L A B

4 BUILDING YOUR FIRST MODEL

Knowing is not enough; we must apply. Willing is not enough; we must do.
—Johann von Goethe

In this lab we build our first simulation model using ProModel. In Section L4.1 we describe some of the basic concepts of building your first ProModel simulation model. Section L4.2 introduces the concept of queue in ProModel. Section L4.3 lets us build a model with multiple locations and multiple entities. In Section L4.4 we show how to modify an existing model and add more locations to it. Finally, in Section L4.5 we show how variability in arrival time and customer service time affect the performance of the system.

L4.1 Building Your First Simulation Model

In this section we describe how you can build your very first simulation model using ProModel software. We introduce the concepts of locations, entities, entity arrivals, processes, and routing.

Customers visit the neighborhood barbershop **Fantastic Dan** for a haircut. The customer interarrival time is exponentially distributed with an average of 10 minutes. Dan (the barber) takes anywhere from 8 to 10 minutes, uniformly distributed (mean and half-width of 9 and 1 minute respectively) for each haircut. This time also includes the initial greetings and the transaction of money at the end of the haircut. Run the simulation model for one day (480 minutes). Find these answers:

a. About how many customers does Dan process per day?
b. What is the average number of customers waiting to get a haircut? What is the maximum?

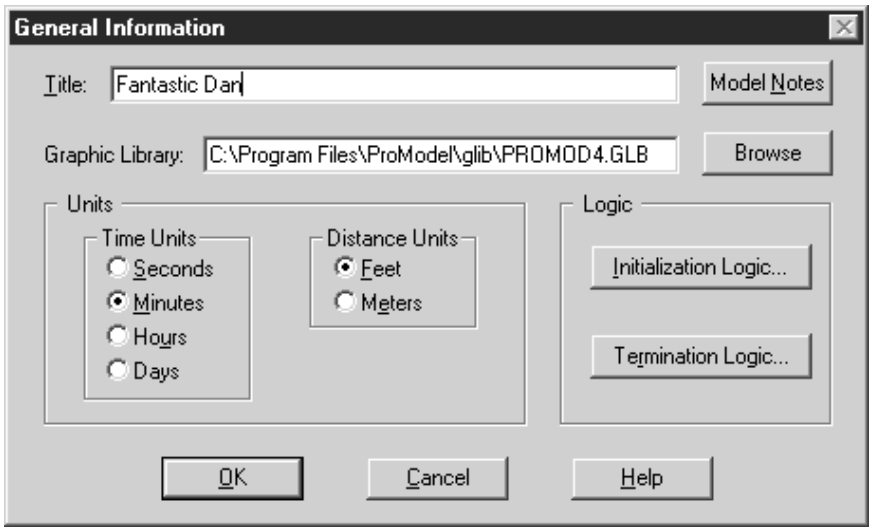


FIGURE L4.1
General Information for the Fantastic Dan simulation model.

c. What is the average time spent by a customer in the salon?

d. What is the utilization of Barber Dan?

e. What is the maximum and average number of customers waiting for a haircut?

From the menu bar select File → New. In the General Information panel (Figure L4.1) fill in the title of the simulation model as "Fantastic Dan." Fill in some of other general information about the model like the time and distance units. Click OK to proceed to define the locations.

From the menu bar select Build → Locations. Define two locations—Waiting_for_Barber and Barber_Dan (Figure L4.2). Note that the first location is actually a region (it is the icon that looks like a square box). A region is a boundary used to represent a location's area. When the model is running the region is not visible. The icon selected for the second location is actually called operator. We changed its name to Barber_Dan (Name column in the Location table).

Check off the New button on the Graphics panel (Figure L4.3) and click the button marked Aa. Click on the location icon in the Layout panel. The name of the location (Barber_Dan) appears on the location icon.

Define the entity (Figure L4.4) and change its name to Customer. Define the processes and the routings (Figures L4.5 and L4.6) the customers go through at the barbershop. All customers arrive and wait at the location Waiting_for_Barber. Then they are routed to the location Barber_Dan. At this location the barber performs the haircut, which takes an amount of time uniformly distributed between 8 and 10 minutes or Uniform (9,1). Use the step-by-step procedure detailed in section L2.2.4 to create the process and routing tables graphically.

FIGURE L4.2

Defining locations Waiting_for_Barber and BarberDan.

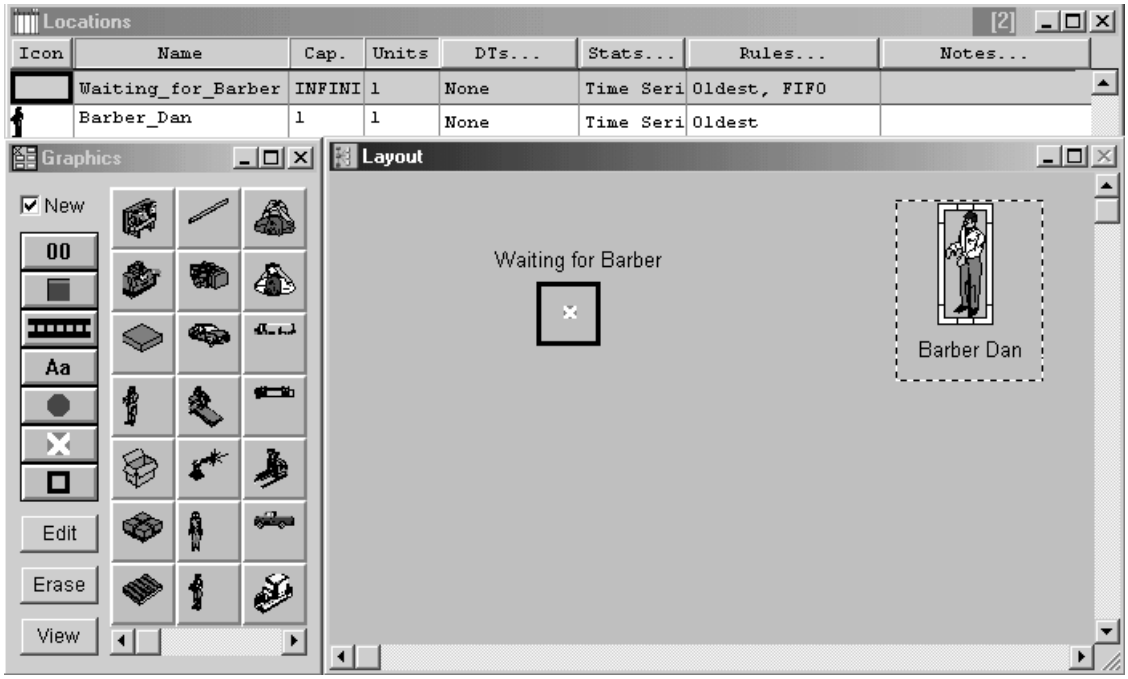


FIGURE L4.3

The Graphics panel.

FIGURE L4.4

Define the entity—Customer.

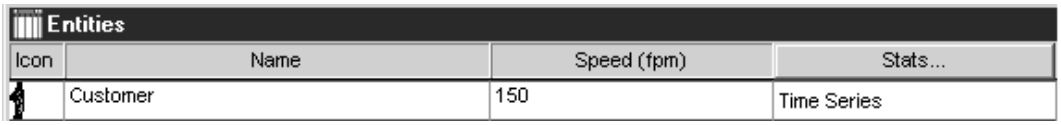


FIGURE L4.5

Process and Routing tables for Fantastic Dan model.

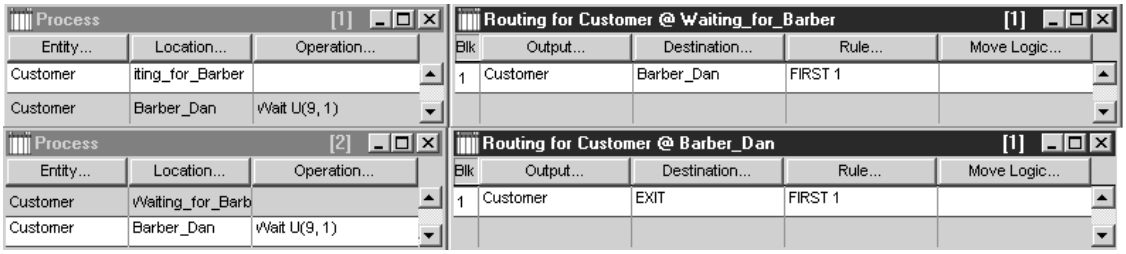


FIGURE L4.6

Process and Routing tables for Fantastic Dan model in text format.

```
                                    Process                 Routing

Entity   Location           Operation         Blk  Output   Destination Rule    Move Logic
-------- ------------------ ----------------- ---- -------- ----------- ------- ----------
Customer Waiting_for_Barber                    1    Customer Barber_Dan  FIRST 1
Customer Barber_Dan         Wait U(9, 1)      1    Customer EXIT        FIRST 1
```

To define the haircut time, click Operation in the Process table. Click the button with the hammer symbol. A new window named Logic Builder opens up. Select the command Wait. The ProModel expression Wait causes the customer (entity) to be delayed for a specified amount of time. This is how processing times are modeled.

Click Build Expression. In the Logic window, select Distribution Function (Figure L4.7). In the Distribution Function window, select Uniform distribution. Click Mean and select 9. Click Half-Range and select 1. Click Return. Click Paste. Close the Logic Builder window. Close the Operation window.

Finally the customers leave the barbershop. They are routed to a default location called EXIT in ProModel. When entities (or customers) are routed to the EXIT location, they are in effect disposed from the system. All the information associated with the disposed entity is deleted from the computer's memory to conserve space.

FIGURE L4.7
The Logic Builder menu.

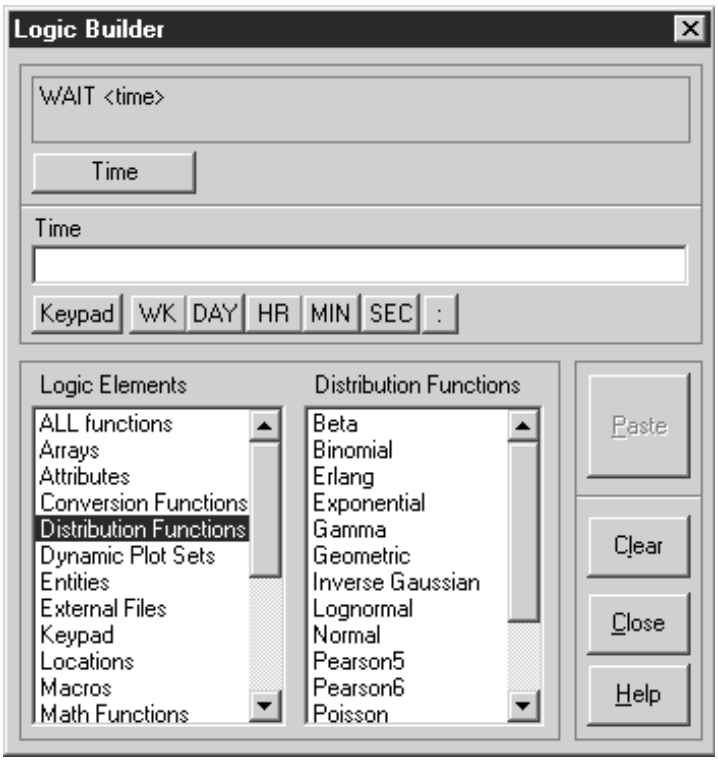


TABLE L4.1 Commonly Used Distribution Functions

Distribution	*ProModel Expression*
Uniform	U (mean, half-range)
Triangular	T (minimum, mode, maximum)
Exponential	E (mean)
Normal	N (mean, std. dev.)

The distribution functions are built into ProModel and generate random values based on the specified distribution. Some of the commonly used distribution functions are shown in Table 4.1.

Now we will define the entity arrival process, as in Figure L4.8.

Next we will define some of the simulation options—that is, run time, number of replications, warm-up time, unit of time, and clock precision (Figure L4.9). The run time is the number of hours the simulation model will be run. The number of replications refers to number of times the simulation model will be run (each time the model will run for an amount of time specified by run hours). The

FIGURE L4.8

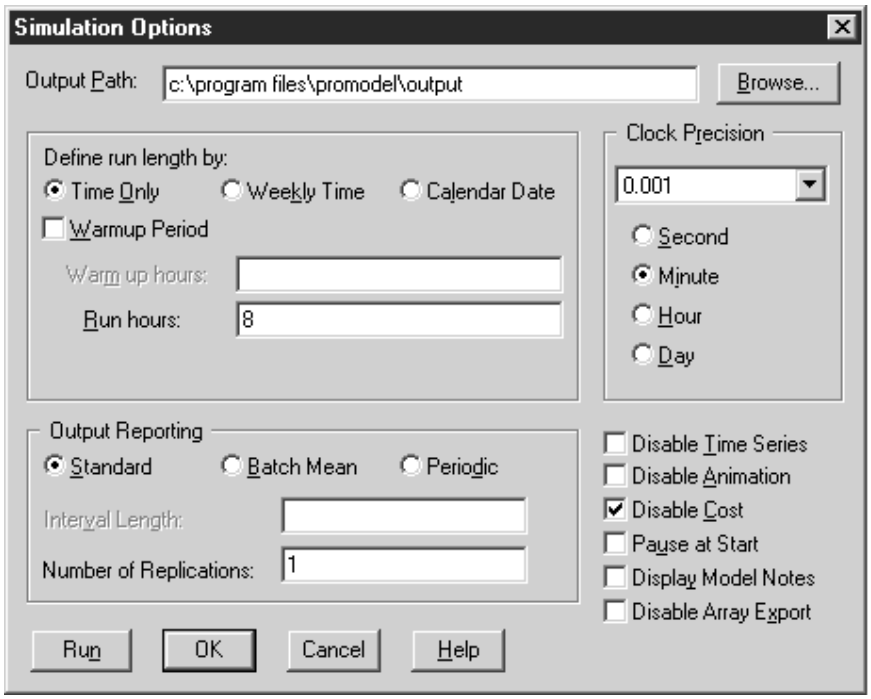
Customer arrival table.

Arrivals [1]

Entity...	Location...	Qty each...	First Time	Occurrences	Frequency	Logic	Disable
Customer	Waiting_for_Barber	1	0	INF	e(10) min		No

FIGURE L4.9

Definition of simulation run options.



warm-up time refers to the amount of time to let the simulation model run to achieve steady-state behavior. Statistics are usually collected after the warm-up period is over. The run time begins at the end of the warm-up period. The unit of time used in the model can be seconds, minutes, or hours. The clock precision refers to the precision in the time unit used to measure all simulation event timings.

Let us select the Run option from the Simulation Options menu (or click F10). Figure L4.10 shows a screen shot during run time. The button in the middle of the scroll bar at the top controls the speed of the simulation run. Pull it right to increase the speed and left to decrease the speed.

After the simulation runs to its completion, the user is prompted, "Do you want to see the results?" (Figure L4.11). Click Yes. Figures L4.12 and L4.13 are part of the results that are automatically generated by ProModel in the 3DR (three-dimensional report) Output Viewer.

FIGURE L4.10

Screen shot at run time.

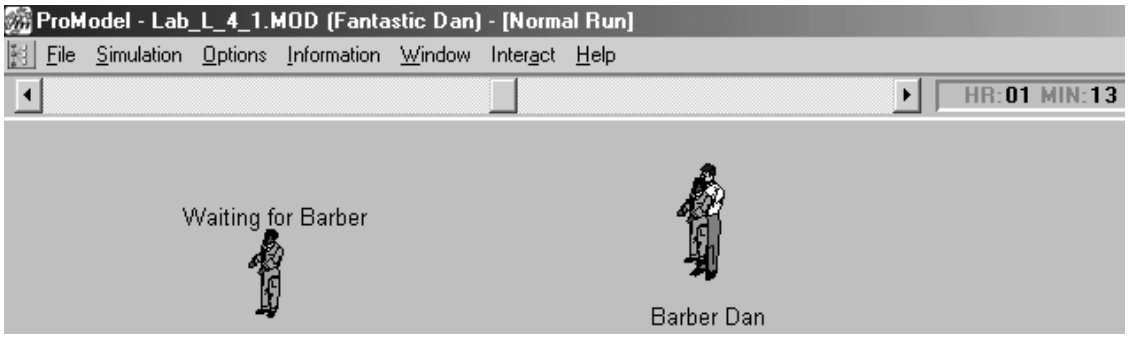


FIGURE L4.11

Simulation complete prompt.

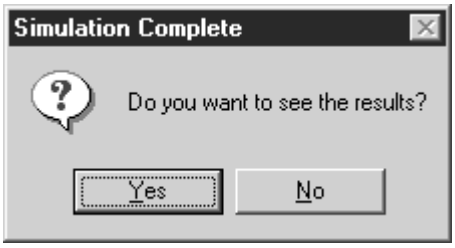
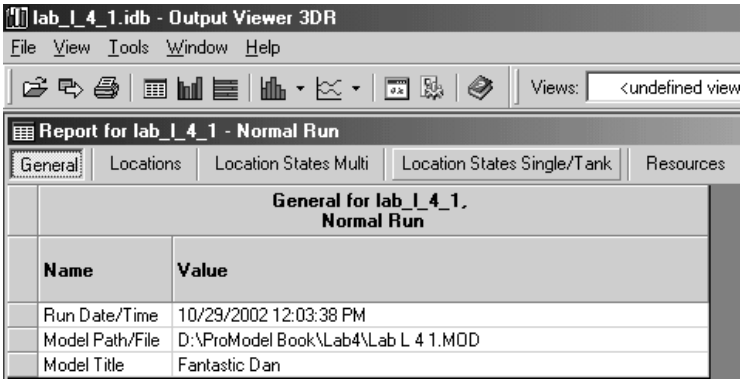


FIGURE L4.12

The 3DR Output Viewer for the Fantastic Dan model.



Note that the average time a customer spends waiting for Barber Dan is 22.95 minutes. The average time spent by a customer in the barbershop is 32.28 minutes. The utilization of the Barber is 89.15 percent. The number of customers served in 480 minutes (or 8 hours) is 47. On average 5.875 customers are served per hour. The maximum number of customers waiting for a haircut is 8, although the average number of customers waiting is only 2.3.

FIGURE L4.13

Results of the Fantastic Dan simulation model.

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resource States | Node Entries | Failed Arrivals

Locations for lab_l_4_1, Normal Run

Name	Scheduled Time (MIN)	Capacity	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Maximum Contents	Current Contents	Pct Utilization
Barber Dan	480.00	1	48	8.92	0.89	1	1	89.15
Waiting for Ba...	480.00	999999	48	22.95	2.30	8	0	0.00

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resour

Location States Multi for lab_l_4_1, Normal Run

Name	Scheduled Time (MIN)	Pct Empty	Pct Part Occupied	Pct Full	Pct Down
Waiting for Ba...	480.00	36.11	63.89	0.00	0.00

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resource States | Node Entries | Fail

Location States Single/Tank for lab_l_4_1, Normal Run

Name	Scheduled Time (MIN)	Pct Operation	Pct Setup	Pct Idle	Pct Waiting	Pct Blocked	Pct Down
Barber Dan	480.00	89.15	0.00	10.85	0.00	0.00	0.00

Failed Arrivals | Entity Activity | Entity States | Variables | Location Costing | Resource Costing | Entity Costing | Logs

Entity Activity for lab_l_4_1, Normal Run

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)	Avg Time Wait For Res (MIN)	Avg Time In Operation (MIN)	Avg Time Blocked (MIN)
Customer	47	1	32.28	0.00	16.91	8.92	6.45

Failed Arrivals | Entity Activity | Entity States | Variables | Location Costing | R

Entity States for lab_l_4_1, Normal Run

Name	Pct In Move Logic	Pct Wait For Res	Pct In Operation	Pct Blocked
Customer	0.00	52.40	27.62	19.98

L4.2 Building the Bank of USA ATM Model

In this section we describe how you can build a simplified version of the automatic teller machine (ATM) system model described in Lab 3, Section L3.1, using ProModel software. We also introduce the concept of a queue.

Customers arrive to use a **Bank of USA ATM.** The average customer interarrival time is 3.0 minutes exponentially distributed. When customers arrive to the system they join a queue to wait for their turn on the ATM. The queue has the capacity to hold an infinite number of customers. Customers spend an average of

2.4 minutes exponentially distributed at the ATM to complete their transactions, which is called the service time at the ATM. Build a simulation model of the Bank of USA ATM. Run the simulation model for 980 hours.

a. About how many customers are served per hour?
b. What is the average customer waiting time in the queue?
c. What is the average time spent by a customer in the system?
d. What is the utilization of the ATM?
e. What are the maximum and average numbers of customers waiting in the ATM queue?

From the menu bar select File → New. In the General Information panel (Figure L4.14) fill in the title of the simulation model as "Bank of USA ATM." Fill in some of the other general information about the model like the time and distance units. Click OK to proceed to define the locations.

From the menu bar select Build → Locations. Define two locations—ATM and ATM_Queue (Figure L4.15). The icon selected for the first location is actually called brake. We changed its name to ATM (Name column in the Location table). The icon for the second location (a queue) is selected from the graphics panel. The icon (third from top) originally looks like a "ladder on its side." To place it in our model layout first, left-click the mouse at the start location of the queue. Then drag the mouse pointer to the end of the queue and right-click. Change the name of this queue location from Loc1 → ATM_Queue. Now double-click the ATM_Queue icon on the layout. This opens another window as follows (Figure L4.16). Make sure to click on the Queue option in the Conveyor/Queue options window. Change the length of the queue to be exactly 31.413 feet.

FIGURE L4.14

General Information for the Bank of USA ATM simulation model.

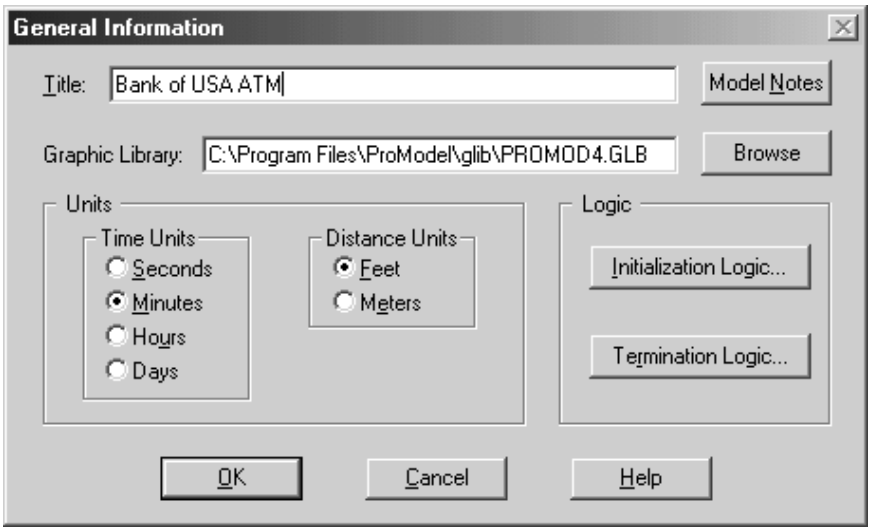


FIGURE L4.15

Defining locations ATM_Queue and ATM.

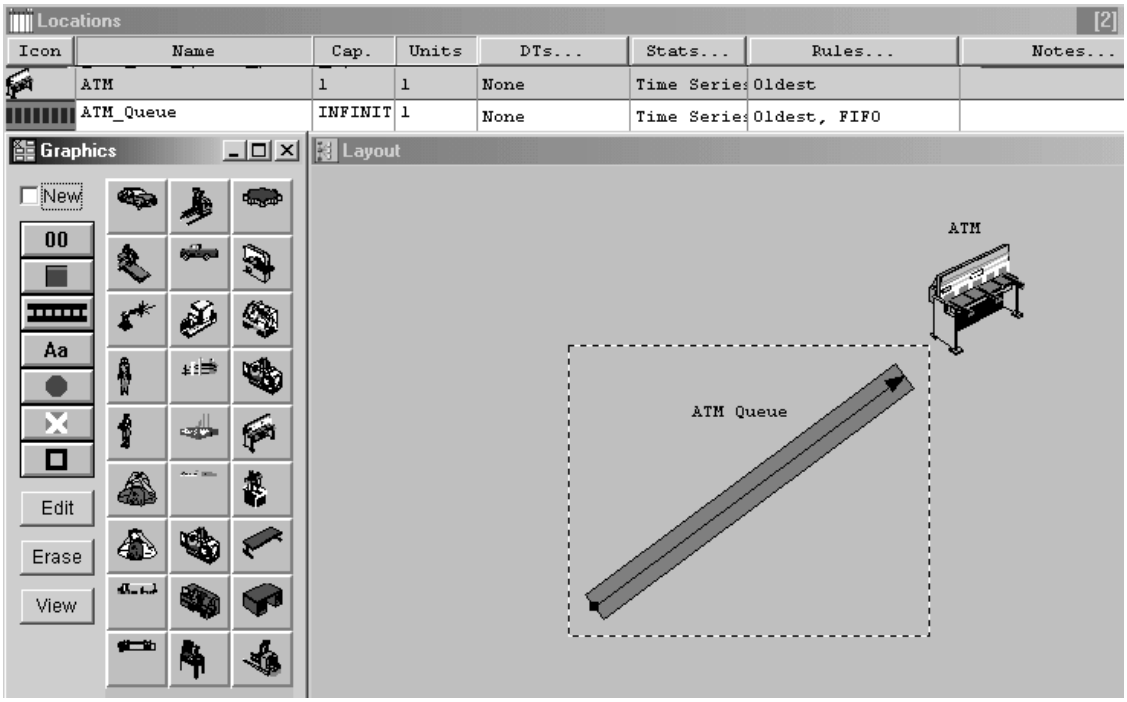
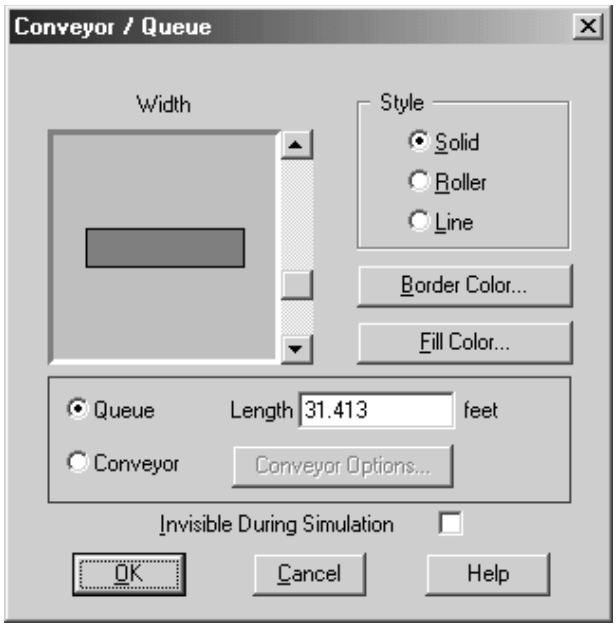


FIGURE L4.16

Click on the Queue option in the Conveyor/Queue options window.



Check off the New button on the graphics panel (Figure L4.15) and click the button marked Aa (fourth icon from top). Click on the location icon in the layout panel. The name of the location (ATM) appears on the location icon. Do the same for the ATM_Queue location.

Define the entity (Figure L4.17) and change its name to ATM_Customer. Define the processes and the routings (Figures L4.18 and L4.19) the customers go through at the ATM system. All customers arrive and wait at the location ATM_Queue. Then they are routed to the location ATM. At this location the customers deposit or withdraw money or check their balances, which takes an average of 2.4 minutes exponentially distributed. Use the step-by-step procedure detailed in section L2.2.4 to create the process and routing tables graphically.

To define the service time at the ATM, click Operation in the Process table. Click the button with the hammer symbol. A new window named Logic Builder opens up. Select the command Wait. The ProModel expression Wait causes the ATM customer (entity) to be delayed for a specified amount of time. This is how processing times are modeled.

FIGURE L4.17

Define the entity—ATM_Customer.

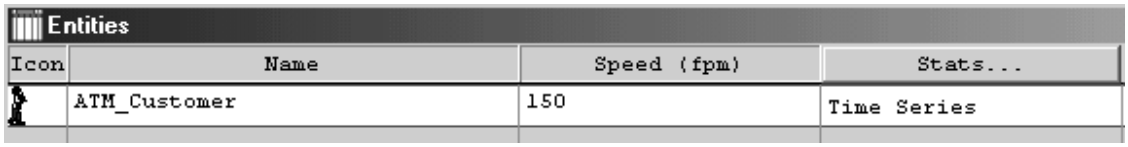


FIGURE L4.18

Process and Routing tables for Bank of USA ATM model.

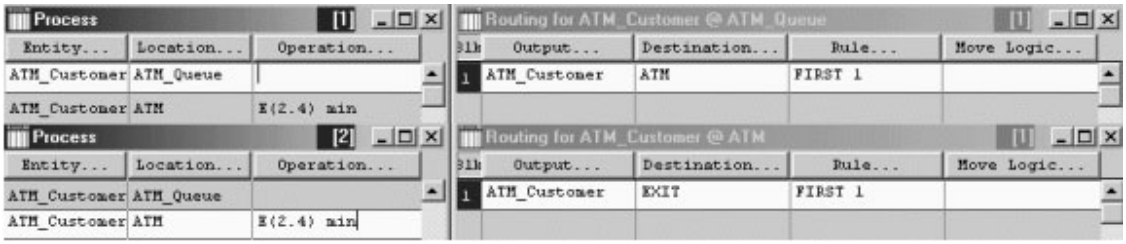


FIGURE L4.19

Process and Routing tables for Bank of USA ATM model in text format.

```
*****************************************************************************
*                              Processing                                   *
*****************************************************************************

                              Process                        Routing

Entity       Location  Operation          Blk  Output       Destination Rule     Move Logic
------------ --------- ------------------ ---- ------------ ----------- -------- ----------
ATM_Customer ATM_Queue                    1    ATM_Customer ATM         FIRST 1
ATM_Customer ATM       E(2.4) min         1    ATM_Customer EXIT        FIRST 1
```

FIGURE L4.20

The Logic Builder menu.

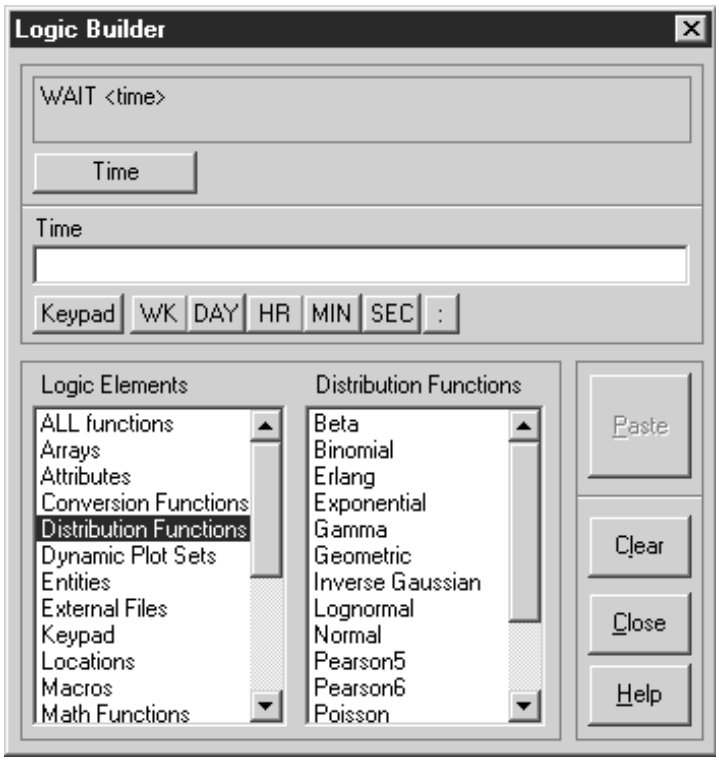


FIGURE L4.21

Customer arrival table.

Arrivals [1]

Entity...	Location...	Qty each...	First Time	Occurrences	Frequency	Logic	Disable
ATM_Customer	ATM_Queue	1		INF	E(3.0)		No

Click Build Expression. In the Logic window, select Distribution Functions (Figure L4.20). In the Distribution Functions window, select Exponential distribution. Click Mean and select 2.4. Click Return. Click MIN. Click Paste. Close the Logic Builder window. Close the Operation window.

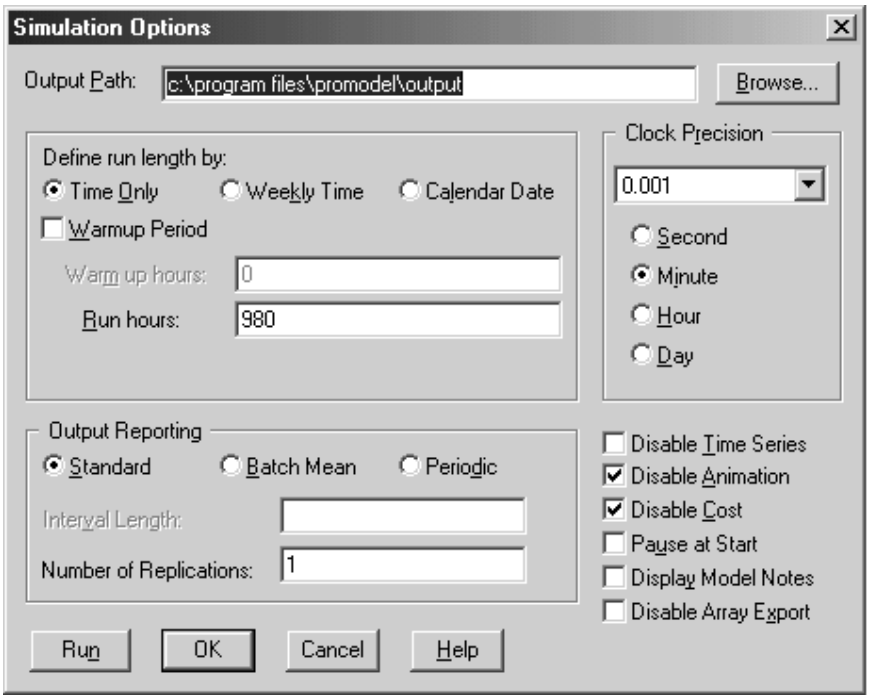
Finally the customers leave the Bank of USA ATM. They are routed to a default location called EXIT in ProModel. When entities (or customers) are routed to the EXIT location, they are in effect disposed from the system. All the information associated with the disposed entity is deleted from the computer's memory to conserve space.

Now we will define the entity arrival process, as in Figure L4.21.

Next we will define some of the simulation options—that is, run time, number of replications, warm-up time, unit of time, and clock precision (Figure L4.22). The run time is the number of hours the simulation model will be run. In this example

FIGURE L4.22

Definition of simulation run options.



we are going to model 980 hours of operation of the ATM system. The number of replications refers to the number of times the simulation model will be run (each time the model will run for an amount of time specified by run hours). The warm-up time refers to the amount of time to let the simulation model run to achieve steady-state behavior. Statistics are usually collected after the warm-up period is over. The run time begins at the end of the warm-up period. For a more detailed discussion on warm-up time, please refer to Chapter 9, Section 9.6.1 and Lab 9. The unit of time used in the model can be seconds, minutes, or hours. The clock precision refers to the precision in the time unit used to measure all simulation event timings.

Let us select the Run option from the Simulation Options menu (or click F10). Figure L4.23 shows a screen shot during run time. The button in the middle of the scroll bar at the top controls the speed of the simulation run. Pull it right to increase the speed and left to decrease the simulation execution speed.

After the simulation runs to its completion, the user is prompted, "Do you want to see the results?" (Figure L4.24). Click Yes. Figures L4.25 and L4.26 are part of the results that are automatically generated by ProModel in the Output Viewer.

Note that the average time a customer spends waiting in the ATM Queue is 9.62 minutes. The average time spent by a customer in the ATM system is 12.02 minutes. The utilization of the ATM is 79.52 percent. Also, 20,000 customers are served in 60,265.64 minutes or 19.91 customers per hour. The maximum number of customers waiting in the ATM Queue is 31, although the average number of

FIGURE L4.23

Screen shot at run time.

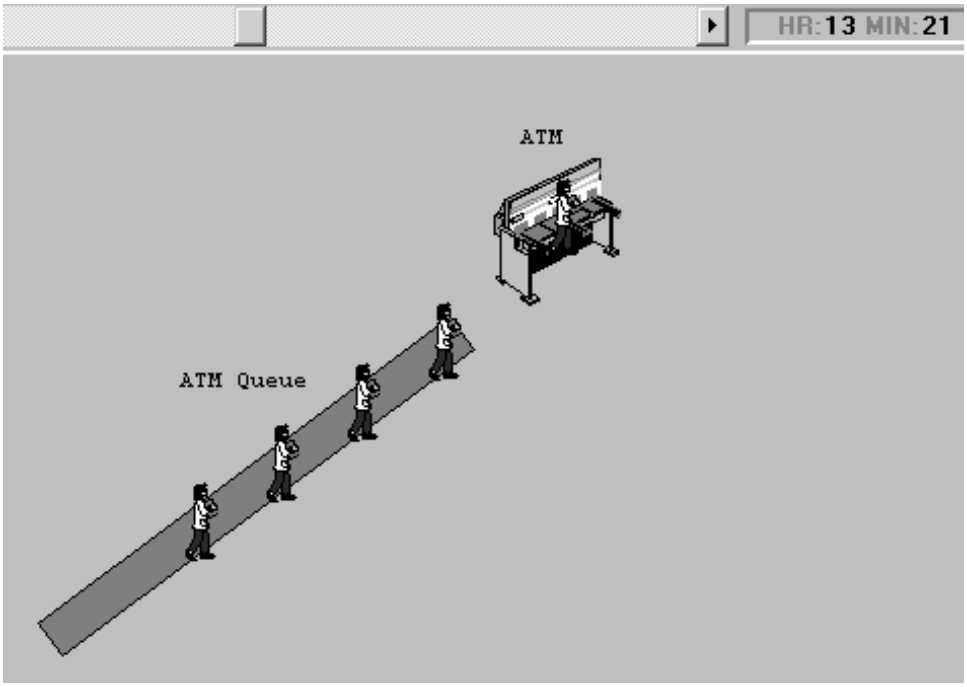


FIGURE L4.24

Simulation complete prompt.

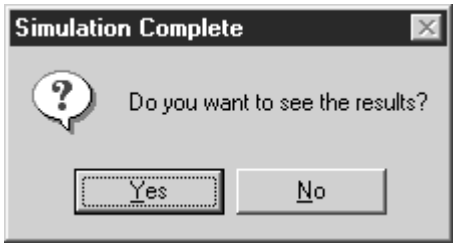


FIGURE L4.25

The output viewer for the Bank of USA ATM model.

Report for bankofusa_atm - Normal Run

General | Locations | Location States Multi | Location States Single/Tank

General for bankofusa_atm, Normal Run

Name	Value
Run Date/Time	10/29/2002 9:38:28 AM
Model Path/File	C:\WINDOWS\Desktop\BankofUSA ATM.MOD
Model Title	Bank of USA ATM

FIGURE L4.26

Results of the Bank of USA ATM simulation model.

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resource States | Node Entries | Failed Arrivals

Locations for lab_l_4_2, Normal Run

Name	Scheduled Time (MIN)	Capacity	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Maximum Contents	Current Contents	Pct Utilization
ATM	60265.64	1	20000	2.40	0.80	1	0	79.52
ATM Queue	60265.64	999999	20000	9.62	3.19	31	0	0.00

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resou

Location States Multi for lab_l_4_2, Normal Run

Name	Scheduled Time (MIN)	Pct Empty	Pct Part Occupied	Pct Full	Pct Down
ATM Queue	60265.64	34.67	65.33	0.00	0.00

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resource States | Node Entries | Fai

Location States Single/Tank for lab_l_4_2, Normal Run

Name	Scheduled Time (MIN)	Pct Operation	Pct Setup	Pct Idle	Pct Waiting	Pct Blocked	Pct Down
ATM	60265.64	79.52	0.00	20.48	0.00	0.00	0.00

Failed Arrivals | Entity Activity | Entity States | Variables | Location Costing | Resource Costing | Entity Costing | Logs

Entity Activity for lab_l_4_2, Normal Run

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)	Avg Time Wait For Res (MIN)	Avg Time In Operation (MIN)	Avg Time Blocked (MIN)
ATM Customer	20000	0	12.02	0.00	7.52	2.61	1.89

Failed Arrivals | Entity Activity | Entity States | Variables | Location Costing | R

Entity States for lab_l_4_2, Normal Run

Name	Pct In Move Logic	Pct Wait For Res	Pct In Operation	Pct Blocked
ATM Customer	0.00	62.57	21.68	15.75

customers waiting is only 3.19. This model is an enhancement of the ATM model in Lab 3, Section L3.1.2. Results will not match exactly as some realism has been added to the model that cannot be addressed in queuing theory.

L4.3 Locations, Entities, Processing, and Arrivals

In Sections L4.1 and L4.2 we have used the basic elements of ProModel. In this section we incorporate locations, entities, arrivals, processing, and routing logic into another simulation model example.

Problem Statement—Multiple Locations, Multiple Entities

Wooden logs are received at the receiving dock of the **Poly Furniture Factory** at the rate of one every 10 minutes. Logs go to the splitter, where four pieces are made from each log. The splitting time is Normal (4,1) minutes. The individual pieces go to the lathe, where they are turned for another Triangular (3,6,9) minutes and made into rounds. The rounds go on to a paint booth, where they are converted into painted logs. Painting takes Exponential (5) minutes. Painted logs go to the store. Consider a material handling time of one minute between each process. Make a simulation model and run the simulation for 10 hours.

We are going to use AutoBuild, the automatic model-building feature of ProModel, to help us build this simulation model step by step. Click AutoBuild from the Tools menu. Fill in some of the general information about the model (Figure L4.27). Define the locations (Figure L4.28)—receiving dock, splitter saw, lathe, paint booth, and painted logs store. Note that the capacity of the receiving dock location has been changed to infinity (INF) to make sure that all incoming entities (raw material) are allowed into the manufacturing facility.

Define the entities (Figure L4.29)—logs, piece, rounds, and painted logs. Define the entity arrival process (Figure L4.30)—logs arriving to the location receiving dock at the rate of one every 10 minutes.

Define the processes and the routings (Figure L4.31). All logs arrive at the receiving dock. From there they go to the splitter. At the splitter each log is made into four pieces. To be able to model this, click on the Rule button in the routing table. Change the quantity to four. This models the process of one log going into the location splitter saw and four pieces coming out. Pieces are routed to the lathe, where they become rounds. Rounds are routed to the paint booth, where they become painted logs. Painted logs are sent to the painted log store. Finally, the painted logs are sent to the default location EXIT for disposal.

FIGURE L4.27

General information for the Poly Furniture Factory simulation.

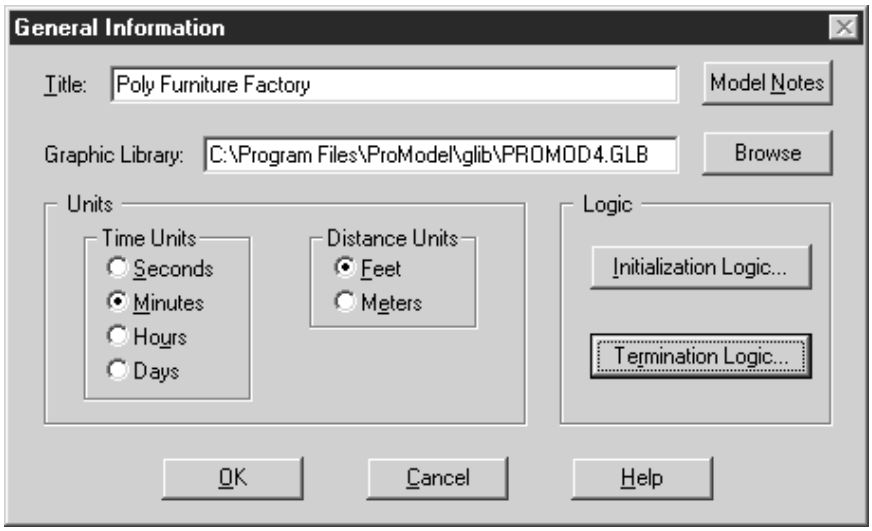


FIGURE L4.28

Locations in the Poly Furniture Factory.

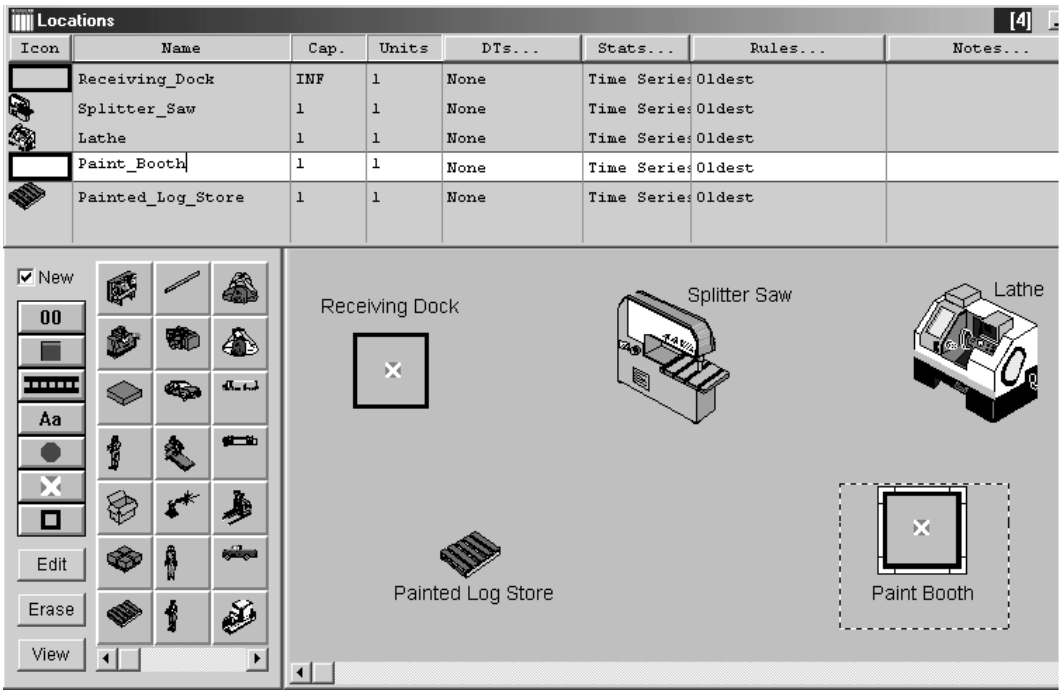


FIGURE L4.29

Entities in the Poly Furniture Factory.

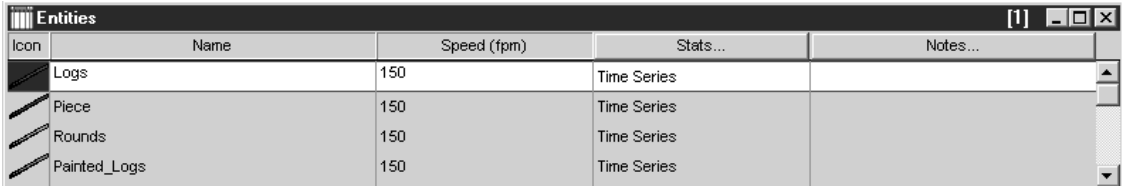


FIGURE L4.30

Entity arrivals in the Poly Furniture Factory.

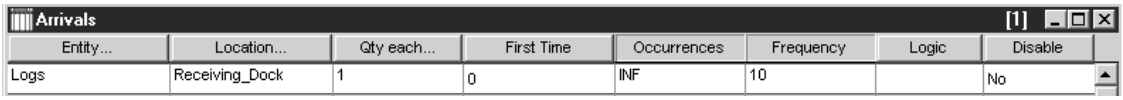


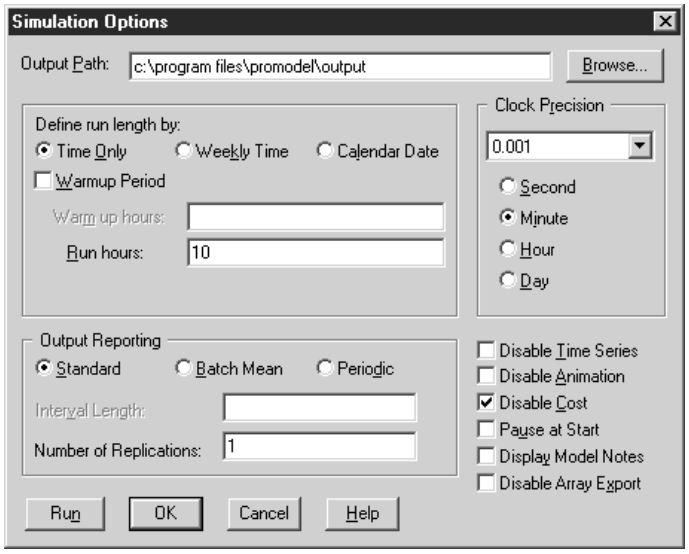
FIGURE L4.31

Processes and routings in the Poly Furniture Factory.

		Process		Routing			
Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Logs	Receiving_Dock		1	Logs	Splitter_Saw	FIRST 1	MOVE FOR 1
Logs	Splitter_Saw	Wait N(4,1)	1	Piece	Lathe	FIRST 4	MOVE FOR 1
Piece	Lathe	Wait T(3,6,9)	1	Rounds	Paint_Booth	FIRST 1	MOVE FOR 1
Rounds	Paint_Booth	Wait E(5)	1	Painted_Logs	Painted_Log_Store	FIRST 1	MOVE FOR 1
Painted_Logs	Painted_Log_Store		1	Painted_Logs	EXIT	FIRST 1	

FIGURE L4.32

Simulation options in the Poly Furniture Factory.



The time to move material between processes is modeled in the Move Logic field of the Routing table. Four choices of constructs are available in the Move Logic field:

- `MOVE`—to move the entity to the end of a queue or conveyor.
- `MOVE FOR`—to move the entity to the next location in a specific time.
- `MOVE ON`—to move the entity to the next location using a specific path network.
- `MOVE WITH`—to move the entity to the next location using a specific resource (forklift, crane).

Define some of the simulation options: the simulation run time (in hours), the number of replications, the warm-up time (in hours), and the clock precision (Figure L4.32).

Now we go on to the Simulation menu. Select Save & Run. This will save the model we have built so far, compile it, and also run it. When the simulation model finishes running, we will be asked if we would like to view the results. Select Yes. A sample of the results is shown in Figure L4.33.

FIGURE L4.33

Sample of the results of the simulation run for the Poly Furniture Factory.

lab_l_4_3.idb - Output Viewer 3DR - [Report for lab_l_4_3 - Normal Run]

File View Tools Window Help

Views: <undefined view>

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resource States | Node Entries | Failed Arrivals

Locations for lab_l_4_3, Normal Run

Name	Scheduled Time (MIN)	Capacity	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Maximum Contents	Current Contents	Pct Utilization
Lathe	600.00	1	69	7.63	0.88	1	1	87.72
Paint Booth	600.00	1	68	5.33	0.60	1	0	60.43
Painted Log S...	600.00	1	68	0.00	0.00	1	0	0.00
Receiving Dock	600.00	999999	61	209.52	21.30	43	43	0.00
Splitter Saw	600.00	1	18	32.33	0.97	1	1	97.00

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resou

Location States Multi for lab_l_4_3, Normal Run

Name	Scheduled Time (MIN)	Pct Empty	Pct Part Occupied	Pct Full	Pct Down
Receiving Dock	600.00	1.67	98.33	0.00	0.00

General | Locations | Location States Multi | Location States Single/Tank | Resources | Resource States | Node Entries | Fai

Location States Single/Tank for lab_l_4_3, Normal Run

Name	Scheduled Time (MIN)	Pct Operation	Pct Setup	Pct Idle	Pct Waiting	Pct Blocked	Pct Down
Lathe	600.00	68.99	0.00	12.28	0.00	18.73	0.00
Paint Booth	600.00	60.43	0.00	39.57	0.00	0.00	0.00
Painted Log S...	600.00	0.00	0.00	100.00	0.00	0.00	0.00
Splitter Saw	600.00	12.34	0.00	3.00	0.00	84.66	0.00

Node Entries | Failed Arrivals | Entity Activity | Entity States | Variables | Location Costing | Resource Costing | Entity Costing

Entity Activity for lab_l_4_3, Normal Run

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)	Avg Time Wait For Res (MIN)	Avg Time In Operation (MIN)	Avg Time Blocked (MIN)
Logs	0	44	0.00	0.00	0.00	0.00	0.00
Painted Logs	68	0	233.32	4.00	0.00	15.53	213.80
Piece	0	1	0.00	0.00	0.00	0.00	0.00
Rounds	0	0	0.00	0.00	0.00	0.00	0.00

Node Entries | Failed Arrivals | Entity Activity | Entity States | Variables | Local

Entity States for lab_l_4_3, Normal Run

Name	Pct In Move Logic	Pct Wait For Res	Pct In Operation	Pct Blocked
Logs	0.00	0.00	0.00	0.00
Painted Logs	1.71	0.00	6.65	91.63
Piece	0.00	0.00	0.00	0.00
Rounds	0.00	0.00	0.00	0.00

L4.4 Add Location

Now let us add a location to an existing model. For the Poly Furniture Factory example in Section L4.3, we will add an oven after the painting booth for drying the painted logs individually. The drying takes a time that is normally distributed with a mean of 20 minutes and standard deviation of 2 minutes. After drying, the painted logs go on to the painted logs store.

To add an additional location to the model, select Locations from the Build menu. With the mouse, first select the appropriate resource icon from the Graphics toolbar (left-click), then left-click again in the Layout window. Change the name of the location (in the Locations table) from Loc1 to Oven (Figure L4.34).

Locations can also be added from the Edit menu. Select Append from the Edit menu. A new location called Loc1 is appended to the end of the Locations table. Change the name to Oven. Deselect the New option in the Graphics toolbar. Select an appropriate icon from the Graphics toolbar. Click in the Layout window.

To display the names of each location in the Layout window, first select a location (left-click). Next deselect the New option in the graphics toolbar. Left-click on the command button Aa in the Graphics toolbar (left column, fourth from top). Finally, left-click on the location selected. The name of the location will appear in the Layout window. Now it can be repositioned and its fonts and color changed.

The complete simulation model layout is shown in Figure L4.35. Note that the capacity of the oven as well as the paint booth has been changed to 10. The processes and routings are created as shown in Figure L4.36. At this point it is worthwhile to note the differences between the capacity and the units of a location.

- *Capacity:* This is the number of units of entities that the location can hold simultaneously. The default capacity of a location is one.
- *Units:* A multiunit location consists of several identical units that are referenced as a single location for processing and routing purposes. A multiunit location eliminates the need to create multiple locations and multiple processes for locations that do the same thing. The default number of units of a location is one.

FIGURE L4.34

Locations at the Poly Furniture Factory with oven.

Locations

Icon	Name	Cap.	Units	DTs...	Stats...	Rules...
	Receiving_Dock	INF	1	None	Time Series	Oldest
	Splitter_Saw	1	1	None	Time Series	Oldest
	Lathe	1	1	None	Time Series	Oldest
	Paint_Booth	10	1	None	Time Series	Oldest
	Painted_Log_Store	1	1	None	Time Series	Oldest
	Oven	10	1	None	Time Series	Oldest

FIGURE L4.35

Simulation model layout of the Poly Furniture Factory.

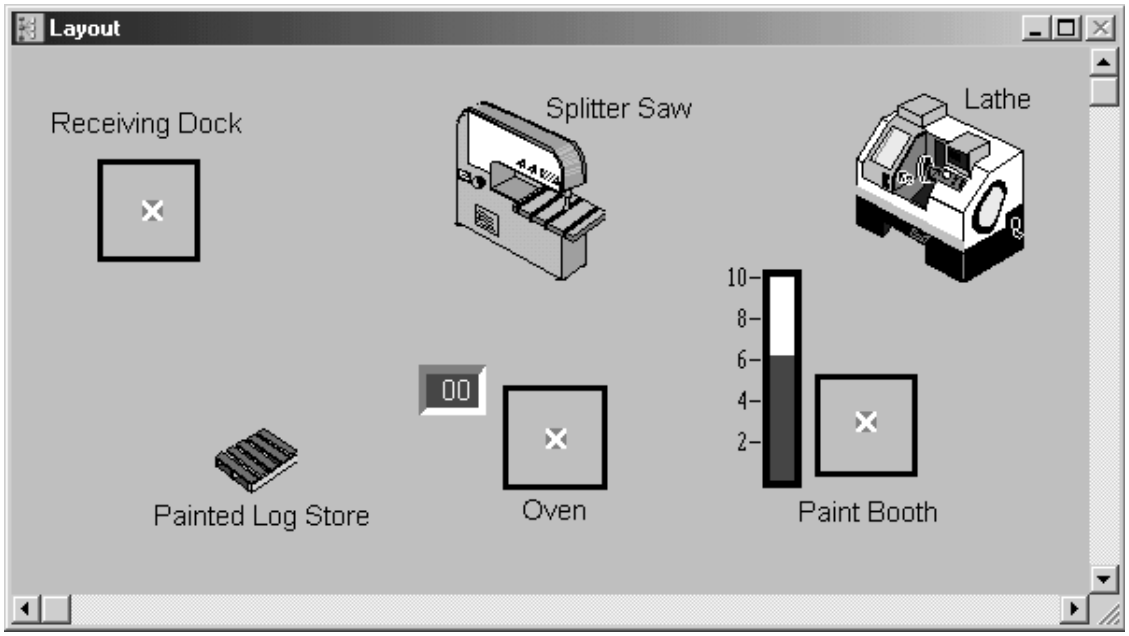


FIGURE L4.36

Processes and routings at the Poly Furniture Factory.

		Process		Routing			
Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Logs	Receiving_Dock		1	Logs	Splitter_Saw	FIRST 1	MOVE FOR 1
Logs	Splitter_Saw	Wait N(4,1)	1	Piece	Lathe	FIRST 4	MOVE FOR 1
Piece	Lathe	Wait T(3,6,9)	1	Rounds	Paint_Booth	FIRST 1	MOVE FOR 1
Rounds	Paint_Booth	Wait E(5)	1	Painted_Logs	Oven	FIRST 1	MOVE FOR 1
Painted_Logs	Oven	Wait N(20,2)	1	Painted_Logs	Painted_Log_Store	FIRST 1	MOVE FOR 1
Painted_Logs	Painted_Log_Store		1	Painted_Logs	EXIT	FIRST 1	

The contents of a location can be displayed in one of the following two alternative ways:

a. To show the contents of a location as a counter, first deselect the New option from the Graphics toolbar. Left-click on the command button 00 in the Graphics toolbar (left column, top). Finally, left-click on the location selected (Oven). The location counter will appear in the Layout window next to the location Oven (Figure L4.35).

b. To show the contents of a location (Paint Booth) as a gauge, first deselect the New option from the Graphics toolbar. Left-click on the second command button from the top in the left column in the Graphics toolbar.

The gauge icon will appear in the Layout window next to the location Paint Booth (Figure L4.35). The fill color and fill direction of the gauge can now be changed if needed.

L4.5 Effect of Variability on Model Performance

Variability in the data makes a big impact on the performance of any system. Let us take the example of Fantastic Dan, the barbershop in Section L4.1. Assume that one customer arrives for getting a haircut every 10 minutes. Also, Dan takes exactly nine minutes for each haircut.

Let us modify the model of Section L4.1 to reflect the above changes. The arrival table is changed as shown in Figure L4.37 and the process table is changed as shown in Figure L4.38. The results of the model with and without variability are compared and shown in Table L4.2.

FIGURE L4.37

Customer arrival for haircut.

Arrivals [1]

Entity...	Location...	Qty each...	First Time	Occurrences	Frequency	Logic	Disable
Customer	Waiting_for_Barb	1	0	INF	10 min		No

FIGURE L4.38

Processing of customers at the barbershop.

Process [1]

Entity...	Location...	Operation...
Customer	Waiting_for_	
Customer	Barber_Dan	Wait 9

Routing for Customer @ Waiting_for_Barber [1]

Blk	Output...	Destination...	Rule...	Move Logic...
	Customer	Barber_Dan	FIRST 1	

TABLE L4.2 Comparison of the Barbershop Model with and without Variability

	With Variability	*Without Variability*
Average customer time at the barbershop	32.27 min.	9 min.
Average waiting in line for barber	22.95 min.	0 min.

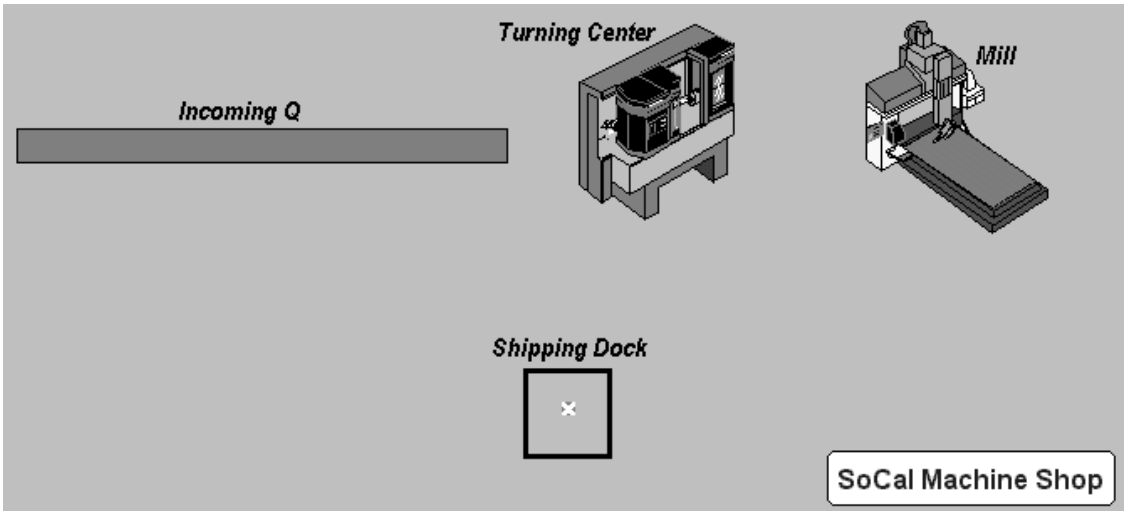
L4.6 Blocking

With respect to the way statistics are gathered, here are the rules that are used in ProModel (see the ProModel Users Manual, p. 636):

1. *Average <time> in system:* The average total time the entity spends in the system, from the time it arrives till it exits the system.
2. *Average <time> in operation:* The average time the entity spends in processing at a location (due to a `WAIT` statement) or traveling on a conveyor or queue.
3. *Average <time> in transit:* The average time the entity spends traveling to the next location, either in or out of a queue or with a resource. The move time in a queue is decided by the length of the queue (defined in the queue dialog, Figure L4.16) and the speed of the entity (defined in the entity dialog, Figure L4.4 or L4.17).
4. *Average <time> wait for resource, etc.:* The average time the entity spends waiting for a resource or another entity to join, combine, or the like.
5. *Average <time> blocked:* The average time the entity spends waiting for a destination location to become available. Any entities held up behind another blocked entity are actually waiting on the blocked entity, so they are reported as "time waiting for resource, etc."

Example
At the **SoCal Machine Shop** (Figure L4.39) gear blanks arriving to the shop wait in a queue (Incoming_Q) for processing on a turning center and a mill, in that

FIGURE L4.39
The Layout of the SoCal Machine Shop.



order. A total of 100 gear blanks arrive at the rate of one every eight minutes. The processing times on the turning center and mill are eight minutes and nine minutes, respectively. Develop a simulation model and run it.

To figure out the time the "gear blanks" are blocked in the machine shop, waiting for a processing location, we have entered "Move for 0" in the operation logic (Figure L4.40) of the Incoming_Q. Also, the decision rule for the queue has been changed to "No Queuing" in place of FIFO (Figure L4.41). This way all the entities waiting in the queue for the turning center to be freed up are reported as blocked. When you specify FIFO as the queuing rule for a location, only the lead entity is ever blocked (other entities in the location are waiting for the lead entity and are reported as "wait for resource, etc.").

FIGURE L4.40

Process and Routing tables for SoCal Machine Shop.

Processing

		Process		Routing		
Entity	Location	Operation	Blk	Output	Destination	Rule
Gear_Blank	Incoming_Q	Move for 0	1	Gear_Blank	Turning_Center	FIRST 1
Gear_Blank	Turning_Center	WAIT 8 min				
			1	Gear_Blank	Mill	FIRST 1
Gear_Blank	Mill	WAIT 9 min	1	Gear_Blank	Shipping_Dock	FIRST 1
Gear_Blank	Shipping_Dock		1	Gear_Blank	EXIT	FIRST 1

FIGURE L4.41

Decision rules for Incoming_Q.

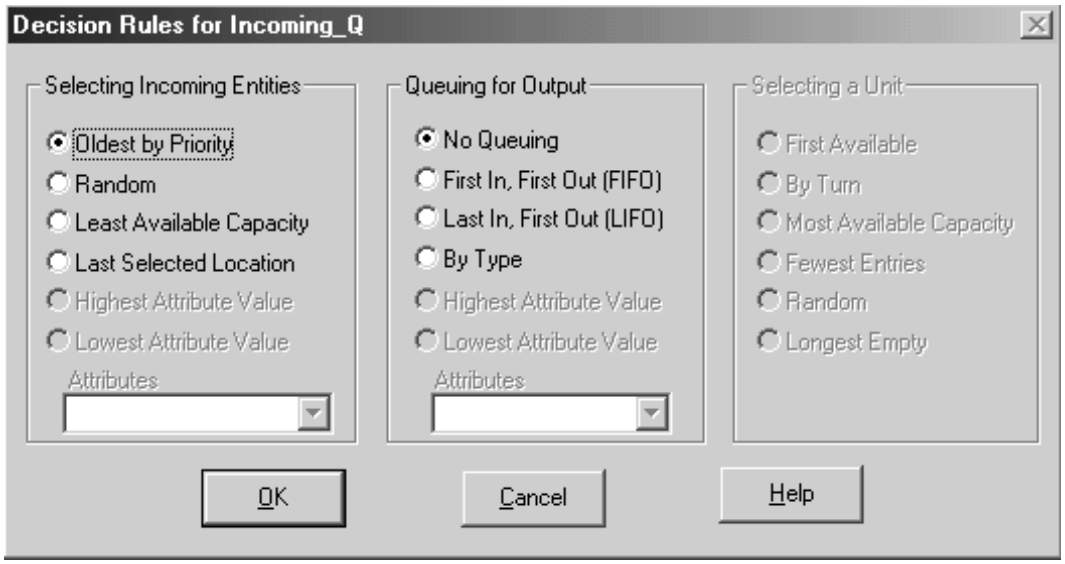


FIGURE L4.42

Entity activity statistics at the SoCal Machine Shop.

ENTITY ACTIVITY

Entity Name	Total Exits	Current Quantity In System	Average Minutes In System	Average Minutes In Move Logic	Average Minutes Wait For Res, etc.	Average Minutes In Operation	Average Minutes Blocked
Gear Blank	100	0	66.50	0.0	0.0	17.00	49.50

FIGURE L4.43

Entity activity statistics at the SoCal Machine Shop with two mills.

ENTITY ACTIVITY

Entity Name	Total Exits	Current Quantity In System	Average Minutes In System	Average Minutes In Move Logic	Average Minutes Wait For Res, etc.	Average Minutes In Operation	Average Minutes Blocked
Gear Blank	100	0	17.00	0.0	0.0	17.00	0.0

From the entity activity statistics (Figure L4.42) in the output report we can see the entities spend on average or 66.5 minutes in the system, of which 49.5 minutes are blocked (waiting for another process location) and 17 minutes are spent in operation (eight minutes at the turning center and nine minutes at the mill). Blocking as a percentage of the average time in system is 74.44 percent. The utilization of the turning center and the mill are 98.14 percent and 98.25 percent, respectively.

In general, the blocking time as a percentage of the time in system increases as the utilization of the processing locations increases. To reduce blocking in the machine shop, let us install a second mill. In the location table, change the number of units of mill to 2. The entity activity statistics from the resulting output report are shown in Figure L4.43. As expected, the blocking time has been reduced to zero.

L4.7 Exercises

1. Run the Tube Distribution Supply Chain example model (logistics.mod) from the demos subdirectory for 40 hours. What are the various entities modeled in this example? What are the various operations and processes modeled in this example? Look at the results and find
   a. The percentage utilization of the locations "Mill" and the "Process Grades Threads."
   b. The capacities of Inventory, and Inventory 2–6; the maximum contents of Inventory and Inventory 2–6.

c. The idle time percentage of the location "Mill."
d. The percentage utilization of the resources Transport 1–5 and Fork Lift 1–6.
e. What are the various states (in percentages) of the location "Process Grades Threads"?

2. Run the Tube Distribution Supply Chain example model (logistics.mod) for 40 hours.
   a. What are the utilizations of the five transport resources? Is anyone overutilized?
   b. How well utilized are the six fork trucks? Can we reduce the fleet of fork trucks without much loss in the level of service?
3. Run the Warehouse model (deaerco.mod) from the demos subdirectory for 100 hours. Run only Scenario 1. Go into the Simulation → Options menu and change the Run Hours from 10 to 100.
   a. What are the average value of inventory of Inventory Aisle 1–12?
   b. What are the averages for Time to Fill, Box, and Check?
   c. What is the Average Time in System?
   d. What are the cost of customer order, receiving order, and the sum total of cost per order?
   e. What are the percentage idle times for Checker 1 and Checker 2?
   f. What are the utilizations of Boxers 1–4 and the average utilization of all the Boxers?
4. Run the Aircraft Fuselage Mating example model (assembly.mod) from the Student subdirectory for 80 hours. Answer the following questions:
   a. What are the utilizations of the Drill and the Cutter?
   b. What percentage of time were the Paint, Assembly Jig Q, and KittingQ fully occupied?
   c. What is the percentage utilization of the Crane?
   d. What is the average time a Fuselage spends in the system?
5. Run the Book Storage (Booksmod.mod) example model from the Student subdirectory for eight hours. Answer the following questions.
   a. What are the utilizations of the forklift (JACK) and the material handler (MTHDLR)?
   b. What is the average time spent in the system by order A, order B, order C, and order D?
   c. What is the percentage of time the orders are waiting for a resource? Which resource? What if any are the problems? What can you suggest to improve the situation?
6. For the example in Section L4.1 (Fantastic Dan), run the simulation model for a whole year (250 days, eight hours each day) and answer the following questions:
   a. On average, how many customers does Dan serve each day?
   b. What is the average number of customers waiting to get a haircut? What is the maximum?

c. What is the average time spent by a customer in the salon?
d. How busy is Dan on average? Is this satisfactory?
e. How many chairs should Dan have for customers waiting for a haircut?

7. If Dan could take exactly nine minutes for each haircut, will it improve the situation? Rework Question 1 and answer parts *a* through *e*.
8. For the example in Section L4.1, what will happen if we change the capacity of the location Waiting_for_Barber to one? Is this change desirable? What are the implications? Make the appropriate change in the model and show the results to support your argument.
9. For the Bank of USA ATM example in Section L4.2, run the model with and without any variability in the customer interarrival time and service time. Compare the average time in system and the average time in queue based on 1000 hours of simulation runs.
10. For the SoCal Machine Shop in Section L4.6 assume the length of the Incoming_Q is 30 feet, and the speed of the arriving Gear_Blanks is 10 feet/minute. Delete the statement `Move for 0` in the operation logic of the Incoming_Q. Change the queuing rule to FIFO. Answer the following questions and explain why.
    a. What is the average time in operation?
    b. What is the average time waiting for resource?
    c. What is the average time blocked?
11. In the Arrivals element (table), what are the differences between Occurrences and Frequency? What is the significance of the Qty each column?
12. In the Locations element (table), what are the differences between Cap and Units?
13. What are the various time units that can be used while developing a model? Where is this information provided? If one forgets to specify the time unit in the model, what time unit is used by ProModel?
14. The Processing element has two tables that need to be edited. What are their names and their functions?
15. When an entity has completed all the processing in the system, what should we do with it? Where should it be routed?
16. Differentiate between the following:
    a. Entity versus locations.
    b. Locations versus resources.
    c. Attributes versus variables.
    d. Save versus Save As.
    e. `Move, Move For, Move On, Move With.`
    f. `Wait` versus `Wait Until.`
    g. `Stop` versus `End.`
17. Increased utilization of processing locations or resources lead to increased levels of blocking in the system. Explain why.