Manual Simulation Using Event Scheduling

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

EXAMPLE 3.3 (single-channel queue)

- Reconsider the grocery store with one checkout counter that was simulated in earlier example.
- 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:

Inter-arrival time; consider previous distribution. Table (2.6)
Service time; consider previous distribution. Table (2.7)

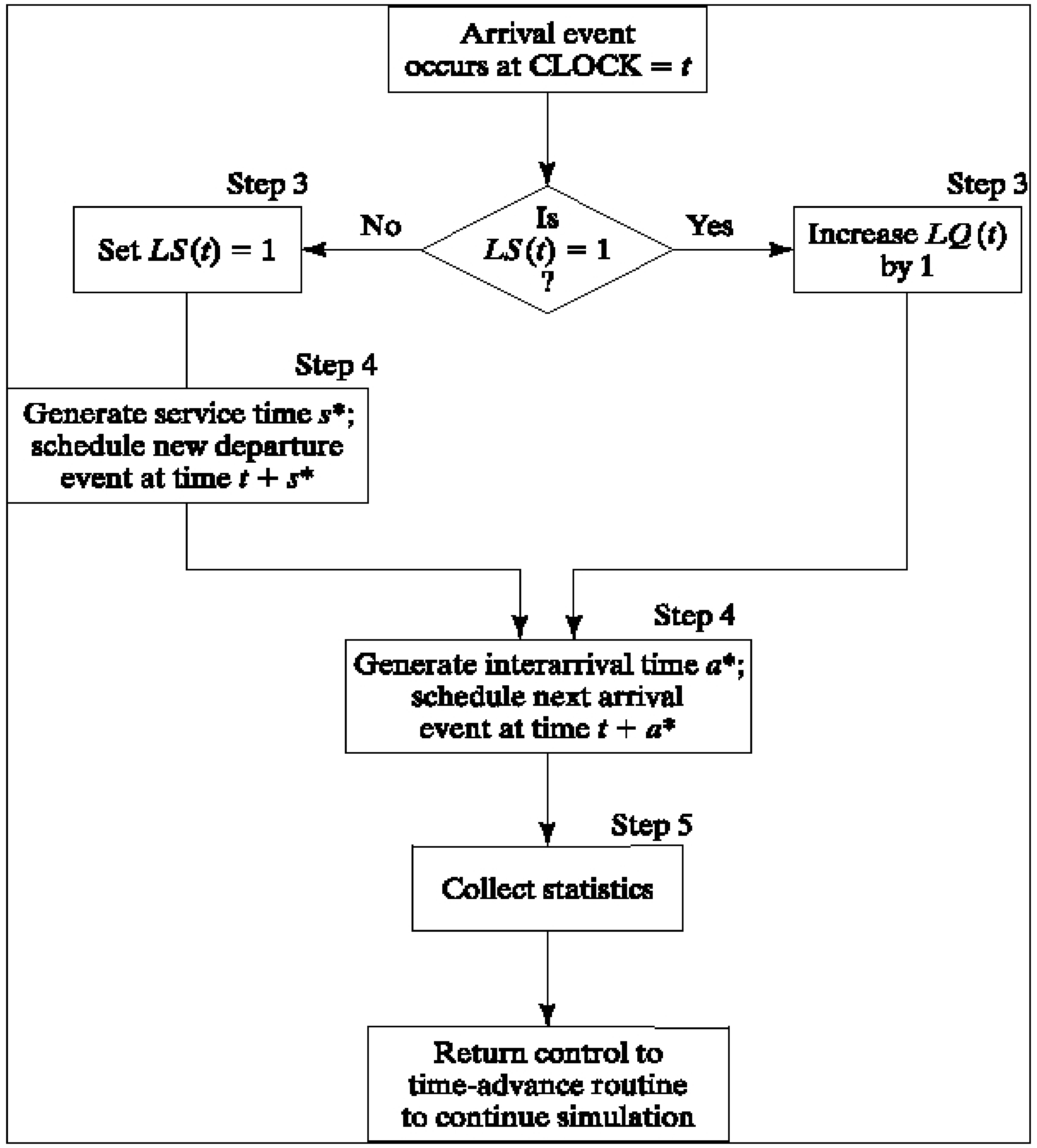
Delay: Customer time spent in waiting line

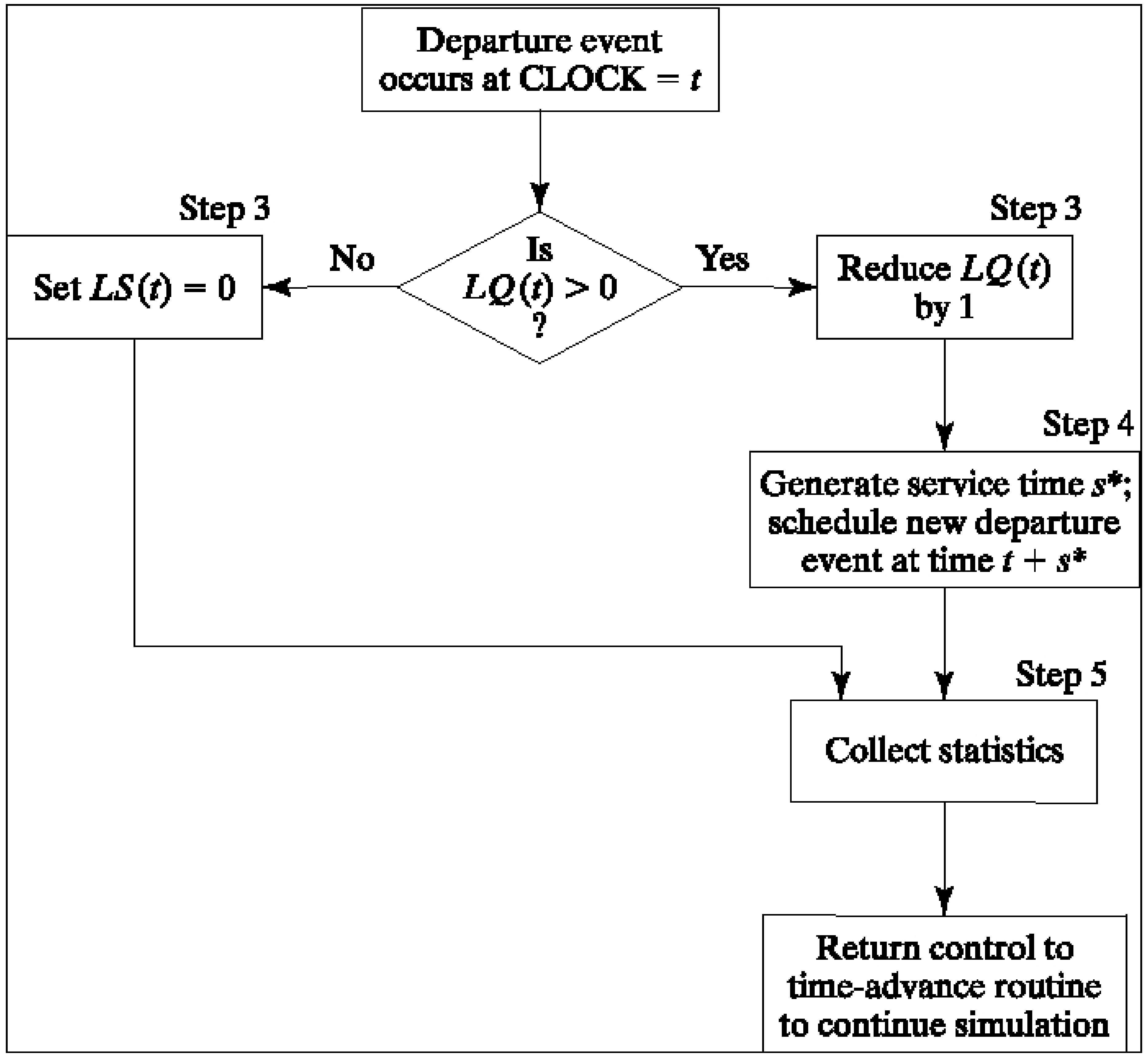
DISTRIBUTION OF TIME BETWEEN ARRIVALS

Time between Arrivals (minutes)	*Probability (occurrence of event) (equally likely to occur)*	*Cumulative Probability*	*Random digit assignment*
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

SERVICE-TIME DISTRIBUTION

Service Time (minutes)	*Probability (not equally likely to occur)*	*Cumulative Probability*	*Random digit assignment*
1	0.10	0.10	01 - 10
2	0.20	0.30	11 - 30
3	0.30	0.60	31 - 60
4	0.25	0.85	61 - 85
5	0.10	0.95	86 - 95
6	0.05	1.00	96 - 00





- The Simulation table for the checkout counter is given in the table below.
- The event notices are written as (event type, event time).
- Initial conditions are that the first customer arrives at time 0 and begins service with LQ(0)=0, LS(0)=1, and both a departure event and arrival event on the FEL
- The Simulation is scheduled to stop at time 60.
- Only two statistics, server utilization and maximum queue length, will be collected.
- Server utilization is defined by total server busy time (B) divided by total time T_E

- Total busy time, B, and maximum queue length, MQ, will be accumulated as the simulation progresses.
- A column headed "comments" is included. (a* and s* are the generated inter arrival and service times, respectively.)
- Simulation in Table covers the time interval [0,21]. The maximum queue length was one.
- At simulated time 21, the system is empty, but the next arrival will occur` at future time 23
- When an event-scheduling algorithm is computerized, only one snapshot (the current one or partially updated one) is kept in computer memory.
- A new snapshot can be derived only from the previous snapshot, newly generated random variables, and the event logic in the logic flow diagrams of arrival and departure
- Past snapshots should be ignored when advancing the clock.
- The current snapshot must contain all information necessary to continue the simulation.
- In this model, the FEL will always contain either two or three event notices.
- The inter arrival times and service times will be identical to those used in previous example:

Inter-arrival Times	0 8 6 1 8 3 8 7 2 3
Service Times	4 1 4 3 2 4 5 4 5 3

	System State				Cumulative Statistics	
Clock	LQ(t)	LS(t)	Future Event List	Comments	B	MQ
0	0	1	(D,4) (A,8) (E,60)	1st A occurs, Schedule next A & 1st D at a*=8 & s*=4	0	0
4	0	0	(A,8) (E,60)	1st D occurs	4	0
8	0	1	(D,9) (A,14) (E,60)	2nd A occurs, Schedule next a*=6,s*=1	4	0
9	0	0	(A,14) (E,60)	2nd D occurs	5	0
14	0	1	(A,15) (D,18) (E,60)	3rd A occurs, Schedule next a*=1,s*=4	5	0
15	1	1	(D,18) (A,23) (E,60)	4th A occurs, customer delayed, next a*=8	5	1
18	0	1	(D,21) (A,23) (E,60)	3rd D occurs, Schedule next s*=3	9	1
21	0	0	(A,23) (E,60)	4th D occurs	12	1

Assignment: Extend above table according to the given distributions of inter-arrival and service times

Example 3.4 (The checkout counter simulation, continued)

- Consider the simulation of the checkout counter in previous example
- Simulation analyst desires to estimate mean response time and mean proportion of customers who spend 4 or more minutes in the system.
- A response time is the length of time a customer spends in the system.
- To estimate these customer averages, it is necessary to expand the model in previous example to explicitly represent the individual customers.
- To compute an individual customer's response time when that customer departs, it will be necessary to know the customer's arrival time.
- Therefore, a customer entity with arrival time as an attribute will be added to the list of model components in previous example.
- These customer entities will be stored in a list to be called “CHECKOUT LINE"; they will be called C1, C2, C3....

- Finally, the event notices on the FEL will be expanded to indicate which customer is affected. For example, (D, 4, C1) means that customer C1 will depart at time 4.
- The additional model components are listed below:

Entities: (Ci, t), representing customer Ci who arrived at time t. (customers are explicitly defined)

Event notices:
(A, t, Ci), the arrival of customer Ci at future time t
(D, t, Cj), the departure of customer Cj at future time t

Set (Queue): "CHECKOUT LINE", the set of all customers currently at the checkout counter (being served or waiting to be served), ordered by time of arrival.

- Three new cumulative statistics will be collected:
    - S, the sum of customer response times for all customers who have departed by the current time;
    - F, the total number of customers who spend 4 or more minutes at the checkout counter, and
    - N_D the total number of departures up to the current simulation time.
- These three cumulative statistics will be updated whenever the departure event occurs.
- The CHECKOUT LINE component is needed for the computation of the cumulative statistics S, F, and N_D
- For example, at time 4 a departure event occurs for customer C1

- The customer entity (C1, 0) is removed from the list, the attribute “time of arrival” is noted to be 0, so the response time for this customer was 4 minutes
- Hence, S is incremented by 4 minutes, and F and N_D are incremented by one customer at Clock = 4
- Similarly, at time 21, the departure event (D, 21, C4) is being executed
- The response time for customer C4 is computed by:

Response time = CLOCK TIME – attribute “time of arrival”= 21-15=6 mins

- Then S is incremented by 6 minutes, and F and N_D by one customer
- The same data for inter-arrival and service times will be used again
- The simulation table for this example is shown below.
- For a simulation run length of 21 minutes, the average response time was S/N_D =15/4 = 3.75 minutes, and the observed proportion of customers who spent 4 or more minutes in the system was F/N_D = 0.75.
- No doubt, this simulation was far too short to regard these estimates with any degree of accuracy.
- The purpose of this example is to illustrate the notion that in many simulation models, the information desired from the simulation (such as the statistics S/N_D and F/N_D) determines to some extent the structure of the model.

SIMULATION TABLE

Clock	System State		List	Future Event List	Cumulative Statistics		
	LQ(t)	LS(t)	"Checkout Line"		S	N_D	F
0	0	1	(C1, 0)	(D,4,C1) (A,8,C2) (E,60)	0	0	0
4	0	0		(A,8,C2) (E,60)	4	1	1
8	0	1	(C2,8)	(D,9,C2) (A,14,C3) (E,60)	4	1	1
9	0	0		(A,14,C3) (E,60)	5	2	1
14	0	1	(C3, 14)	(A,15,C4) (D,18,C3) (E,60)	5	2	1
15	1	1	(C3, 14) (C4, 15)	(D,18,C3) (A,23,C5) (E,60)	5	2	1
18	0	1	(C4, 15)	(D,21,C4) (A,23,C5) (E,60)	9	3	2
21	0	0		(A,23,C5) (E,60)	15	4	3

Assignment: Extend above table according to the given distribution values of inter-arrival and service times.