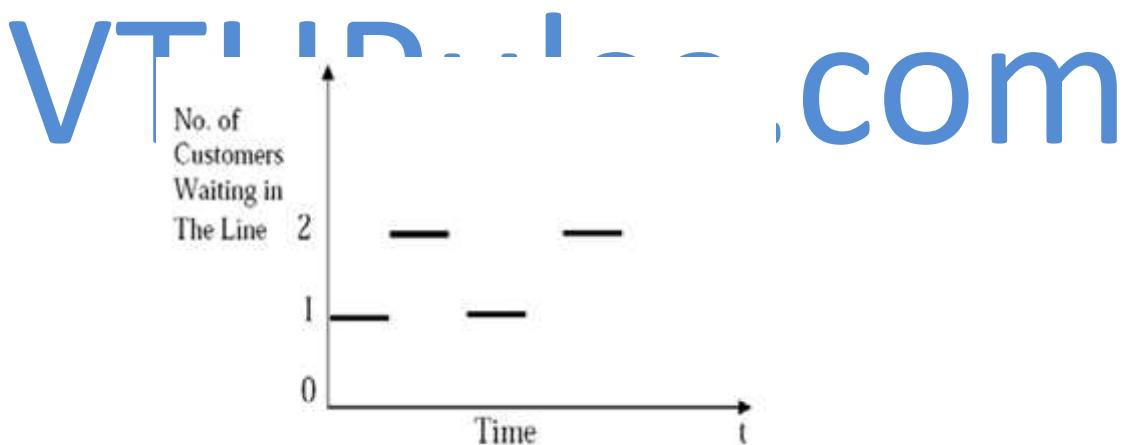
- 1) **Entity:** An entity is an object of interest in a system.
Ex: In the factory system, departments, orders, parts and products are the entities.
- 2) **Attribute:** An attribute denotes the property of an entity.
Ex: Quantities for each order, type of part, or number of machines in a department are attributes of factory system.
- 3) **Activity:** Represent a time period of specified length
Ex: Manufacturing process of the department.
- 4) **State of the System:** 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.
- 5) **Event:** An event is defined as an instantaneous occurrence that may change the state of the system.

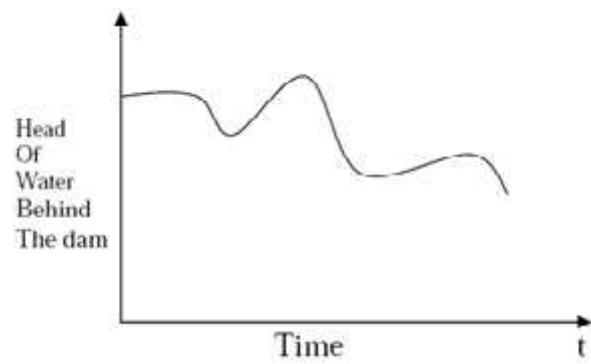
Endogenous : IS used to described activites and events occurring with in the system

Exogenous: Is used to described activites and events in the environment that affect the system.

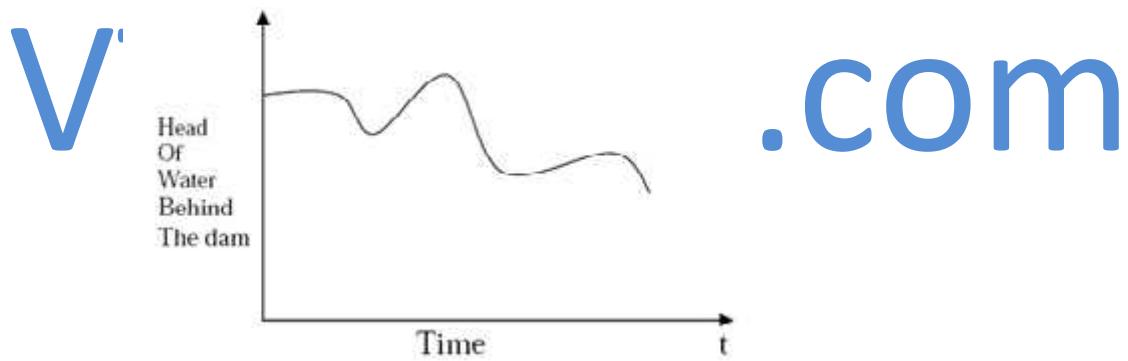
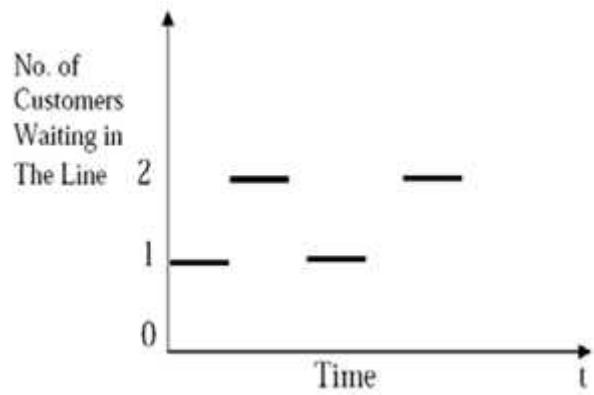
Examples of system and components

System	Entities	Attributes	Activities	Events	State variables
Banking	Customers	Checking-account balance	Making deposits	Arrival; departure	No. of busy tellers; no. of customers waiting.
Rapid rail	Riders	Origination; destination	Traveling	Arrival at station; arrival at destination	No. of riders waiting at each station; No. of riders in transit
Production	Machines	Speed; capacity; breakdown rate length	Welding; stamping	Breakdown	Status of machines (busy, idle or down)
Inventory	Warehouse	Capacity	Withdrawing	Demand	Levels of inventory; backlogged demands





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systems.

1.11 Steps in a simulation study:

1. Problem formulation
2. Setting of objectives and overall project plan
3. model conceptualization
4. data Collection
5. model translation
6. verified
7. validated
8. Experimental design
9. production runs and analysis
10. more runs
11. documentation and reporting
12. Implementation

1. Problem formulation:

- Every study should begin with a statement of the problem.
- If the statement is provided by the policy makers or those that have the problem, The analyst must ensure that the problem being described is clearly understood
- If the problem statement is being developed by the analyst, it is important that the policy makers understand and agree with the formulation.

2. Setting of objective and overall project plan:

- The objectives indicate the questions to be answered by simulation.
- At this point a determination should be made concerning whether simulation is the appropriate methodology. Assuming that it is appropriate,
- the overall project plan should include the study in terms of
 - A statement of the alternative systems
 - A method for evaluating the effectiveness of these alternatives
 - Plans for the study in terms of the number of people involved
 - Cost of the study
 - The number of days required to accomplish each phase of the work with the anticipated results.

3. Model Conceptualization:

- The construction of a model of a system is probably as much art as science.
- The art of modeling is enhanced by ability to have following:
 - To abstract the essential features of a problem.
 - To select and modify basic assumptions that characterizes the system.
 - To enrich and elaborate the model until a useful approximation results.

4. Data Collection:

- There is a constant interplay between the construction of the model and the collection of the needed input data.
- As complexity of the model changes the required data elements may also change.
- Since data collection takes such a large portion of the total time required to perform a simulation it is necessary to begin it as early as possible.

5. Model Translation:

- Since most real world system result in model that require a great deal of information storage and computation, the model must be entered into a computer recognizable format.
- we use term program even though it is possible to accomplish the desired result in many instances with little or no actual coding.

6.Varified:

- It pertains to the computer program and checking the performance.
- If the input parameters and logical structure are correctly represented, verification is completed.

7.Validated:

- validation is the determination that a model is an accurate representation of the real system.
- Is usually achieved through the calibration of the model an iterative process of comparing the model to actual system behavior and using the discrepancy between the two and the insights gained to improve the model.
- This process is repeated until model accuracy is judged acceptable.

8.Experimental Design:

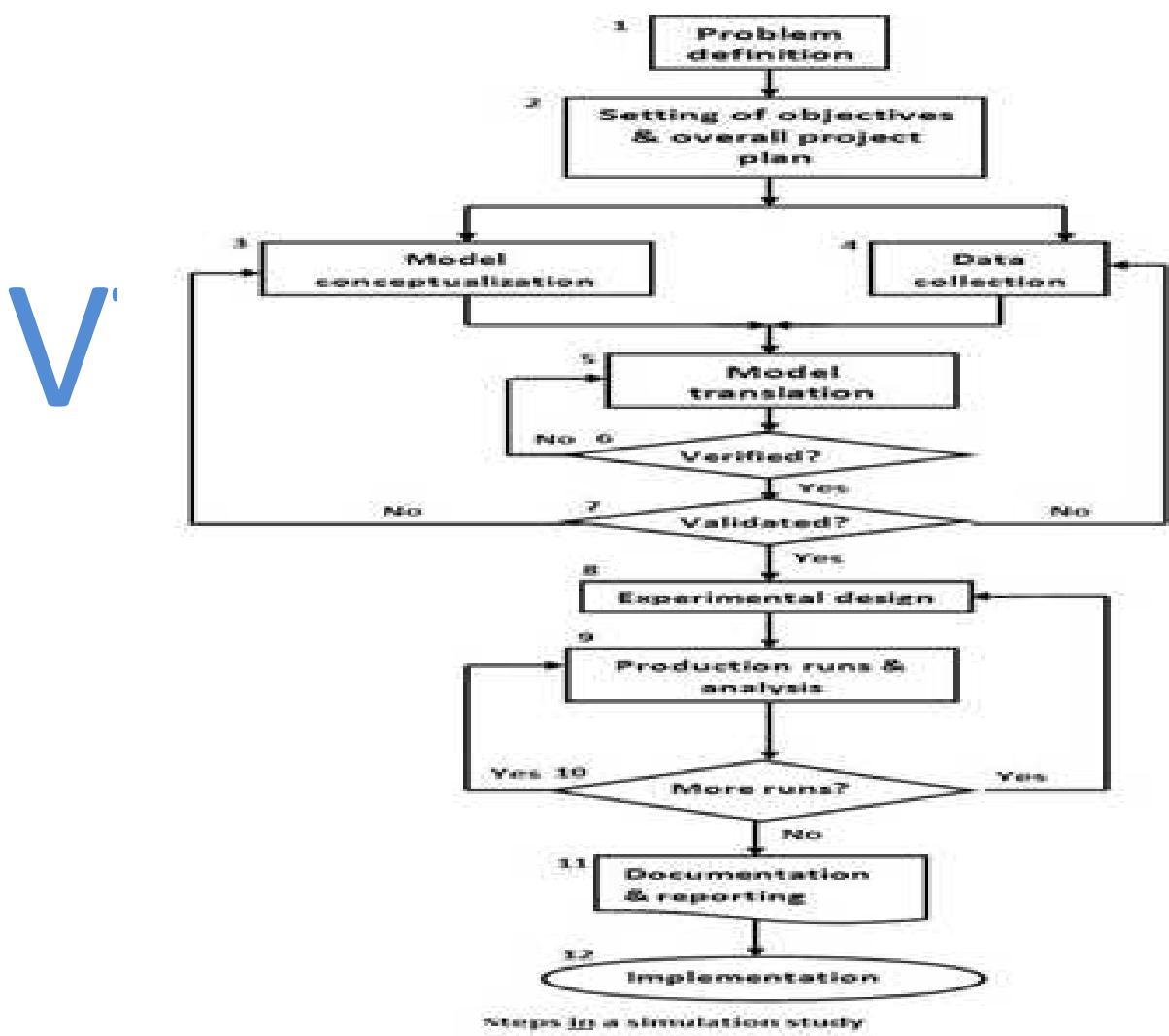
- The alternatives that are to be simulated must be determined. For each system design, decisions need to be made concerning
 - a. Length of the initialization period
 - b. Length of simulation runs
 - c. Number of replication to be made of each run

9.Production runs and analysis:

- They are used to estimate measures of performance for the system designs that are being simulated.

10.More runs:

- Based on the analysis of runs that have been completed. The analyst determines if additional runs are needed and what design those additional experiments should follow.



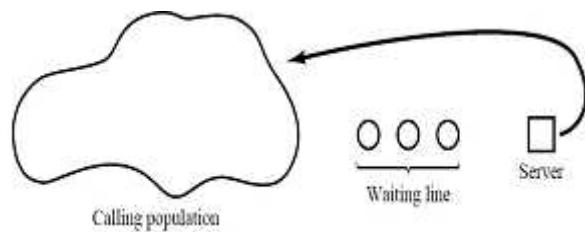


Figure 1 Queueing system.

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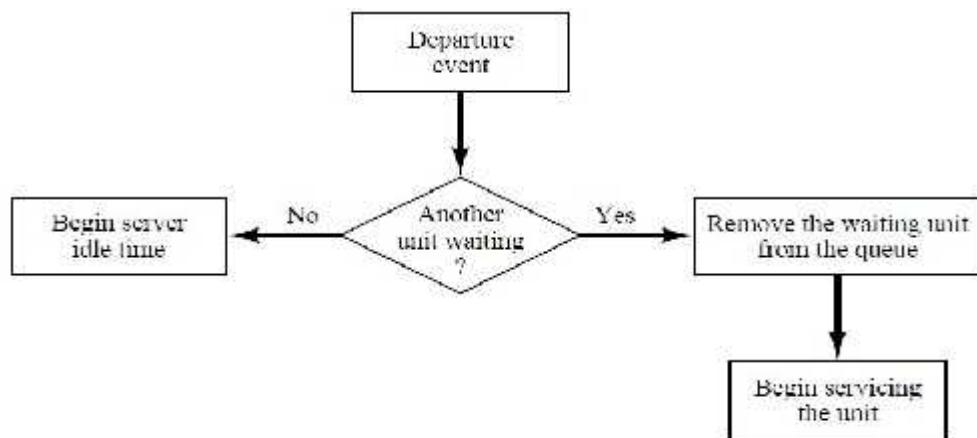


Figure 2.2 Service-just-completed flow diagram.

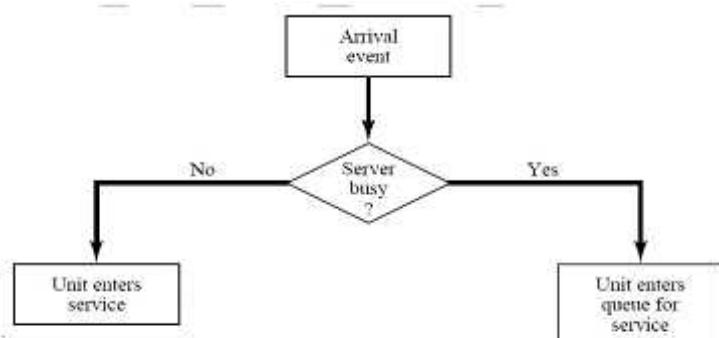


Figure 2.3 Unit-entering-system flow diagram.

		Queue status	
		Not empty	Empty
Server status	Busy	Enter queue	Enter queue
	Idle	Impossible	Enter service

Figure 2.4 Potential unit actions upon arrival.

		Queue status	
		Not empty	Empty
Server outcomes	Busy		Impossible
	Idle	Impossible	

Figure 2.5 Server outcomes after service completion.

Problems:

Single channel queuing system problem formulas:

1. Time Customer wait in queue= Time service begin – Arrival Time
2. Time Service End= Service time + Time service begin
3. Time customer Spend In system= Time service end-Arrival Time
4. Idel Time of Server=Time service Begin(N)-Time Service end(N-1)

Standard Formulas:

1.**Average waiting time(i.e customer wait)**=total time customer wait in queue / Total number of customer

2.**Probability(Wait i.e customer wait)**=Number of Customer who wait / Total number of customer

3.**Probability of idle server(idle time of server)**=total idle time of server / total run time of simulation

4.**average service time**=total service time/total number of customer

5.**average times between arrivals**=sum of all times between arrival/number of arrivals-1

6.**Average waiting time those who wait in queue**=total time customer wait in queue/total number of customer who wait

7.**Average time customer spend In the system**=Total time customer spend in system/total number of customer



① Single channel and Multi channel (Able Baker prob.)
Queuing system problem ?

UNIT-1

$$\text{Average Waiting time} = \frac{\text{Total time customer waiting in queue}}{\text{Total no. of customers}}$$

$$\text{Probability of wait} = \frac{\text{No. of customers to wait}}{\text{Total no. of customers}}$$

$$\text{Probability of idle server} = \frac{\text{Total idle time of server}}{\text{Total run time of simulation (TSE last value)}}$$

$$\text{Average Service Time} = \frac{\text{Total service time}}{\text{Total no. of customers}}$$

$$\text{Average time b/w arrival} = \frac{\text{sum of all time b/w arrival}}{\text{No. of arrival - 1}}$$

$$\text{Average waiting time those who wait in queue} = \frac{\text{Total time customer wait in queue}}{\text{Total no. of customer who wait}}$$

$$\text{Average time customer spends in S/R in the system} = \frac{\text{Total time customer spends in S/R}}{\text{Total no. of customers}}$$

AT → Arrival Time

TSB → Time Service Begin

IAT → Inter Arrival Time

TSE → Time Service End

ST → Service Time

CP → Cumulative Probability

C.No → Customer Number

P → Probability

RD → Random Digit

RDA → Random Digit Assessment

i) A small grocery store has only one check out counter. The customer arrives at this check out counter at random from 1 to 8 min apart. Each possible value of service time has same probability of occurrence. The service time varies from 1 to 6 mins apart. Each possible value of service time has same probability of occurrence. Develop simulation distribution table for 8 customers.

Random digit for arrival time :

913 727 015 948 309 922 753 235 302

Service Time : (Random digit)

84 10 74 53 17 79 91 67 89 38

ii) Determine Inter Arrival Time distribution table

C.No	$P(1/8)$	Cumulative Probability	Random Digit Assessment
1	0.125	0.125	001 - 125
2	0.125	0.250	126 - 250
3	0.125	0.375	251 - 375
4	0.125	0.500	376 - 500
5	0.125	0.625	501 - 625
6	0.125	0.750	626 - 750
7	0.125	0.875	751 - 875
8	0.125	1.000	876 - 000

②

ii] Compute Arrival time from IAT

C.No	Random Digit	IAT	Arrival Time
1	-	-	0
2	913	8	8
3	727	6	14
4	015	1	15
5	948	8	23
6	309	3	26
7	922	8	34
8	753	7	41
9	235	2	43
10	302	3	46

iii] Determine Service Time Distribution Table

S.No	P(1/6)	Cumulative probability	Random Digit Assess.
1	0.16	0.16	01-16
2	0.16	0.32	17-32
3	0.16	0.48	33-48
4	0.16	0.64	49-64
5	0.16	0.80	65-80
6	0.16	0.96	81-96

iv] Compute Service Time

S.No	Random digit	Service Time
1	84	6
2	10	1
3	74	5
4	53	4
5	17	2
6	79	5
7	91	6
8	67	5
9	89	6
10	38	3

✓) Simulation Table for 10 customers

C.No	Arrival Time	Service Time	Total Service Begin	Time Service End	TSE - AT	TSB(n) - TSE(n-1)	TSB - AT
					Customer Time spent in System	Idle Server Time	Customer time wait in queue
1	0	6	0	6	6 (6-0)	0	0
2	8	1	8	9	1 (9-8)	2 (8-6)	0 (8-8)
3	14	5	14	19	5 (19-14)	5 (14-9)	0 (14-14)
4	15	4	19	23	4 (23-19)	0	4 (19-15)
5	23	2	23	25	2 (25-23)	0	0
6	26	5	26	31	5 (31-26)	0	0
7	34	6	34	40	6 (40-34)	2 (40-31)	1 (31-34)
8	41	5	41	46	5 (46-41)	0	0
9	43	6	46	52	9 (52-46)	0	0
10	46	3	52	55	9 (55-52)	3 (55-52)	6 (52-46)

Average waiting time

$$= \frac{\text{Total time customer waiting in queue}}{\text{Total no. of customers}} = \frac{4+3+6}{10} = \frac{13}{10} = 1.3 \text{ min}$$

Probability to wait

$$= \frac{\text{No. of customers to wait}}{\text{Total no. of customers}} = \frac{3}{10} = 0.3 \text{ min}$$

Probability of idle servers

$$= \frac{\text{Total idle time of servers}}{\text{Total run time of simulation (TSE last value)}} = \frac{2+5+1+3+1}{55} = \frac{12}{55} = 0.218 \text{ min}$$

13 27 15 48 9 33 53 35 2

Take a random digit for arrival;

Develop a simulation Table for 10 customers

P : 0.10 0.20 0.25 0.30 0.10 0.05

ST : 4 2 3 4 5 6

Probability shewn below.

The service time vary from 4 to 6 mins with

of IAT has the same probability of occurrence.

at random from 4-6 min apart. Each possible value

• A small grocery store has only one check out counter

$$\frac{10}{56} = \underline{\underline{5.6 \text{ min}}} =$$

10

$$\frac{6+1+5+8+3+5+6+5+9+7}{9+1+5+8+3+5+6+5+9+7} =$$

Total no. of customers in system

Customer spent = $\frac{\text{Total time customer spends in system}}{\text{Total time customer spends in system}}$

Average time

$$\frac{3}{13} = \frac{3}{13} = \underline{\underline{4.3 \text{ min}}} =$$

Total no. of customer who wait in queue

wait in queue

time those who

average waiting

$$\frac{10-1}{46} = \frac{9}{46} = \underline{\underline{5.11 \text{ min}}} =$$

No. of arrival - 1

Average Time = $\frac{\text{Sum of all time b/w arrival}}{\text{No. of arrival}} =$

b/w arrival

$$\frac{10}{43} = \frac{10}{43} = \underline{\underline{4.8 \text{ min}}} =$$

Total no. of customers

Time

Average service time

Random digit for Service Time

84 10 74 53 17 91 79 67 38 89 sequentially.

Calc. Avg Service Time, probability of idle service time, average b/w arrivals & avg. time customer spent in system.

i) Determine IAT Distribution Table

C.No	Probability (1/6)	Cumulative probability	Random digit assessment
1	0.16	0.16	01-16
2	0.16	0.32	17-32
3	0.16	0.48	33-48
4	0.16	0.64	49-64
5	0.16	0.80	65-80
6	0.16	0.96	81-96

ii) Compute Arrival time
from IAT

iv) Compute Service Time
from Distribution Table

C.No	RD	IAT	AT
1	-	-	0
2	13	1	1
3	27	2	3
4	15	1	4
5	48	3	7
6	9	1	8
7	22	2	10
8	53	4	14
9	35	3	17
10	2	1	18

S.No	RD	ST
1	84	4
2	10	1
3	74	4
4	53	3
5	17	2
6	91	5
7	79	4
8	67	4
9	38	3
10	89	5

iii) Determine ST Dist. Table

S.No	Probability	CP	RDA
1	0.10	0.10	01-10
2	0.20	0.30	11-30
3	0.25	0.55	31-55
4	0.30	0.85	56-85
		0.95	86-95

(4)

Simulation Table for 10 customers

No	Arrival Time	Service Time	Time Service Begin	Time Service End	Cust. time spent in system	Idle Server Time	Cust. time wait in queue
0	0	4	0	4	4	0	0
1	1	4	4	5	4	3	8
2	4	5	9	12	6	5	5
3	3	2	12	14	7	8	0
4	7	9	14	19	11	13	0
5	8	5	19	24	13	13	0
6	10	4	23	27	13	13	0
7	14	4	27	30	17	17	0
8	17	3	30	35	17	17	0
9	18	5			12	12	0

Average Service Time = $\frac{35}{10} = \underline{\underline{3.5 \text{ min}}}$
 Probability of Idle Server Time = $\frac{0}{35} = \underline{\underline{0}}$

Average time b/w arrivals = $\frac{18}{9} = \underline{\underline{2 \text{ min}}}$

Average time customer spent in system = $\frac{61}{10} = \underline{\underline{6.1 \text{ min}}}$

3. Consider a store with one checkout counter.
 Prepare simulation table & find out average waiting time of customer in waiting queue,
 probability of idle server, average service time

IAT : 3 2 6 4 4 5 8 7

ST : 4 5 5 8 4 6 2 3 4

Assume 1st customer arrives at t=0.

i) Inter arrival distribution Table

C.No	IAT	AT
1	-	0
2	3	3
3	2	5
4	6	11
5	4	15
6	4	19
7	5	24
8	8	32
9	7	39

ii) Simulation table for 9 customers

C.No	AT	ST	TSB	TSE	Cust. spent in s/m.	Idle time of server	Cust. time wait in que
1	0	4	0	4	4	0	0
2	3	5	4	9	6	0	1
3	5	5	9	14	9	0	4
4	11	8	14	22	11	0	3
5	15	4	22	26	11	0	7
6	19	6	26	32	13	0	7
7	24	2	32	34	10	0	8
8	32	3	34	37	5	0	2
9	39	4	39	43	4	2	0

(B) Average waiting time of customer in waiting queue = $\frac{32}{7} = 4.57 \text{ min}$

Probability of Idle Server = $\frac{2}{10} = 0.2 \text{ min}$

Average Service Time = $\frac{41}{9} = 4.56 \text{ min}$

Multichannel Problems :

Type I

4 Consider a simulation with a restaurant system where car & hope takes order & brings an item to the car. The car arrives in the manner :

Time b/w arrival : 1 2 3 4
Probability : 0.25 0.40 0.20 0.15

Consider 2 persons Able & Baker. Able is better & bit faster than Baker.

Able Service Time :

ST : 2 3 4 5

Prob : 0.30 0.28 0.25 0.17

Baker Service Time :

ST : 3 4 5 6

Prob : 0.35 0.25 0.20 0.20

Take a random digit for arrival :

26 98 90 26 42 74 80 68 22

Random digit for service time :

95 21 51 92 89 38 13 61 50 49

i) Determine Inter Arrival distribution Table

C.No	Probability	Cumulative Probability	Random Digit Assessment
1	0.25	0.25	01-25
2	0.40	0.65	26-65
3	0.20	0.85	66-85
4	0.15	1.00	86-00

ii) Compute AT from IAT distribution Table

C.No	RD	IAT	AT
1	-	-	0
2	26	2	2
3	98	4	6
4	90	4	10
5	26	2	12
6	42	2	14
7	74	3	17
8	80	3	20
9	68	3	23
10	22	1	24

iii) Able Service Time Distribution Table

S.No	Probability	CP	RDA
2	0.30	0.30	01-30
3	0.28	0.58	31-58
4	0.25	0.83	59-83
5	0.17	1.00	84-00

iv) Baker Service Time Distribution Table

S.No	Probability	CP	RDA
3	0.35	0.35	01-35
4	0.25	0.60	36-60
5	0.20	0.80	61-80
6	0.20	1.00	81-00

v) Simulation table for 10 customers

C.No.	AT	RD for service	ST	When Able is Available	When Baker is Available	Server chosen	Able		Baker		cust. in s/m	Idle Server time	wq
							TSB	TSE	TSB	TSE			
1	0	95	5	0	0	A	0	5	-	-	5	0	0
2	2	21	3	5	0	B	-	-	2	5	3	2	0
3	6	51	5	5	5	A	6	9	-	-	3	1	0
4	10	93	3	5	5	A	10	15	-	-	5	1	0
5	12	89	2	5	5	B	-	-	12	18	6	7	0
6	14	38	3	15	18	A	15	18	-	-	4	0	1
7	17	13	4	18	18	A	18	20	-	-	3	0	0
8	20	61	4	20	18	A	20	24	-	-	4	0	0
9	23	50	4	24	18	B	-	-	23	27	4	5	0
10	24	49	3	24	27	B	24	27	-	-	3	0	0

5) Consider Simulation table for Able & Baker problem where time b/w arrival are :

Time b/w arrival : 1 2 3 4 5

Probability : 0.20 0.15 0.05 0.20 0.40

Baker is faster than Able.

Service Time for Able :

ST : 3 4 5 6 2

Prob : 0.20 0.05 0.15 0.20 0.40

Service Time for Baker :

ST : 2 3 5 6 1

Prob : 0.15 0.20 0.05 0.20 0.40

Random Digit for Arrival :

98 90 42 80 22 26 74 26 68

Random Digit for Service Time :

49 50 61 13 38 89 92 51 21 95

i) Determine IAT distribution Table

C.No	Probability	CP	RDA
1	0.20	0.20	01-20
2	0.15	0.35	21-35
3	0.05	0.40	36-40
4	0.20	0.60	41-60
5	0.40	1.00	61-00

ii) Compute Arrival Time from IAT dist. table.

C.No	RD	IAT	AT
1	-	-	0
2	98	5	5
3	90	5	10
4	42	4	14
5	80	5	19
6	22	2	21
7	26	2	23
8	74	5	28
9	26	2	30
10	68	5	35

iii) Able Service Time Distribution Table

S.No	P	CP	RDA
3	0.20	0.20	01-20
4	0.05	0.25	21-25
5	0.15	0.40	26-40
6	0.20	0.60	41-60
2	0.40	1.00	61-00

iv) Baker Service Time Distribution Table

S.No	P	CP	RDA
2	0.15	0.15	01-15
3	0.20	0.35	16-35
5	0.05	0.40	36-40
6	0.20	0.60	41-60
1	0.40	1.00	61-00

(RD - Random Digit)

v) Simulation table for 10 customers

C.No	Arrival Time	RD of Service	Service Time	When Able is Available	When Baker is Available	Server chosen	Able		Baker		Cust. time spent in s/m	Idle time of Server	Cust. + wait queue
							TSB	TSE	TSB	TSE			
1	0	49	6	0	0	B	-	-	0	6	6	0	0
2	5	50	6	0	6	A	5	11	-	-	6	5	0
3	10	61	1	11	6	B	-	-	10	11	1	4	0
4	14	13	2	11	11	B	-	-	14	16	2	3	0
5	19	38	5	11	16	B	-	-	19	24	5	3	0
6	21	89	2	11	24	A	21	23	-	-	2	10	0
7	23	92	2	23	24	A	23	25	-	-	2	0	0
8	28	51	6	25	24	B	-	-	28	34	6	4	0
9	30	21	4	25	34	B	30	34	-	-	4	5	0
10	35	95	1	34	34	A	-	-	35	36	1	1	0

Customer time Spent in s/m = TSE - AT

Idle time of server = TSB(n) - TSE(n-1)

Customer time waiting in queue = TSB - AT

6. Consider Able Baker Dist. table, IAT having equal probability ratio 1 to 6 min apart.
- * Able Service Time have equal probability ratio 1-5 min
 Baker Service Time have equal probability ratio 1-4 min.
 Random Digit for time b/w arrival :
 62 89 9 62 24 47 8 86 22
- Random Digit for Service Time :
 59 12 15 29 28 83 13 16 5 94
- Able is faster than Baker.

i) Determine IAT Distribution Table

C.No	P	CP	RDA
1	0.16	0.16	01-16
2	0.16	0.32	17-32
3	0.16	0.48	33-48
4	0.16	0.64	49-64
5	0.16	0.80	65-80
6	0.16	0.96	81-96

ii) Compute Arrival Time from IAT Dist. Table

C.No	RD	IAT	AT
1	-	-	0
2	62	4	4
3	89	6	10
4	9	1	11
5	62	4	15
6	24	2	17
7	47	3	20
8	8	1	21
9	86	6	27
10	22	2	29

Distribution Table

S.No	P	CP	RDA
1	0.20	0.20	01-20
2	0.20	0.40	21-40
3	0.20	0.60	41-60
4	0.20	0.80	61-80
5	0.20	1.00	81-00

Distribution Tabu

S.No	P	CP	RDA
1	0.25	0.25	01-25
2	0.25	0.50	26-50
3	0.25	0.75	51-75
4	0.25	1.00	76-00

v) Simulation Table for 10 customers

C.No	AT	RD of service	ST	When Table is Available	When Baker is Available	Server Chooser	Table		Baker		Cust. spent in s/m	Idle time of servers	Cust. time wait in queue
							TSB	TSE	TSB	TSE			
1	0	59	3	0	0	A	0	3	-	-	3	0	0
2	4	12	1	3	0	A	4	5	-	-	1	1	0
3	10	15	1	5	0	A	10	11	-	-	1	5	0
4	11	29	2	11	0	A	11	13	-	-	2	0	0
5	15	98	15	13	0	A	15	20	-	-	2	2	0
6	17	83	4	20	0	B	-	-	17	21	2	17	0
7	20	13	1	20	21	B	20	21	-	-	1	0	0
8	21	16	1	21	21	A	21	22	-	-	1	0	0
9	27	5	1	22	21	A	27	28	-	-	2	5	0
10	29	94	5	28	21	A	29	34	-	-	5	1	0

7. Develop a simulation table for Able & Baker problem.

Inter Arrival Times : 3 2 1 5 4 6

Service Time (Able) : 3 5 2 6 2 1 7

Service Time (Baker) : 2 1 4 5 7 6 2

Able is much faster than Baker

i) Compute AT from IAT

C. NO	IAT	AT
1	-	0
2	3	3
3	2	5
4	1	6
5	5	11
6	4	15
7	6	21

ii) Simulation Table for 7 customers

C.No	AT	ST	When Able is Available	When Baker is Available	Server chosen	Able		Baker		Cust. spent in s/m	Idle time of Server	Cust. time wait index
						TSB	TSE	TSB	TSE			
1	0	3	0	0	A	0	3	-	-	0	0	3
2	3	5	3	0	A	3	8	-	-	0	0	5
3	5	4	8	0	B	-	-	5	9	0	5	4
4	6	6	8	9	A	8	14	-	-	2	0	8
5	11	7	14	9	B	-	-	11	18	0	2	7
6	15	1	14	18	A	15	16	-	-	0	1	1
7	21	7	16	18	A	21	28	-	-	0	5	7

⑨ having equal probability ratio 1 to 7 min apart.

Service Time for Able :

ST : 1 2 3 4 5

Prob : 0.20 0.10 0.30 0.20 0.20

Service Time for Baker :

ST : 1 2 3 4 5

Prob. : 0.10 0.20 0.20 0.30 0.20

Random Visit for Arrival : 95 60 35 40 52 54 10

Random visit for Service : 60 95 35 40 24 54 10 25

Baker is faster than Able.

i) Determine Inter Arrival

Distribution Table.

C.No	P	CP	RDA
1	0.14	0.14	01-14
2	0.14	0.28	15-28
3	0.14	0.42	29-42
4	0.14	0.56	43-56
5	0.14	0.70	57-70
6	0.14	0.84	71-84
7	0.14	0.98	85-98

ii) Compute AT from IADT.

C.No	RD	IAT	AT
1	-	-	0
2	95	7	7
3	60	5	12
4	35	3	15
5	40	3	18
6	52	4	22
7	54	4	26
8	10	1	27

iii) Determine Able Service Time Distribution Table

S.No	P	CP	RDA
1	0.20	0.20	01-20
2	0.10	0.30	21-30
3	0.30	0.60	31-60
4	0.20	0.80	61-80
5	0.20	1.00	81-00

iv) Determine Baker Service Time Distribution Table

S.No	P	CP	RDA
1	0.10	0.10	1-10
2	0.20	0.30	11-30
3	0.20	0.50	31-50
4	0.30	0.80	51-80
5	0.20	1.00	81-00

v) Simulation Table for 8 customers.

C.No	Arrival Time	RD of Service	Service Time	When Able is Available	When Baker is Available	Server Chosen	Able		Baker		Cust. Spent in S/m	Idle Server Time	Cust. W in que
							TSB	TSE	TSB	TSE			
1	0	60	4	0	0	B	-	-	0	4	4	0	0
2	7	95	5	0	4	B	-	-	7	12	5	3	0
3	12	35	3	0	12	B	-	-	12	15	3	0	0
4	15	40	3	0	15	B	-	-	15	18	3	0	0
5	18	24	2	0	18	B	-	-	18	20	2	0	0
6	22	54	4	0	20	B	-	-	22	26	4	2	0
7	26	10	1	0	26	B	-	-	26	27	1	0	0
8	27	25	2	0	27	B	-	-	27	29	2	0	0

General Principles

1. Discrete-event simulation

- The basic building blocks of all discrete-event simulation models: entities and attributes, activities and events.
- A system is modeled in terms of
 - Its state at each point in time
 - The entities that pass through the system and the entities that represent system resources
 - The activities and events that cause system state to change.
- Discrete-event models are appropriate for those systems for which changes in system state occur only at discrete points in time.
- This chapter deals exclusively with dynamic, stochastic systems (i.e., involving time and containing random elements) which change in a discrete manner.

Concepts in Discrete-Event Simulation(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 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.

The Event-Scheduling/Time-Advance Algorithm

- The mechanism for advancing simulation time and guaranteeing that all events occur in correct chronological order is based on the future event list (FEL).
- **Future Event List (FEL)**
 - To contain all event notices for events that have been scheduled to occur at a future time.
 - To be ordered by event time, meaning that the events are arranged chronologically; that is, the event times satisfy.
 - Scheduling a future event means that at the instant an activity begins, its duration is computed or drawn as a sample from a statistical distribution and the end-activity event, together with its event time, is placed on the future event list.

The sequence of actions which a simulator must perform to advance the clock system snapshot is called **the event-scheduling/time-advance algorithm**.

The system snapshot at time t=0 and t=t1 (VIP VTU question)

ClK	System State	Future Event List	
T	(5,1,6)	(3, t1)— Type 3 event to occur at timet1 (1, t2)— Type 1 event to occur at time t2 (1, t3)- Type 1 event to occur at time t3 (2, tn)—Type 2 event to occur at time tn	

Event-scheduling/time-advance algorithm

Step 1. Remove the event notice for the imminent event
(event 3, time t1) from FEL

Step 2. Advance CLOCK to imminent event time
(i.e., advance CLOCK from r to t1).

Step 3. Execute imminent event: update system state, change entity attributes, and set membership as needed

Step 4. Generate future events (if necessary) and place their event notices on PEL ranked by event time.

(Example: Event 4 to occur at time t^* , where $t_2 < t^* < t_3$.)

Step 5. Update cumulative statistics and counters.

New system snapshot at time t_1

OCK	System	Future Event List	
T1	(5,1,5)	(1, t_2)— Type 1 event to occur at time t_1 (4, t^*)— Type 4 event to occur at time t^* (1, t_3)— Type 1 event to occur at time t_3 (2, t_n)— Type 2 event to occur at time t_n	

2. Manual Simulation Using Event Scheduling

In an event-scheduling simulation, a simulation table is used to record the successive system snapshots as time advances.

Let us consider the example of a grocery shop which has only one checkout counter. ([Single-Channel Queue](#))

The system consists of those customers in the waiting line plus the one (if any) checking out. The model has the following components:

System state ($LQ(t)$, $LS(t)$), where $LQ(t)$ is the number of customers in the waiting line, and $LS(t)$ is the number being served (0 or 1) at time t .

Entities: The server and customers are not explicitly modeled, except in terms of the state variables above.

Events

Arrival(A)

Departure(D)

Stopping event (E), scheduled to occur at time 60.

Event notices

(A, t). Representing an arrival event to occur at future time t

(D, t), representing a customer departure at future time t

(E, 60), representing the simulation-stop event at future time 60

Activities

Interarrival time, Service time,

Delay Customer time spent in waiting line.

In this model, the FEL will always contain either two or three event notices.

Flow Chart for execution of arrival and departure event using time advance /Event scheduling algorithm (vtu Question)

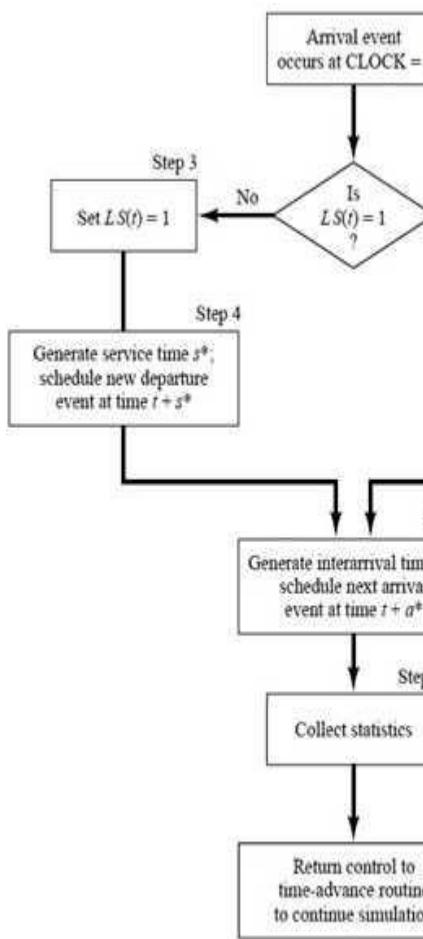


Figure Execution of the arrival event.

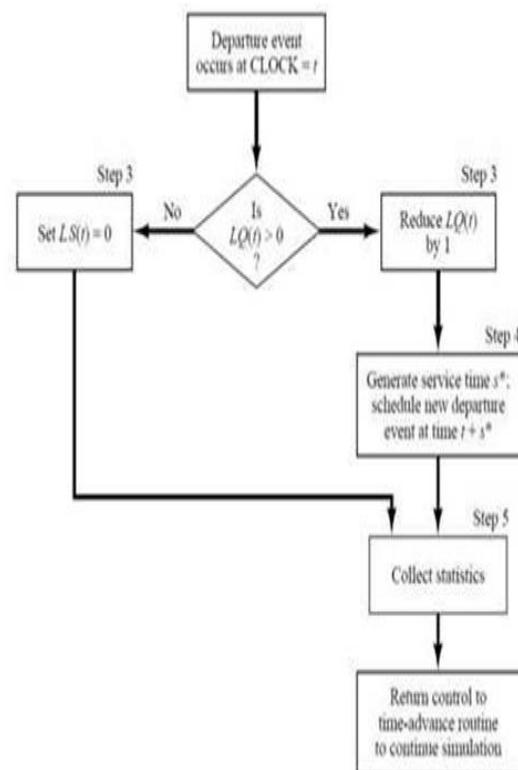


Figure Execution of the departure event.

Question Bank

1. When the simulation is appropriate tool & when it is not.
2. Advantages & disadvantages of simulation.
3. Components of systems & model and its types.
4. Steps in simulation study.
5. Examples (single server channel queue refer 2015, 2014, 2013 question paper, & class problem).
6. Examples Able & Baker's call center problem (two channel server problem)
7. Explain the terms used in discrete event simulation with an example (Ex. Able & Baker)
8. Explain the event scheduling algorithm by generating system snapshots at clock = t and clock = t1.
9. Explain the event scheduling algorithm with an example (single-channel-queue – execution of arrival event & execution of departure event).

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UNIT-2 [NOTE: Check out time column should be included in prob. No 1 to 5. It is included in prob. 6 to 8.]

Problems on Event Scheduling / Time advanced Algorithm

1. Prepare a simulation table for 1 channel queuing S/m using ES/TA algorithm. Stopping event is at 30.

IAT : 8 6 1 8 2 8 LQ → Load Queue
 ST : 4 1 4 3 2 4 LS → Load Service

Step 1 : Compute Departure Time

C.No	Inter Arrival Time	Arrival Time	Service Time	Departure Time
1	-	0	4	4
2	8	8	1	9 (8+1)
3	6	14	4	18 (14+4)
4	1	15	3	21 (18+3)
5	8	23	2	25 (23+2)
6	2	25	4	29 (25+4)
7	8	33	-	-

Step 2 : Simulation Table for 6 customers

Event Type	Clock	System State		Future Event List	Cumulative Statistics	
		LQ(E)	LS(E)		Busy	Maximum Queue
A ₁	0	0	1	(D, 4) (A, 8) (E, 30)	0	0
D ₁	4	0	0	(A, 8) (D, 9) (E, 30)	4	0
A ₂	8	0	1	(D, 9) (A, 14) (E, 30)	4	0
D ₂	9	0	0	(A, 14) (D, 18) (E, 30)	5	0
A ₃	14	0	1	(A, 15) (D, 18) (E, 30)	5	0
A ₄	15	1	1	(D, 18) (A, 23) (E, 30)	6	1
D ₃	18	0	1	(D, 21) (A, 23) (E, 30)	9	1
D ₄	21	0	0	(A, 23) (D, 25) (E, 30)	12	1
A ₅	25	0	1	(D, 25) (A, 25) (E, 30)	12	1

A_6/D_5	25	0	1	(A, 33) (D, 29) (E, 30)	14	1
D_6	29	0	0	(E, 30) (A, 33)	14	1
D_6	29	0	0	(E, 30)	18	1

2. Stopping Time = 30

IAT : 2 4 3 1 2 5 6

ST : 4 3 2 5 2 1

i] Compute Departure Time

C.No	IAT	AT	ST	DT
1	-	0	4	4
2	2	2	3	7
3	4	6	2	9
4	3	9	5	14
5	1	10	2	16
6	2	12	1	17
7	5	17	-	-
8	6	23	-	-

ii] Simulation Table for 6 customers

Event Type	Clock	System State		Future Event List	CS	
		LQ(t)	LS(t)		B	MQ
A_1	0	0	1	(A, 2) (D, 4) (E, 30)	0	0
A_2	2	1	1	(D, 4) (A, 6) (E, 30)	2	1
D_1	4	0	1	(A, 6) (D, 7) (E, 30)	4	1
A_3	6	1	1	(D, 7) (A, 9) (E, 30)	6	1
D_2	7	0	1	(A, 9) (D, 9) (E, 30)	7	1
A_4/D_3	9	0	1	(A, 10) (D, 14) (E, 30)	9	1
E	*	*	*	(A, 10) (D, 14) (E, 30)	*	*

②

A ₆	12	2	1	(D, 14) (A, 17) (E, 30)	12	2
D ₄	14	1	1	(A, 17) (D, 16) (E, 30)	14	2
D ₅	16	1	1	(A, 17) (D, 17) (E, 30)	16	2
A ₇ /D ₆	17	0	1	(A, 23) (E, 30)	17	2

3. Stopping Time = 60

IAT : 1 1 6 3 7 5 2 4 1

ST : 4 2 5 4 1 5 4 1 4

i] Compute Departure Time

C. No	IAT	AT	ST	DT
1	-	0	4	4
2	1	1	2	6
3	1	2	5	11
4	6	8	4	15
5	3	11	1	16
6	7	18	5	23
7	5	23	4	27
8	2	25	1	28
9	4	29	4	33
10	1	-	-	-

ii] Simulation Table for 9 customers

Event Type	Clock	S/m State		Future Event List	CS	
		LQ(t)	LS(t)		B	MQ
A ₁	0	0	1	(A, 1) (D, 4) (E, 60)	0	0
A ₂	1	1	1	(A, 2) (D, 4) (E, 60)	1	1
A ₃	2	2	1	(D, 4) (A, 8) (E, 60)	2	2
D ₁	4	1	1	(D, 6) (A, 8) (E, 60)	4	2
D ₂	6	0	1	(A, 8) (D, 11) (E, 60)	6	2
A ₄	8	1	1	(A, 11) (D, 11) (E, 60)	8	2

D_3/A_5	11	1	1	(D, 15) (A, 18) (E, 60)	11	2
D_3	11	1	1	(D, 15) (A, 18) (E, 60)	11	2
D_4	15	0	1	(D, 16) (A, 18) (E, 60)	15	2
D_5	16	0	0	(A, 18) (D, 23) (E, 60)	16	2
A_6	18	0	1	(D, 23) (A, 23) (E, 60)	16	2
D_6	23	0	1	(A, 23) (D, 27) (E, 60)	21	2
A_7	23	0	1	(D, 27) (A, 25) (E, 60)	21	2
A_8	25	1	1	(D, 27) (A, 29) (E, 60)	23	2
D_7	27	0	1	(A, 29) (A, 28) (E, 60)	25	2
D_8	28	0	0	(A, 29) (D, 33) (E, 60)	26	2
A_9	29	0	1	(D, 33) (E, 60)	26	2
D_9	33	0	0	(E, 60)	30	2

4. Prepare a simulation table using ES/TA algorithm until the clock reaches time 23 using IAT & ST given :

Stopping Time is 30.

IAT : 5 1 2 3 4 9 5 8 6 1

ST : 4 7 8 1 4 2 5 3 1 4

i) Compute Departure Time

C. No	IAT	AT	ST	DT
1	-	0	4	4
2	5	5	7	12
3	1	6	8	20
4	2	8	1	21
5	3	11	4	25
6	4	15	2	27
7	9	24	5	32
8	5	29	3	35

C. No	IAT	AT	ST	DT
9	8	37	1	38
10	6	43	4	47
11	1	-	-	-

③ ii) Simulation Table for 9 customers.

Event Type	Clock	S/m State		Future Event List	CS	
		LQ(t)	LS(t)		B	MQ
A ₁	0	0	1	(A, 1) (D, 4)	0	0
A ₂	1	1	1	(D, 4) (A, 7)	1	1
D ₁	4	0	1	(D, 6) (A, 7)	4	1
D ₂	6	0	0	(A, 7) (D, 12)	6	1
A ₃	7	0	1	(A, 8) (D, 12)	6	1
A ₄	8	1	1	(A, 11) (D, 12)	7	1
A ₅	11	2	1	(D, 12) (A, 16)	10	2
D ₃	12	1	1	(A, 16) (D, 17)	11	2
A ₆	16	2	1	(D, 17) (A, 23)	15	2
D ₄	17	1	1	(D, 18) (A, 23)	16	2
D ₅	18	0	1	(D, 22) (A, 23)	17	2
D ₆	22	0	0	(A, 23) (D, 27)	21	2
A ₇	23	0	1	(A, 24) (D, 27)	21	2
A ₈	24	1	1	(D, 27) (A, 28)	22	2
D ₇	27	0	1	(A, 28) (D, 31)	25	2
A ₉	28	1	1	(D, 31) (D, 32)	26	2
D ₈	31	0	1	(D, 32)	29	2
D ₉	32	1	0	-	30	2

S → Customer who taken response time from system

N_D → No. of customer departed

F → Customer who spent more than given time (Eg: 4 min)

s = Response Time + Current Departure

Response Time = Clock - Current Arrival

iii) Simulation Table

Event Type	Clock	Sim State		Future Event List	CS	
		LQ(t)	LS(t)		B	MQ
A ₁	0	0	1	(D, 4) (A, 5) (E, 30)	0	0
D ₁	4	0	0	(A, 5) (D, 12) (E, 30)	4	0
A ₂	5	0	1	(A, 6) (D, 12) (E, 30)	4	0
A ₃	6	1	1	(A, 8) (D, 12) (E, 30)	5	1
A ₄	8	2	1	(A, 11) (D, 12) (E, 30)	7	2
A ₅	11	3	1	(D, 12) (A, 15) (E, 30)	10	3
D ₂	12	2	1	(A, 15) (D, 20) (E, 30)	11	3
A ₆	15	3	1	(D, 20) (A, 24) (E, 30)	14	3
D ₃	20	2	1	(D, 21) (A, 24) (E, 30)	19	3
D ₄	21	1	1	(A, 24) (D, 25) (E, 30)	20	3

5. Prepare a simulation table using Time Advanced Algorithm :

IAT : 1 6 1 3 5 7 1 4

ST : 4 2 5 5 1 4 4 4 1

i) Compute Departure Time

C. No	IAT	AT	ST	DT
1	-	0	4	4
2	1	1	2	6
3	6	7	5	12
4	1	8	5	17
5	3	11	1	18
6	5	16	4	22
7	7	23	4	27
8	1	24	4	31
9	4	28	1	32

6. Prepare a simulation table using Time advanced algorithm

(4) with IAT : 1 1 8 6 8
ST : 4 2 3 4 1 2

Find customers who spent more than 4 min.

i) Compute Departure Time

C. No	IAT	AT	ST	DT
1	-	0	4	4
2	1	1	2	6
3	1	2	3	9
4	8	10	4	14
5	6	16	1	17
6	8	24	2	26

ii) Simulation table of 6 customers.

Event type	Clock	S/m state		Check out time	Future Event list	CS				
		LQ(t)	LS(t)			S	N _D	F	B	MQ
A ₁	0	0	1	(C ₁ , 0)	(A, 1) (D, 4)	0	0	0	0	0
A ₂	1	1	1	(C ₁ , 0) (C ₂ , 1)	(A, 2) (D, 4)	0	0	0	1	1
A ₃	2	2	1	(C ₁ , 0) (C ₂ , 1) (C ₃ , 2)	(D, 4) (A, 10)	0	0	0	2	2
D ₁	4	1	1	(C ₂ , 1) (C ₃ , 2)	(D, 6) (A, 10)	4	1	0	4	2
D ₂	6	0	1	(C ₃ , 2)	(D, 9) (A, 10)	9	2	1	6	2
D ₃	9	0	0	-	(A, 10) (D, 14)	16	3	2	9	2
A ₄	10	0	1	(C ₄ , 10)	(D, 14) (A, 16)	16	3	2	9	2
D ₄	14	0	0	-	(A, 16) (D, 17)	20	4	2	13	2
A ₅	16	0	1	(C ₅ , 16)	(D, 17) (A, 24)	20	4	2	13	2
D ₅	17	0	0	-	(A, 24) (D, 26)	21	5	2	14	2
A ₆	24	0	1	(C ₆ , 24)	(D, 26)	21	5	2	14	2
D ₆	26	0	0	-	-	23	6	2	16	2

7. Consider single server queue with one checkout counter using ES/TA algorithm

IAT : 4 2 8 1 8 3 6 8

ST : 4 6 5 2 3 4 4 1

Find the no. of customers who spent 4 or more min in the system. Stopping time = 32

i) Compute Arrival & Departure time

C.No	IAT	AT	ST	DT
1	-	0	4	4
2	4	4	6	10
3	2	6	5	15
4	8	14	2	17
5	1	15	3	20
6	8	23	4	27
7	3	26	4	31
8	6	32	1	33
9	8	40	-	-

ii) Simulation table

Event type	Clock	Sim state		Checkout time	Future Event List	CS				
		LQ(t)	LS(t)			S	N _D	F	B	M _Q
A ₁	0	0	1	(C ₁ , 1)	(A, 4) (D, 4) (E, 32)	0	0	0	0	0
D ₁ /A ₂	4	0	1	(C ₂ , 4)	(A, 6) (D, 10) (E, 32)	4	1	1	4	0
A ₃	6	1	1	(C ₂ , 4) (C ₃ , 6)	(D, 10) (A, 14) (E, 32)	4	1	1	6	1
D ₂	10	0	1	(C ₃ , 6)	(A, 14) (D, 15) (E, 32)	10	2	2	10	1
A ₄	14	1	1	(C ₃ , 6) (C ₄ , 14)	(A, 15) (D, 15) (E, 32)	10	2	2	14	1
A ₅ /D ₃	15	1	1	(C ₄ , 14) (C ₅ , 15)	(D, 17) (A, 23) (E, 32)	19	3	3	15	1
D ₄	17	0	1	(C ₅ , 15)	(D, 20) (A, 23) (E, 32)	22	4	3	17	1
D ₅	20	0	0	-	(A, 23) (D, 27) (E, 32)	27	5	4	20	1
A ₆	23	0	1	(C ₆ , 23)	(A, 26) (D, 27) (E, 32)	27	5	4	20	1

(5)

D ₆	27	0	1	(C ₇ , 26)	(D, 31) (A, 32) (E, 32)	31	6	5	24	1
D ₇	31	0	0	-	(A, 32) (D, 33) (E, 32)	36	7	6	28	1
A ₈	32	0	1	(C ₈ , 32)	(A, 40) (D, 33) (E, 32)	36	7	6	28	1

8. Develop a simulation table for single server queue with one check out counter using TA algorithm. Find busy time of server, maximum queue length, Total no. of customer who spent 3 min or more in system, Total number of departure.

IAT : 1 6 8 8 3 8 4 2 8

ST : 4 1 4 4 2 3 5 6 4

i) Compute Arrival and Departure time

C.No	IAT	AT	ST	DT
1	-	0	4	4
2	1	1	1	5
3	6	7	4	11
4	8	15	4	19
5	8	23	2	25
6	3	26	3	29
7	8	34	5	39
8	4	38	6	45
9	2	40	4	49
10	8	48	-	-

Event type	Clock	S/m state		Check Out Time	Future Event List	CS				
		LQ(t)	LS(t)			S	N _D	F	B	MQ
A ₁	0	0	1	(C ₁ , 0)	(A, 1) (D, 4)	0	0	0	0	0
A ₂	1	1	1	(C ₁ , 0) (C ₂ , 1)	(A, 7) (D, 4)	0	0	0	1	1
D ₁	4	0	1	(C ₂ , 1)	(A, 7) (D, 5)	4	1	1	4	1
D ₂	5	0	0	-	(A, 7) (D, 11)	8	2	2	5	1
A ₃	7	0	1	(C ₃ , 7)	(A, 15) (D, 11)	8	2	2	5	1
D ₃	11	0	0	-	(A, 15) (D, 19)	12	3	3	9	1
A ₄	15	0	1	(C ₄ , 15)	(D, 19) (A, 23)	12	3	3	9	1
D ₄	19	0	0	-	(A, 23) (D, 25)	16	4	4	13	1
A ₅	23	0	1	(C ₅ , 23)	(D, 25) (A, 26)	16	4	4	13	1
D ₅	25	0	0	-	(A, 26) (D, 29)	18	5	4	15	1
A ₆	26	0	1	(C ₆ , 26)	(D, 29) (A, 34)	21	6	5	18	1
D ₆	29	0	0	-	(A, 34) (D, 39)	21	6	5	18	1
A ₇	34	0	1	(C ₇ , 34)	(A, 38) (D, 39)	21	6	5	22	1
A ₈	38	1	1	(C ₇ , 34) (C ₈ , 38)	(D, 39) (A, 40)	21	6	5	22	1
D ₇	39	0	1	(C ₈ , 38)	(A, 40) (D, 45)	26	7	6	23	1
A ₉	40	1	1	(C ₆ , 38) (C ₉ , 40)	(A, 40) (D, 45)	26	7	6	24	1
D ₈	45	0	1	(C ₉ , 40)	(D, 45) (D, 49)	33	8	7	29	1
	*	*	*	(C ₉ , 40) (C ₁₀ , 48)	(D, 49)	*	*	*	*	*
D ₉	49	0	0	(C ₁₀ , 48)	-	42	9	8	33	1

Busy time of server = 33 min

Maximum Queue Length = 1

Total no. of customer who spent 3 or more in System = 8

Total no. of departure = 9

Travel Times as given below: Consider stopping time 32 clock cycle.
 Q) The stopping event will be completion of 2 weighings (2 AQ₁₆)

Loading Times	5	15	10	15	15	10	5
Weighing Times	17	15	15	15	15	15	12
Travel Times	40	60	60	60	80		

Solution:

Simulation table for Dump-truck Operation.

Clock t	System State				Lists		Future Event List	Cumulative statistics	
	LQ(t)	L(t)	WQ(t)	W(t)	Loader Queue	Weight Queue		B _L	B _S
0	4	2	0	1	DT ₄ DT ₅ DT ₆ DT ₇	-	(EL, 5, DT ₂)* (EL, 15, DT ₃) (EW, 17, DT ₁)	0	0
5	3	2	1	1	DT ₅ DT ₆ DT ₇	DT ₂	(EL, 15, DT ₃)* (EW, 17, DT ₁) (EL, 15, DT ₄) (S-0)*20 (5-0)*0	10	5
15	2	2	2	1	DT ₆ DT ₇	DT ₂ DT ₃	(EW, 17, DT ₁) (EL, 15, DT ₄)* (EL, 30, DT ₅) (S-5)*2 (15-5)+5 +10	30	15
15	1	2	3	1	DT ₇	DT ₂ DT ₃ DT ₄	(EW, 17, DT ₁)* (EL, 30, DT ₅) (EL, 30, DT ₆)	30	15
17	1	2	2	1	DT ₇	DT ₃ DT ₄	(EL, 30, DT ₅)* (EL, 30, DT ₆) (AQ ₁₆ , 57, DT ₁) ⁽¹⁷⁺⁴⁰⁾ (EW, 32, DT ₂) ⁽¹⁷⁺¹⁵⁾	34	17
30	0	2	3	1	-	DT ₃ DT ₄ DT ₅	(EL, 30, DT ₆)* (AQ ₁₆ , 57, DT ₁) (EW, 32, DT ₂) (EL, 40, DT ₇)	60	30
30	0	1	4	1	-	DT ₃ DT ₄ DT ₅ DT ₆	(AQ ₁₆ , 57, DT ₁) (EW, 32, DT ₂)* (EL, 40, DT ₇)	60	30
32	0	1	3	1	-	DT ₄ DT ₅ DT ₆	(AQ ₁₆ , 57, DT ₁) (EL, 40, DT ₇) (AQ ₁₆ , 92, DT ₂) (EW, 47, DT ₃)	62	32

2. Consider 6 Dump-trucks with loading times, weighing time & Traveling times are given below,

Loading Times	5	5	10	15	20	5	5
Weighing Times	12	15	20	12	15	15	
Travel Time	40	60	30	80			

- Until Clock cycle 52
- Calculate
 - Avg loader utilization
 - Avg scale utilization.

Solution:

Simulation table for Dump truck operations.

Clock t	System State				Lists		Future Event List	Cumulative Statistics	
	LQ(t)	L(t)	WQ(t)	WT(t)	Loader queue	Weigh queue		B_L	B_S
0	3	2	0	1	DT4 DT5 DT6	-	(EL, 5, DT ₂) (EL, 5, DT ₃) (EW, 12, DT ₁)	0	0
5	2	2	1	1	DT5 DT6	DT ₂	(EL, 5, DT ₃) (EW, 12, DT ₁) (EL, 15, DT ₄)	10	5
5	1	2	2	1	DT6	DT ₂ DT ₃	(EW, 12, DT ₁) (EL, 15, DT ₄) (EL, 20, DT ₅)	10	5
12	1	2	1	1	DT6	DT ₃	(EL, 15, DT ₄) (EL, 20, DT ₅) (AQ _L , 52, DT ₁) (EW, 27, DT ₂)	24	12
15	0	2	2	1	-	DT ₃ DT ₄	(EL, 20, DT ₅) (AQ _L , 52, DT ₁) (EW, 27, DT ₂) (EL, 35, DT ₆)	30	15
20	0	1	3	1	-	DT ₃ DT ₄ DT ₅	(AQ _L , 52, DT ₁) (EW, 27, DT ₂) (EL, 35, DT ₆)	40	20
27	0	1	2	1	-	DT ₄ DT ₅	(AQ _L , 52, DT ₁) (EL, 35, DT ₆) (AQ _L , 87, DT ₂) (EW, 47, DT ₃)	47	27
35	0	0	3	1	-	DT ₄ DT ₅ DT ₆	(AQ _L , 52, DT ₁) (AQ _L , 87, DT ₂) (EW, 47, DT ₃)	55	35

Clock t	System State				Lists		Future Event List	Cumulative Statistics	
	LQ(t)	LC(t)	WQ(t)	WC(t)	Loaders queue	weigh queue		B _L	B _S
47	0	0	2	1	-	DT ₅ DT ₆	(AQL, 52, DT ₁) * (AQL, 87, DT ₂) (AQL, 67, DT ₃) (EW, 59, DT ₄)	55	47
52	0	1	2	1	-	DT ₅ DT ₆	(AQL, 87, DT ₂) (AQL, 67, DT ₃) (EL, 57, DT ₁) [S2+5] (EW, 59, DT ₄)	55	52

i) Average Loader Utilization = $\frac{55/2}{52} = 0.529$

ii) Average Scale Utilization = $\frac{62}{52} = 1.00$

3. Consider Loading Times, weighing Times & Travel times of 6 Dump trucks. Loading Times & weighing Times are based on FIFO, until clock cycle 60 entire system runs for 1 hour. estimation time is 60 mins.

Loading Times	10	10	15	5	10	5
weighing Times	10	15	5	10	10	
Travel Times	40	60	80	100		

* if all the trucks have equal value use FIFO method.

Solution:

Simulation table for Dump-truck operation.

Clock t	System State				Lists		Future event List	Cumulative Statistics	
	LQ(t)	LC(t)	WQ(t)	WC(t)	Loaders queue	weigh queue		B _L	B _S
0	3	2	0	1	DT ₄ DT ₅ DT ₆	-	(EL, 10, DT ₂) (EL, 10, DT ₃) (EW, 10, DT ₁) *	0	0
10	2	2	0	1	DT ₅ DT ₆	-	(EL, 10, DT ₃) * (AQL, 50, DT ₁) [10+10] (EW, 25, DT ₂) [10+15] (EL, 25, DT ₄) [0+15]	20	10
10	1	2	1	1	DT ₆	DT ₃	(AQL, 50, DT ₁) (EW, 25, DT ₂) (EL, 25, DT ₄) (EL, 15, DT ₅) [0+15]	20	10

Clock t	System State				Lests		Future Event List	Cumulative Statistics	
	LQ(t)	L(t)	WQ(t)	WT(t)	Loaders Queue	Writers Queue		B_L	B_S
15	0	2	2	1	-	DT ₃ DT ₅	(AQL, 50, DT ₁) (EW, 25, DT ₂) (EL, 25, DT ₄) (EL, 25, DT ₆)	30	15
25	0	2	1	1	-	DT ₅	(AQL, 50, DT ₁) (EL, 25, DT ₄) (EL, 25, DT ₆) (AQL, 85, DT ₂) (EW, 30, DT ₃)	50	25
25	0	1	2	1	-	DT ₅ DT ₄	(AQL, 50, DT ₁) (EL, 25, DT ₆) (AQL, 85, DT ₂) (EW, 30, DT ₃)	50	25
25	0	0	3	1	-	DT ₅ DT ₄ DT ₆	(AQL, 50, DT ₁) (AQL, 85, DT ₂) (EW, 30, DT ₃) *	50	25
30	0	0	2	1	-	DT ₄ DT ₆	(AQL, 50, DT ₁) (AQL, 85, DT ₂) (AQL, 110, DT ₃) (EW, 40, DT ₅) *	50	30
40	0	0	1	1	-	DT ₆	(AQL, 50, DT ₁) (AQL, 85, DT ₂) (AQL, 110, DT ₃) (AQL, 140, DT ₅) (EW, 50, DT ₄)	50	40
50	0	1	1	1	-	DT ₆	(AQL, 85, DT ₂) (AQL, 110, DT ₃) (EL, 55, DT ₁) (EW, 50, DT ₄) *(AQL, 140, DT ₅)	50	50
50	0	1	0	1	-	-	(AQL, 85, DT ₂) (AQL, 110, DT ₃) (AQL, 140, DT ₅) (AQL, 90, DT ₄) (EW, 60, DT ₆) (EL, 55, DT ₁) *	50	50
55	0	0	1	1	-	DT ₁	(AQL, 85, DT ₂) (AQL, 110, DT ₃) (AQL, 140, DT ₅) (AQL, 90, DT ₄) (EW, 60, DT ₆) *	55	55

Clock t	System State				Lists		Future Event List	Cumulative Statistics	
	L(t)	R(t)	W(t)	W(t)	Loader Queue	Wedge Queue		B_L	B_S
60	0	0	0	1	-	-	(AQL, 85, DT ₂) (AQL, 110, DT ₃) (AQL, 140, DT ₂) (AQL, 90, DT ₄) (AQL, 120, DT ₆) (EW, 70, DT ₁)	55	60