L A B

12 Intermediate Modeling Concepts

All truths are easy to understand once they are discovered; the point is to discover them.
—Galileo Galilei

In this lab we expand on the ProModel concepts discussed in Chapters 3 and 6. Section L12.1 introduces the concept of attributes; Section L12.2 shows its application in the calculation of cycle times; and Section L12.3 shows the process of sortation, sampling inspection, and rework. In Section L12.4 we show how to merge two different submodules. Section L12.5 discusses various aspects of machine breakdowns and maintenance; Section L12.6 shows how ProModel can conveniently model shift-working patterns; Section L12.7 shows the application of ProModel in a job shop; Section L12.8 introduces the modeling of priorities; and Section L12.9 has a couple of examples of pull system applications in manufacturing. Costs are modeled and tracked in Section L12.10. Section L12.11 shows how to import background graphics into a model, and Section L12.12 shows how to define and display various views of a model.

L12.1 Attributes

Attributes can be defined for entities or for locations. Attributes are placeholders similar to variables but are attached to specific entities or locations and usually contain information about that entity or location. Attributes are changed and assigned when an entity executes the line of logic that contains an operator, much like the way variables work. Some examples of attributes are part type, customer number, and time of arrival of an entity, as well as length, weight, volume, or some other characteristic of an entity.

To define an attribute use the attribute editor, as follows:

1. Go to the Build/More Elements/Attributes menu and create a name (ID) for the attribute.
2. Select the type of attribute—integer or real.
3. Select the class of attribute—entity or location.

L12.1.1 Using Attributes to Track Customer Types

Problem Statement

Customers visit the neighborhood barbershop **Fantastic Dan** for a haircut. Among the customers there are 20 percent children, 50 percent women, and 30 percent men. The customer interarrival time is triangularly distributed with a minimum, mode, and maximum of seven, eight, and nine minutes respectively. The haircut time (in minutes) depends on the type of customer and is given in Table L12.1. 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).

a. About how many customers of each type does Dan process per day?

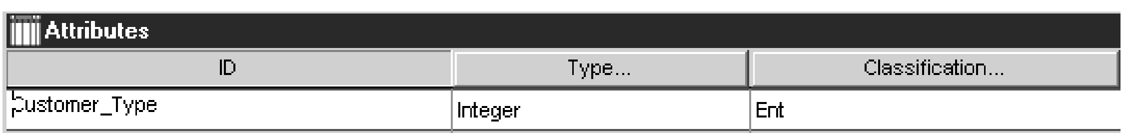
b. What is the average number of customers of each type waiting to get a haircut? What is the maximum?

c. What is the average time spent by a customer of each type in the salon? What is the maximum?

Two locations (Barber Dan and Waiting for Dan) and an entity (Customer) are defined. Customer_Type is defined as an attribute (type = integer and classification = entity) as shown in Figure L12.1. The process/routing and customer arrivals are defined as shown in Figures L12.2 and L12.3. A snapshot of the simulation model is shown in Figure L12.4.

FIGURE L12.1

Customer_Type declared as an attribute.



Attributes

ID	Type...	Classification...
Customer_Type	Integer	Ent

TABLE L12.1 The Haircut Time for All Customers

	Haircut Time (minutes)	
Customers	*Mean*	*Half-Width*
Children	8	2
Women	12	3
Men	10	2

FIGURE L12.2

Process and routing tables for Fantastic Dan.

Process			Routing				
Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Customer	Waiting_for_Barber		1	Customer	Waiting_for_Barber	0.300000 1	customer_Type = 1 graphic 1
				Customer	Waiting_for_Barber	0.500000	customer_Type = 2 graphic 2
				Customer	Waiting_for_Barber	0.200000	customer_Type = 3 graphic 3
Customer	Waiting_for_Barber		1	Customer	Barber_Dan	FIRST 1	
Customer	Barber_Dan	if customer_type = 1 then wait u(10,2) min if customer_type = 2 then wait u(12,3) min if customer_type = 3 then wait u(8,2) min					
			1	Customer	EXIT	FIRST 1	

FIGURE L12.3

Arrival of customers at Fantastic Dan.

```
**************************************************************************************
*                                    Arrivals                                        *
**************************************************************************************
```

Entity	Location	Qty each	First Time	Occurrences	Frequency	Logic
Customer	Waiting_for_Barber	1	0	inf	t(7,8,9) min	

FIGURE L12.4

Simulation model for Fantastic Dan.

L12.2 Cycle Time

The Clock and Log are functions built into ProModel to allow us to keep track of system events such as cycle time, lead time, or flow time within the system. The Clock function returns the current simulation clock time in hours, minutes, or seconds. The value returned is real.

The Log function is used to subtract an expression from the current simulation clock time and stores the result with a text string header.

```
Time_In = Clock()
Log "Cycle Time =", Time_In
```

For the example in Section L12.1, find

a. The cycle time for each type of customer of Barber Dan.

b. The average cycle time for all customers.

Define Time_In as an attribute to track the time of arrival for all customer types. Figure L12.5 shows the setting of the attribute Time_In and also the logging of the average cycle time. The cycle times for children, women, and men are reported in Figure L12.6.

FIGURE L12.5

Setting the attribute Time_In and logging the cycle time.

```
                                   Process                                      Routing

Entity   Location           Operation            Blk  Output   Destination        Rule
-------- ------------------ -------------------- ---- -------- ------------------ ----------
Customer Waiting_for_Barber Time_In=Clock()
                                                 1    Child    Waiting_for_Barber 0.200000 1
                                                      Woman    Waiting_for_Barber 0.500000
                                                      Man      Waiting_for_Barber 0.300000
Child    Waiting_for_Barber                      1    Child    Barber_Dan         FIRST 1
Child    Barber_Dan         wait u(8,2) min
                            Log "Child Cycle Time=",time_in
                                                 1    Child    EXIT               FIRST 1
Woman    Waiting_for_Barber                      1    Woman    Barber_Dan         FIRST 1
Woman    Barber_Dan         wait u(12,3) min
                            Log "Woman Cycle Time=",time_in
                                                 1    Woman    EXIT               FIRST 1
Man      Waiting_for_Barber                      1    Man      Barber_Dan         FIRST 1
Man      Barber_Dan         wait u(10,2) min
                            Log "Man Cycle Time=",time_in
                                                 1    Man      EXIT               FIRST 1
```

FIGURE L12.6

The minimum, maximum, and average cycle times for various customers.

Report for lab_l_11_2 - Normal Run

Entity States | Variables | Location Costing | Resource Costing | Entity Costing | Logs

Logs for lab_l_11_2, Normal Run

Name	Number Observations	Minimum Value	Maximum Value	Avg Value
Child Cycle Ti...	8	27	124	74
Man Cycle Ti...	14	19	115	62
Woman Cycle...	23	12	128	69

L12.3 Sorting, Inspecting a Sample, and Rework

Problem Statement

Orders for two types of widgets (widget A and widget B) are received by **Widgets-R-Us Manufacturing Inc.** Widget A orders arrive on average every five minutes (exponentially distributed), while widget B orders arrive on average every ten minutes (exponentially distributed). Both widgets arrive at the input queue. An attribute Part_Type is defined to differentiate between the two types of widgets.

Widget A goes to the lathe for turning operations that take Normal(5,1) minutes. Widget B goes on to the mill for processing that takes Uniform(6,2) minutes. Both widgets go on to an inspection queue, where every fifth part is inspected. Inspection takes Normal(6,2) minutes. After inspection, 70 percent of the widgets pass and leave the system; 30 percent of the widgets fail and are sent back to the input queue for rework. Determine the following:

a. How many widgets of each type are shipped each week (40-hour week)?
b. What is the cycle time for each type of widget?
c. What are the maximum and minimum cycle times?
d. What is the number of widgets reworked each week?
e. What is the average number of widgets waiting in the inspection queue?

Five locations (Mill, Input_Queue, Lathe, Inspect, and Inspect_Q) are defined for this model. Three variables are defined, as in Figure L12.7. Figure L12.8 shows how we keep track of the machined quantity as well as the probabilistic routings

FIGURE L12.7
Variables for Widgets-R-Us.

Variables (global)

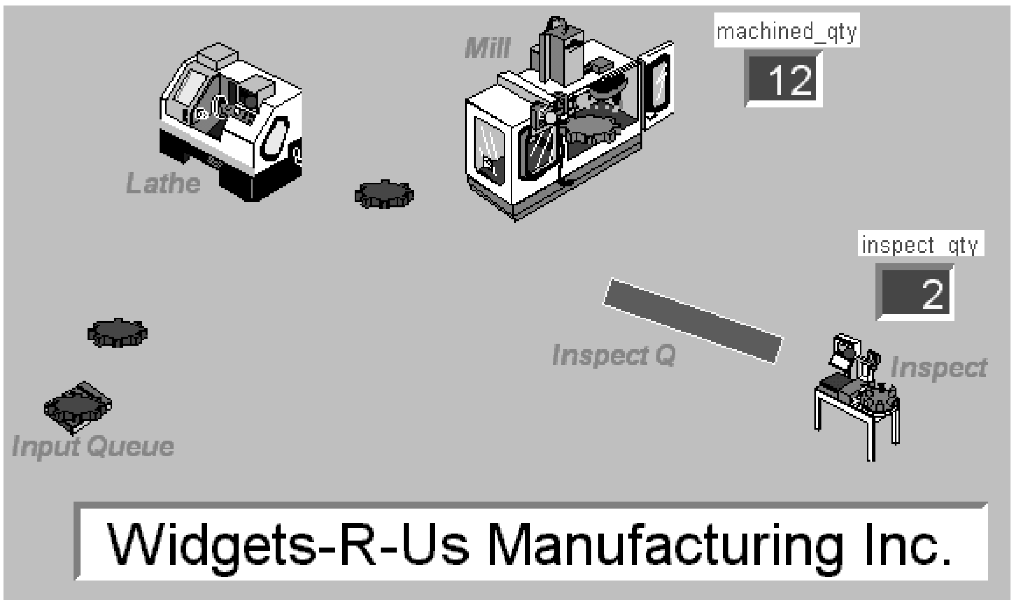
Icon	ID	Type...	Initial value	Stats...
No	qty	Integer	0	Time Series,
Yes	machined_qty	Integer	0	Time Series,
Yes	inspect_qty	Integer	0	Time Series,

FIGURE L12.8
Keeping track of machined_qty and probabilistic routings at the Inspect location.

```
                                   Process                         Routing

Entity    Location     Operation            Blk  Output     Destination  Rule            Move Logic
--------  -----------  -------------------  ---  ---------  -----------  --------------  ------------
Widget_A  Input_Queue  wait 0               1    Widget_A   Lathe        FIRST 1         move for 1
Widget_A  Lathe        Wait N(5,1) min      1    Widget_A   Inspect_Q    FIRST 1         move for 1
Widget_B  Input_Queue  wait 0               1    Widget_B   Mill         FIRST 1         move for 1
Widget_B  Mill         wait U(6,2) min      1    Widget_B   Inspect_Q    FIRST 1         move for 1
ALL       Inspect_Q    INC machined_qty
                       INC QTY              1    ALL        EXIT         IF qty < 5, 1
                                                 ALL        Inspect      IF qty = 5      INC inspect_qty
                                                                                         qty = 0
ALL       Inspect      Wait N(6,2) min      1    ALL        Input_Queue  0.300000 1      move for 1
                                                 ALL        EXIT         0.700000
```

FIGURE L12.9

Simulation model for Widgets-R-Us.



after inspection. Figure L12.9 shows the complete simulation model with counters added for keeping track of the number of widgets reworked and the number of widgets shipped.

L12.4 Merging a Submodel

Sometimes a large model is built in smaller segments. A model segment can be a manufacturing cell or a department. Different analysts can build each segment. After all segments are complete, they can be merged together to form a single unified model.

The Merge Model option in the File menu allows two or more independent (complete or incomplete) models to be merged together into a single model. Entity and attribute names common to both models are considered common elements in the merged model. Duplicate locations, resources, or path networks must first be renamed or deleted from the original merging model. If the graphic libraries are different, the user has an option to append the merging model's graphic library to the base model's graphic library. All other duplicate elements cause a prompt to appear with a choice to delete the duplicate element.

Problem Statement

Poly Casting Inc. (Lab 7, Section L7.4) decides to merge with **El Segundo Composites** (Lab 7, Section L7.6.1). The new company is named **El Segundo**

Castings N' Composites. Merge the model for Section L7.4 with the model for Section L7.6.1. All the finished products—castings as well as composites—are now sent to the shipping queue and shipping clerk. The model in Section L7.4 is shown in Figure L12.10. The complete simulation model, after the model for Section L7.6.1 is merged, is shown in Figure L12.11. After merging, make the necessary modifications in the process and routing tables.

We will make suitable modifications in the Processing module to reflect these changes (Figure L12.12). Also, the two original variables in Section L7.4 (WIP and PROD_QTY) are deleted and four variables are added: WIPCasting, WIPComposite, PROD_QTY_Casting, and PROD_QTY_Composite.

FIGURE L12.10

The layout of the simulation model for Section L7.4.

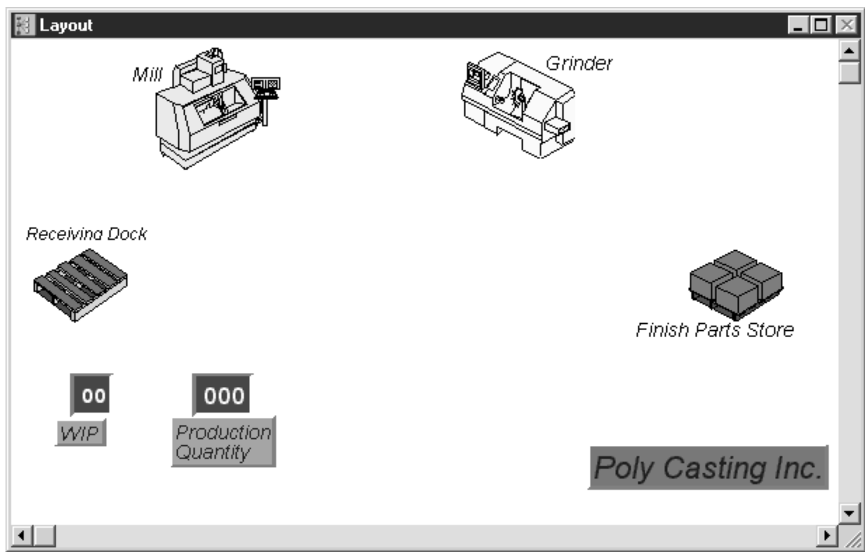


FIGURE L12.11

Merging the models from Section L7.4 and Section L7.6.1.

FIGURE L12.12

Changes made to the process table after merging.

Entity	Location	Operation (Process)	Blk	Output	Destination (Routing)	Rule	Move Logic
Casting	Receiving_Dock	WIPCasting = WIPCasting +1					
			1	Casting	Mill	FIRST 1	MOVE FOR 1 MIN
Casting	Mill	Wait N(3,1) min	1	Casting	Grinder	FIRST 1	MOVE FOR 1 MIN
Casting	Grinder	Wait U(5,1) min	1	Casting	Finish_Parts_Store	FIRST 1	MOVE FOR 1 MIN
Casting	Finish_Parts_Store		1	Casting	Ship_Q	FIRST 1	move for 1
Casting	Ship_Q		1	Casting	Ship_Clerk	FIRST 1	
Casting	Ship_Clerk	wait N(40,5) min					
		WIPCasting = WIPCasting -1					
		PROD_QTY_Casting = PROD_QTY_Casting + 1					
			1	Casting	EXIT	FIRST 1	
Composite	Order_Q	Inc WIPComposite	1	Composite	Ply_Cutting	FIRST 1	Move for 15 min
Composite	Ply_Cutting	Wait U(20,5) min	1	Composite	LayUp	FIRST 1	Move for 15 min
Composite	LayUp	Wait U(30,10) min					
			1	Composite	Oven	FIRST 1	Move for 15 min
Composite	Oven	Group 5 as Batch					
Batch	Oven	Wait U(100,10) min					
		UNGROUP					
Composite	Oven		1	Composite	Ship_Q	FIRST 1	Move for 15 min
Composite	Ship_Q		1	Composite	Ship_Clerk	FIRST 1	Move for 15 min
Composite	Ship_Clerk	Wait N(20,5) min					
		Dec WIPComposite					
		PROD_QTY_Composite=PROD_QTY_Composite+1					
			1	Composite	EXIT	FIRST 1	

L12.5 Preventive Maintenance and Machine Breakdowns

Downtime stops a location or resource from operating. Downtime can occur in one of two ways: preventive maintenance or breakdown. A down resource (or location) no longer functions and is not available for use. Downtimes may represent scheduled interruptions such as shifts, breaks, or scheduled maintenance. They may also represent unscheduled and random interruptions such as equipment failures.

The mean time between failures (MTBF) can be calculated as the reciprocal of the failure rate (distribution of failure over time). Often MTBF will follow a negative exponential distribution. In particular, the probability of failure before time T is given by $1 - e^{-T/\text{MTBF}}$. The reliability is viewed as performance over time and is the probability that a given location or resource will perform its intended function for a specified length of time T under normal conditions of use:

$$\text{Reliability} = \text{P(no failure before time } T) = e^{-T/\text{MTBF}}$$

The mean time to repair (MTTR) refers to the time the location or resource remains down for repair. The MTTR depends on the ease and/or cost with which a location or resource can be maintained or repaired.

For single-capacity locations, downtime of a location or resource can be scheduled at regular intervals based on the clock time that has expired, the number of entities processed at a location, the usage of the machine (resource) in time, or a change in entity type. Unscheduled breakdown of a machine can also be modeled in a similar fashion.

To model preventive maintenance or breakdowns, use the following procedure:

1. Go to the Build/Locations menu.
2. Click on the DT button.

3. Enter the frequency of downtime:
   a. Clock based.
   b. Number of entries based.
   c. Usage based.
4. Enter the first time downtime occurs.
5. Enter the priority of the downtime.
6. In the logic field, enter any logic associated with downtime.

   Example:

```
DISPLAY "The Lathe is down for preventive maintenance"
WAIT N(20,5) min
```

7. To disable the downtime feature, click Yes in the disable field. Otherwise, leave this field as No.

L12.5.1 Downtime Using MTBF and MTTR Data

The lathe and the mill at **Widgets-R-Us Manufacturing Inc.** (Section L12.3) have the maintenance schedule shown in Table L12.2. The logic for the preventive maintenance operation is created in Figure L12.13. The processes and

FIGURE L12.13

The logic for preventive maintenance at Widgets-R-Us Manufacturing Inc.

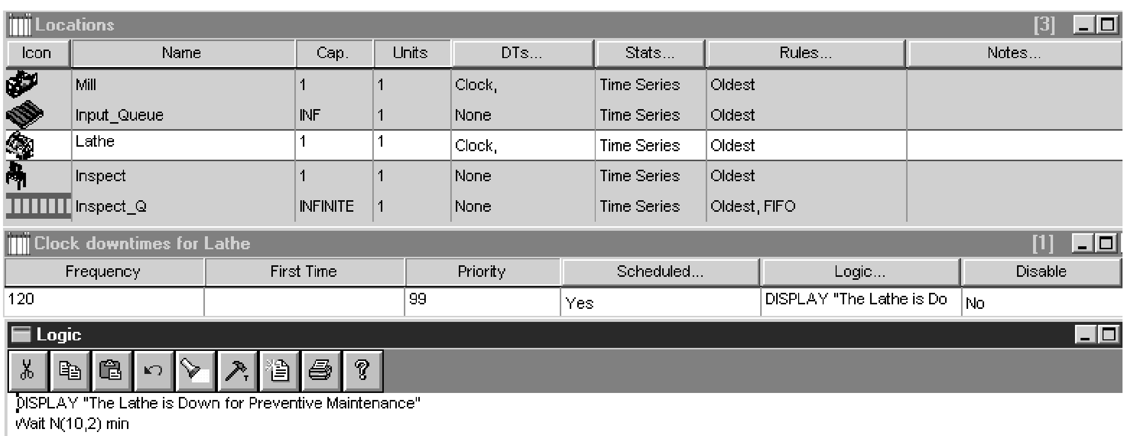


TABLE L12.2 Maintenance Schedule for Machines at Widgets-R-Us

Machine	*Time between Repairs*	*Time to Repair*
Lathe	120 minutes	N(10,2) minutes
Mill	200 minutes	T(10,15,20) minutes

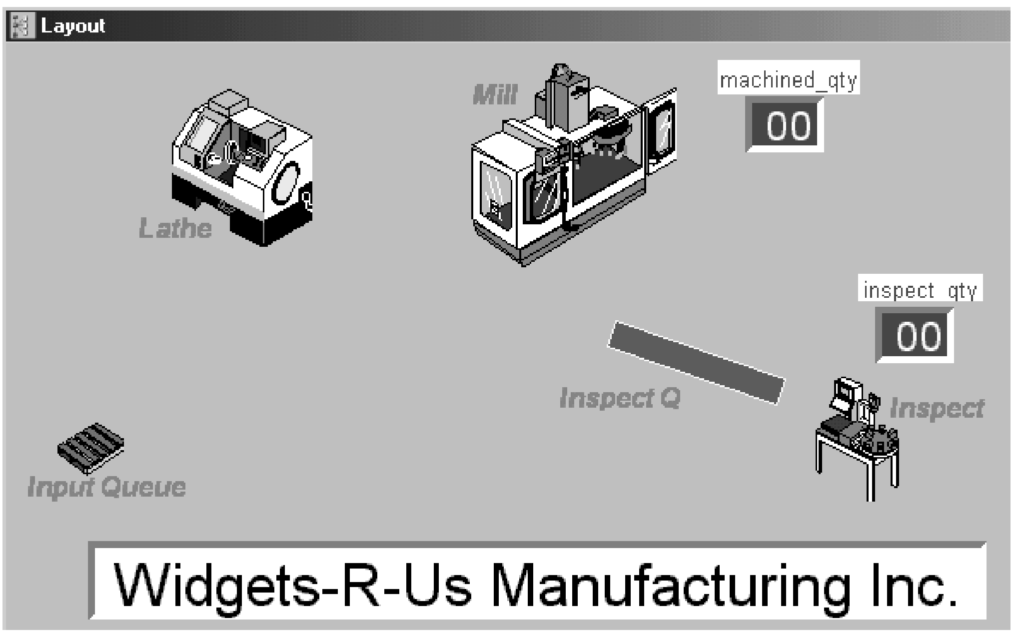
FIGURE L12.14

Processes and routings at Widgets-R-Us Manufacturing Inc.

Process			Routing				
Entity	**Location**	**Operation**	**Blk**	**Output**	**Destination**	**Rule**	**Move Logic**
Widget_A	Input_Queue	wait 0	1	Widget_A	Lathe	FIRST 1	move for 1
Widget_A	Lathe	Wait N(5,1) min	1	Widget_A	Inspect_Q	FIRST 1	move for 1
Widget_B	Input_Queue	wait 0	1	Widget_B	Mill	FIRST 1	move for 1
Widget_B	Mill	wait U(6,2) min	1	Widget_B	Inspect_Q	FIRST 1	move for 1
ALL	Inspect_Q	INC machined_qty INC QTY	1	ALL	EXIT	IF qty < 5, 1	
				ALL	Inspect	IF qty = 5	INC inspect_qty qty = 0
ALL	Inspect	Wait N(6,2) min	1	ALL	Input_Queue	0.300000 1	move for 1
				ALL	EXIT	0.700000	

FIGURE L12.15

Complete simulation model for Widgets-R-Us Manufacturing Inc.



routings are shown in Figure L12.14. Figure L12.15 shows the complete simulation model.

L12.5.2 Downtime Using MTTF and MTTR Data

Reliability of equipment is frequently calibrated in the field using the mean time to failure (MTTF) data instead of the MTBF data. MTTR is the expected time between the end of repair of a machine and the time the machine fails. Data collected in the field are often based on TTF for clock-based failures.

Problem Statement

The turning center in this machine shop (Figure L12.16) has a time to failure (TTF) distribution that is exponential with a mean of 10 minutes. The repair time (TTR) is also distributed exponentially with a mean of 10 minutes.

This model shows how to get ProModel to implement downtimes that use time to failure (TTF) rather than time between failures (TBF). In practice, you most likely will want to use TTF because that is how data will likely be available to you, assuming you have unexpected failures. If you have regularly scheduled downtimes, it may make more sense to use TBF. In this example, the theoretical percentage of uptime is MTTF/(MTTF + MTTR), where M indicates a mean value. The first time to failure and time to repair are set in the variable initialization section (Figure L12.17). Others are set in the downtime logic (Figure L12.18).

The processing and routing tables are shown in Figure L12.19. Run this model for about 1000 hours, then view the batch mean statistics for downtime by picking "averaged" for the period (Figure L12.20) when the output analyzer (classical) comes up. The batch mean statistics for downtime for the turning center are shown in Figure L12.21. (This problem was contributed by Dr. Stephen Chick, University of Michigan, Ann Arbor.)

FIGURE L12.16
Layout of the machine shop—modeling breakdown with TTF and TTR.

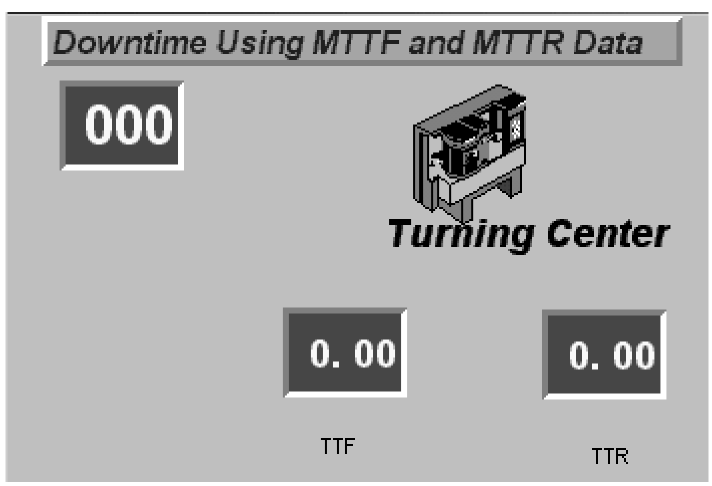


FIGURE L12.17
Variable initializations.

```
**********************************************************
*                                   Variables (global)
**********************************************************

  ID         Type         Initial value Stats
  ---------- ------------ ------------- -----------
  ttf        Real         e(MTTF)       Time Series
  ttr        Real         e(MTTR)       Time Series
```

FIGURE L12.18

Clock downtime logic.

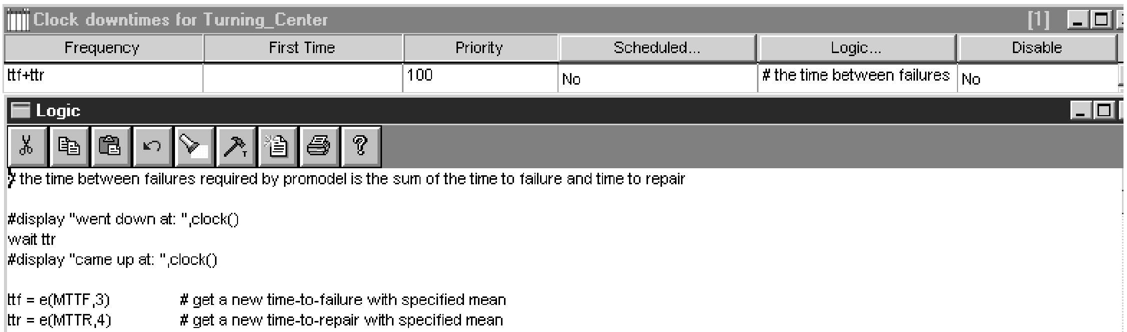


FIGURE L12.19

Process and routing tables.

Process			Routing				
Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Machinist	Loc1		1	Machinist	Turning_Center	FIRST 1	
Machinist	Turning_Center	wait e(.5,5)	1	Machinist	EXIT	FIRST 1	

FIGURE L12.20

Average of all the batches in the Classical ProModel Output Viewer.

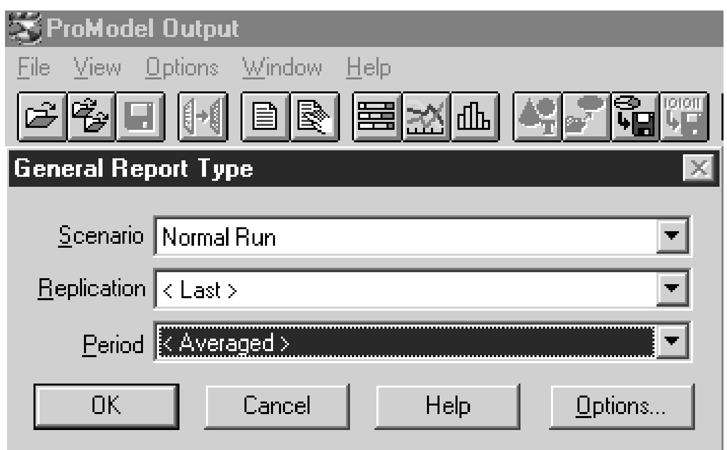


FIGURE L12.21

Batch mean statistics for downtime.

BATCH MEAN ANALYSIS (Sample size 50)

Statistic	Avg	Median	Min	Max	Std Dev	Low 90% CI	High 90% CI
Turning_Center - % Down	49.18	49.59	38.41	55.88	4.56	48.08	50.28

L12.6 Operator Shifts

ProModel offers an excellent interface to include the operator (location or resource) shift working schedules in the simulation model. The shift work for each operator in the model can be defined separately. Work cycles that repeat either daily or weekly can be defined.

Problem Statement

Orders for two types of widgets (widget A and widget B) are received by **Widgets-R-Us Manufacturing Inc.** Widget A orders arrive on average every 5 minutes (exponentially distributed), while widget B orders arrive on average every 10 minutes (exponentially distributed). Both widgets arrive at the input queue. An attribute Part_Type is defined to differentiate between the two types of widgets.

Widget A goes on to the lathe for turning operations that take Normal(5,1) minutes. Widget B goes on to the mill for processing that takes Uniform(4,8) minutes. Both widgets go on to an inspection queue, where every fifth part is inspected. Inspection takes Normal(6,2) minutes. After inspection, 70 percent of the widgets pass and leave the system, while 30 percent of the widgets fail and are sent back to the input queue for rework.

An operator is used to process the parts at both the lathe and the mill. The operator is also used to inspect the part. The operator moves the parts from the input queue to the machines as well as to the inspection station. The operator is on a shift from 8 A.M. until 5 P.M. with breaks as shown in Table L12.3 and Figures L12.22 and L12.23.

Use the `DISPLAY` statement to notify the user when the operator is on a break. Set up a break area (Figure L12.24) for the operator by extending the path network to a break room and indicating the node as the break node in Resource specs. The processes and the routings at Widgets-R-Us are shown in Figure L12.25. Determine the following:

a. How many widgets of each type are shipped each week (40-hour week).

b. The cycle time for each type of widgets.

c. The maximum and minimum cycle times.

TABLE L12.3 The Operator Break Schedule at Widgets-R-Us Manufacturing Inc.

Breaks	*From*	*To*
Coffee break	10 A.M.	10:15 A.M.
Lunch break	12 noon	12:45 P.M.
Coffee break	3 P.M.	3:15 P.M.

FIGURE L12.22

The operator Joe's weekly work and break times at Widgets-R-Us.

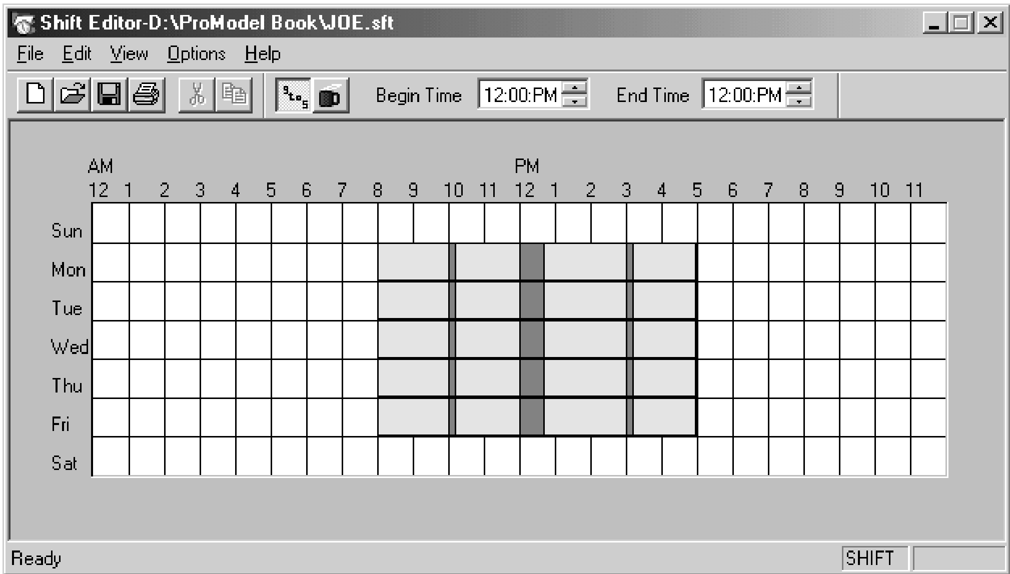
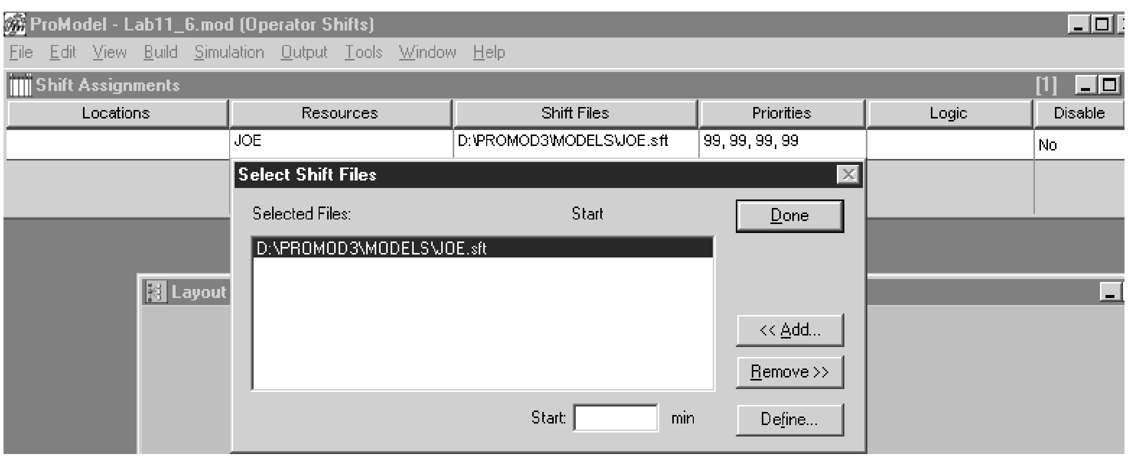


FIGURE L12.23

Assigning the Shift File to the operator Joe.



d. The number of widgets reworked each week.

e. The average number of widgets waiting in the inspection queue.

Run the model with and without shift breaks (Figure L12.26). What difference do you notice in these statistics? How can you improve the system?

FIGURE L12.24

The layout and path network at Widgets-R-Us.

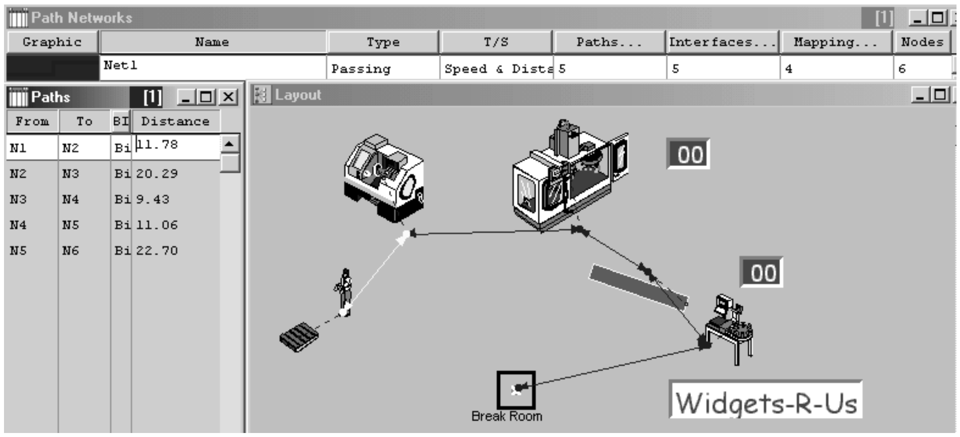


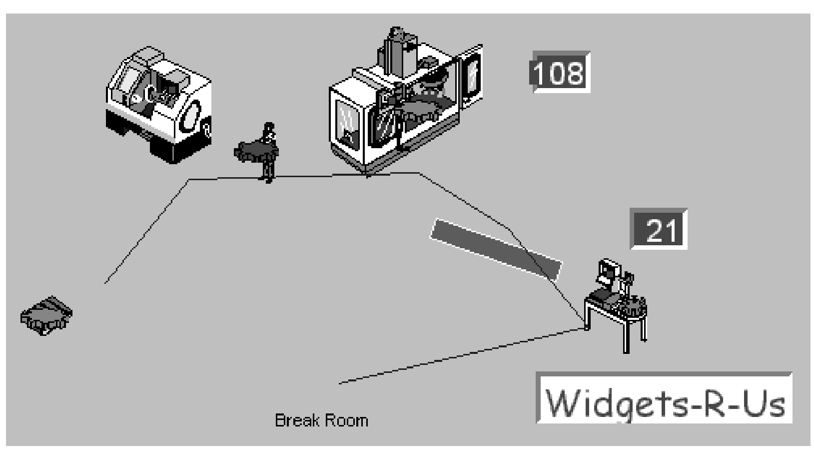
FIGURE L12.25

Processes and routings at Widgets-R-Us.

Process			Routing				
Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Widget_A	Input_Queue	wait 0	1	Widget_A	Lathe	FIRST 1	move WITH JOE THEN FREE
Widget_A	Lathe	GET JOE Wait N(5,1) FREE JOE	1	Widget_A	iNSPECT_Q	FIRST 1	Move WITH JOE THEN FREE
Widget_B	Input_Queue	wait 0	1	Widget_B	Mill	FIRST 1	Move WITH JOE THEN FREE
Widget_B	Mill	GET JOE wait U(4,8) FREE JOE	1	Widget_B	iNSPECT_Q	FIRST 1	Move WITH JOE THEN FREE
ALL	iNSPECT_Q	inc machined_qty INC QTY	1	ALL	EXIT	IF qty < 5, 1	
				ALL	Inspect	IF qty = 5	inc inspect_qty qty = 0
ALL	Inspect	GET JOE Wait N(6,2) FREE JOE	1	ALL	Input_Queue	0.300000 1	Move WITH JOE THEN FREE
				ALL	EXIT	0.700000	

FIGURE L12.26

A snapshot during the simulation model run for Widgets-R-Us.



L12.7 Job Shop

A job shop is a collection of processing centers through which jobs are routed in different sequences depending on the characteristics of the particular job. It is a common method of grouping resources for producing small lots with widely varying processing requirements.

Each job in a job shop usually has a unique routing sequence. Job shops usually have a process layout. In other words, similar processes are geographically grouped together.

Problem Statement

In **Joe's Jobshop** there are three machines through which three types of jobs are routed. All jobs go to all machines, but with different routings. The data for job routings and processing times (minutes) are given in Table L12.4. The process times are exponentially distributed with the given average values. Jobs arrive at the rate of Exponential(30) minutes. Simulate for 10 days (80 hours). How many jobs of each type are processed in 10 days?

Figures L12.27, L12.28, L12.29, L12.30, and L12.31 show the locations, entities, variables, processes, and layout of Joe's Jobshop.

FIGURE L12.27

Locations at Joe's Jobshop.

Locations

Icon	Name	Cap.	Units	DTs...	Stats...	Rules...
	Machining_Center1	1	1	None	Time Series	Oldest
	Machining_Center2	1	1	None	Time Series	Oldest
	Machining_Center3	1	1	None	Time Series	Oldest
	Incoming	INFINITE	1	None	Time Series	Oldest, FIFO
	MC1_Q	INFINITE	1	None	Time Series	Oldest, FIFO
	MC2_Q	INFINITE	1	None	Time Series	Oldest, FIFO
	MC3_Q	INFINITE	1	None	Time Series	Oldest, FIFO

TABLE L12.4 Summary of Process Plan for Joe's Jobshop

Jobs	*Machines*	*Process Times (minutes)*	*Job Mix*
A	2–3–1	45–60–75	25%
B	1–2–3	70–70–50	35%
C	3–1–2	50–60–60	40%

FIGURE L12.28
Entities at Joe's Jobshop.

```
****************************************************
                      Entities
****************************************************

Name        Speed (fpm)  Stats        Cost
----------  ------------ ------------ ------------
Job         150          Time Series
Job_A       150          Time Series
Job_B       150          Time Series
Job_C       150          Time Series
```

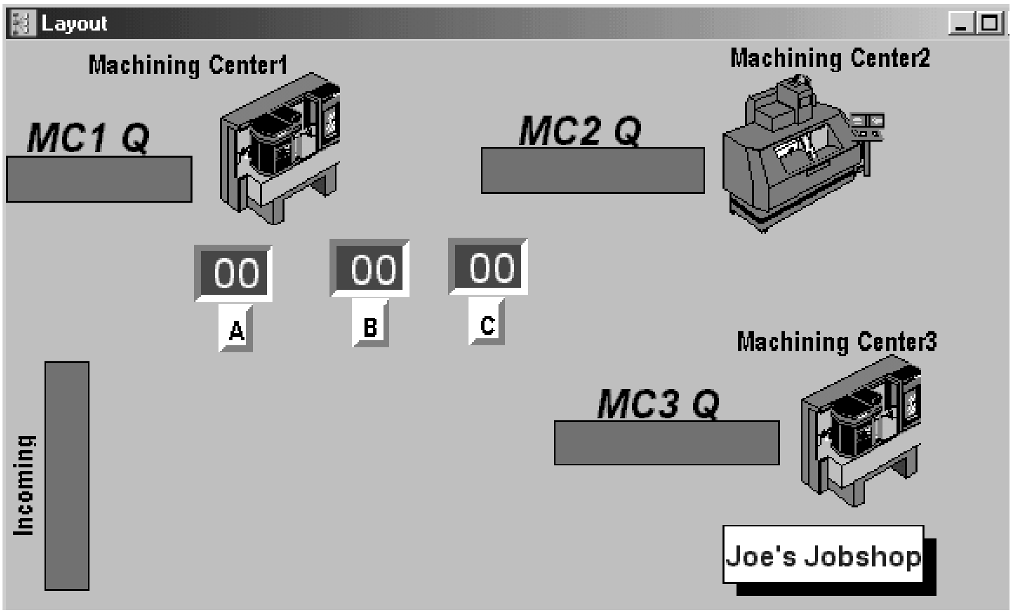
FIGURE L12.29
Variables to track jobs processed at Joe's Jobshop.

```
****************************************************
                      Variables (global)
****************************************************

ID          Type         Initial value Stats
----------  ------------ ------------- -----------
qty_A       Integer      0             Time Series
qty_B       Integer      0             Time Series
qty_C       Integer      0             Time Series
```

FIGURE L12.30
Processes and routings at Joe's Jobshop.

```
                                   Process                        Routing

Entity   Location          Operation         Blk  Output   Destination       Rule
-------- ----------------- ----------------- ---- -------- ----------------- ----------
Job      Incoming                            1    Job_A    MC2_Q             0.250000 1
                                                  Job_B    MC1_Q             0.350000
                                                  Job_C    MC3_Q             0.400000
Job_A    MC2_Q                               1    Job_A    Machining_Center2 FIRST 1
Job_A    Machining_Center2 wait e(45) min    1    Job_A    MC3_Q             FIRST 1
Job_A    MC3_Q                               1    Job_A    Machining_Center3 FIRST 1
Job_A    Machining_Center3 wait e(60) min    1    Job_A    MC1_Q             FIRST 1
Job_A    MC1_Q                               1    Job_A    Machining_Center1 FIRST 1
Job_A    Machining_Center1 wait e(75) min
                           qty_A = qty_A + 1
                                             1    Job_A    EXIT              FIRST 1
Job_B    MC1_Q                               1    Job_B    Machining_Center1 FIRST 1
Job_B    Machining_Center1 wait e(70) min    1    Job_B    MC2_Q             FIRST 1
Job_B    MC2_Q                               1    Job_B    Machining_Center2 FIRST 1
Job_B    Machining_Center2 wait e(70) min    1    Job_B    MC3_Q             FIRST 1
Job_B    MC3_Q                               1    Job_B    Machining_Center3 FIRST 1
Job_B    Machining_Center3 wait e(50) min
                           qty_B = qty_B + 1
                                             1    Job_B    EXIT              FIRST 1
Job_C    MC3_Q                               1    Job_C    Machining_Center3 FIRST 1
Job_C    Machining_Center3 wait e(50) min    1    Job_C    MC1_Q             FIRST 1
Job_C    MC1_Q                               1    Job_C    Machining_Center1 FIRST 1
Job_C    Machining_Center1 wait e(60) min    1    Job_C    MC2_Q             FIRST 1
Job_C    MC2_Q                               1    Job_C    Machining_Center2 FIRST 1
Job_C    Machining_Center2 wait e(60) min
                           qty_C = qty_C + 1
                                             1    Job_C    EXIT              FIRST 1
```

FIGURE L12.31
Layout of Joe's Jobshop.



L12.8 Modeling Priorities

Priorities allow us to determine the order in which events occur in the simulation. The most common uses of priorities are

1. Selecting among upstream processes.
2. Selecting among downstream processes—already discussed in Lab 7, Section L7.3.
3. Selecting resources.
4. Prioritizing downtimes—discussed in Section L12.5.

L12.8.1 Selecting among Upstream Processes

This is the process of choosing among a set of upstream processes or queues for entity removal and routing to a downstream process. When one downstream destination exists and two or more upstream entities are competing to get there, priorities can be used. In the example in Figure L12.32 two entities at different locations (Process A and Process B) are both trying to get to Process C.

Problem Statement
At **Wang's Export Machine Shop** in the suburbs of Chicago, two types of jobs are processed: domestic and export. The rate of arrival of both types of jobs is

FIGURE L12.32

Choosing among upstream processes.

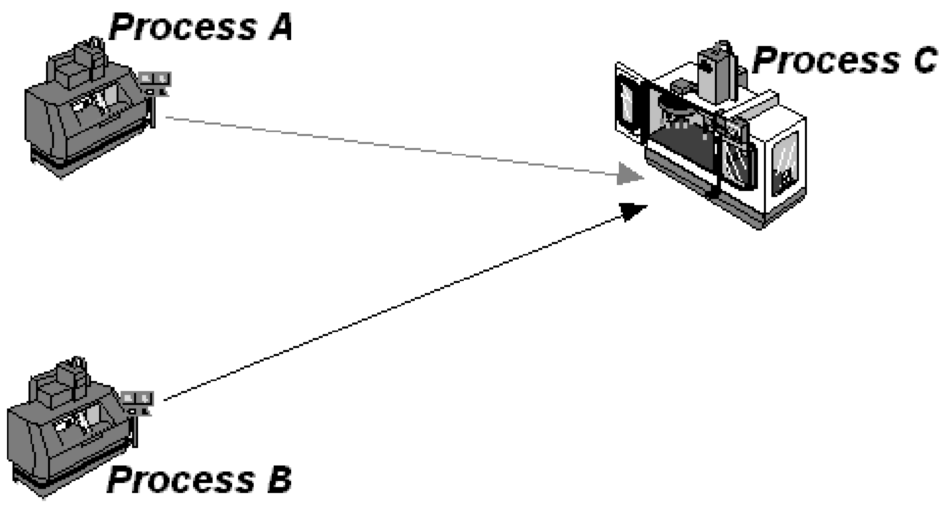


TABLE L12.5 Process Times at Wang's Export Machine Shop

Machine	*Process Time*
Machining center	Triangular(10,12,18) minutes
Lathe	Triangular(12,15,20) minutes

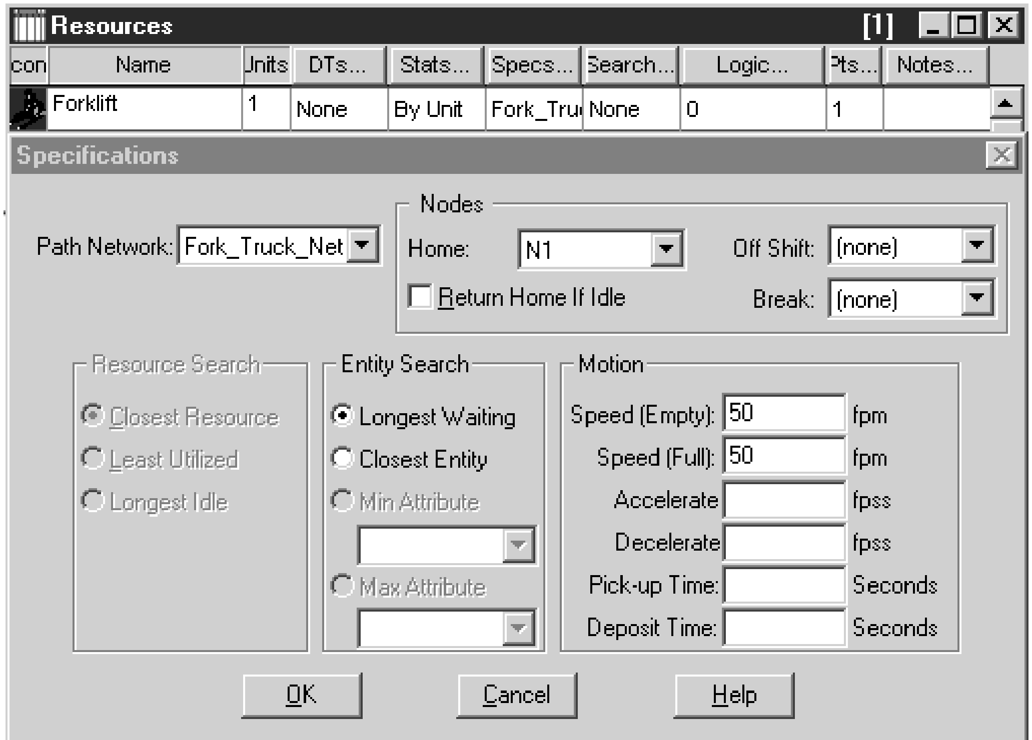
TABLE L12.6 Distances between Locations

From	*To*	*Distance (feet)*
Incoming	Machining center	200
Machining center	Lathe	400
Lathe	Outgoing	200
Outgoing	Incoming	400

Exponential(60) minutes. All jobs are processed through a machining center and a lathe. The processing times (Table L12.5) for all jobs are triangularly distributed. A forklift truck that travels at the rate of 50 feet/minute handles all the material. Export jobs are given priority over domestic jobs for shop release—that is, in moving from the input queue to the machining center. The distance between the stations is given in Table L12.6. Simulate for 16 hours.

FIGURE L12.33

Forklift resource specified for Wang's Export Machine Shop.



Five locations are defined: Lathe, Machining_Center, In_Q_Domestic, In_Q_Export, and Outgoing_Q. Two entities (domestic and export) are defined. Both these entities arrive with an interarrival time that is exponentially distributed with a mean of 60 minutes. The resource (forklift) and its path network are shown in Figures L12.33 and L12.34, respectively. The processes and routings are shown in Figure L12.35. Note that the priority of domestic jobs is set at a value of 1 (Figure L12.33), while that of export jobs is set at 10. Higher priority numbers signify higher priority in terms of selecting the upstream process. The priorities can range from 0 to 999. The default priority is 0.

L12.8.2 Selecting Resources

Priorities can also be used to decide which process, among two or more competing processes requesting the same resource, will have priority in capturing that resource.

FIGURE L12.34

Definition of path network for forklift for Wang's Export Machine Shop.

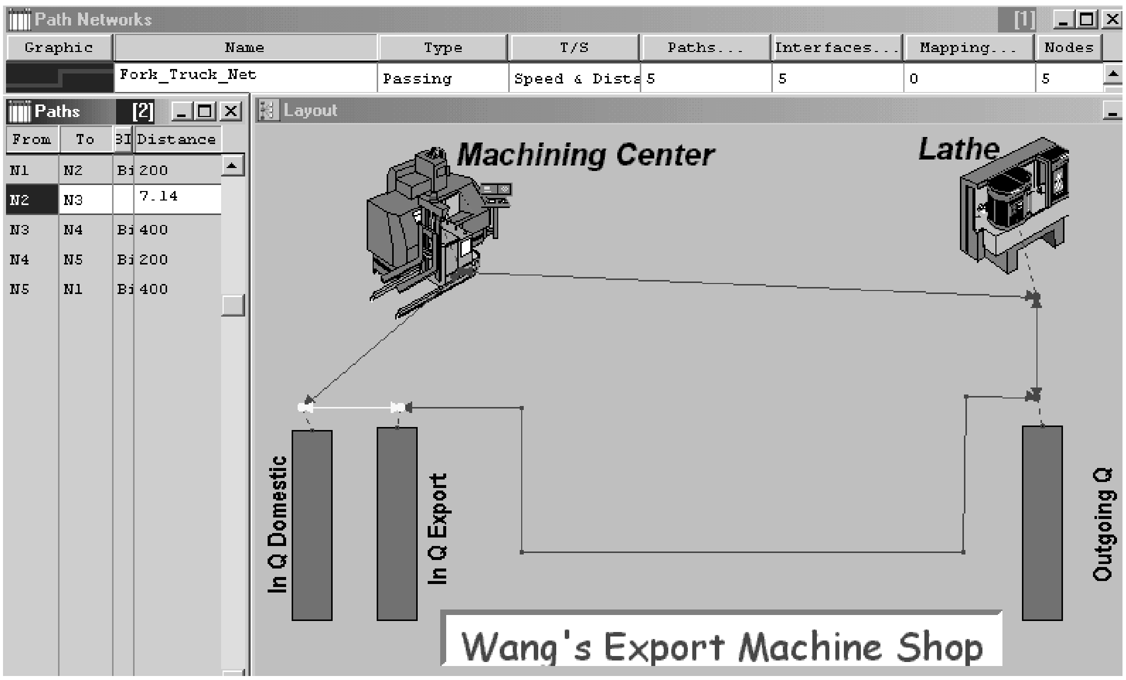


FIGURE L12.35

Processes and routings defined for Wang's Export Machine Shop.

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

                              Process                         Routing

Entity   Location         Operation          Blk  Output   Destination         Rule    Move Logic
-------- ---------------- ------------------ ---- -------- ------------------- ------- ------------
Domestic In_Q_Domestic
                                             1    Domestic Machining_Center.1  FIRST 1 Move with Forklift Then Free


Domestic Machining_Center wait t(10,12,18) min

                                             1    Domestic Lathe               FIRST 1 Move with Forklift Then Free
Domestic Lathe            wait t(12,15,20) min

                                             1    Domestic Outgoing_Q          FIRST 1 Move with Forklift Then Free
Domestic Outgoing_Q                          1    Domestic EXIT                FIRST 1
Export   In_Q_Export                         1    Export   Machining_Center.10 FIRST 1 Move with Forklift Then Free
Export   Machining_Center wait t(10,12,18) min

                                             1    Export   Lathe               FIRST 1 Move with Forklift Then Free
Export   Lathe            wait t(12,15,20) min
                                             1    Export   Outgoing_Q          FIRST 1 Move with Forklift Then Free
Export   Outgoing Q                          1    Export   EXIT                FIRST 1
```

Problem Statement

At **Wang's Export Machine Shop,** two types of jobs are processed: domestic and export. Mr. Wang is both the owner and the operator. The rate of arrival of both types of jobs is Exponential(60) minutes. Export jobs are processed on machining center E, and the domestic jobs are processed on machining center D. The processing times for all jobs are triangularly distributed (10, 12, 18) minutes. Mr. Wang gives priority to export jobs over domestic jobs. The distance between the stations is given in Table L12.7.

Five locations (Machining_Center_D, Machining_Center_E, In_Q_Domestic, In_Q_Export, and Outgoing_Q) are defined. Two types of jobs (domestic and export) arrive with an exponential interarrival frequency distribution of 60 minutes. Mr. Wang is defined as a resource in Figure L12.36. The path network and the processes are shown in Figures L12.37 and L12.38 respectively. Mr. Wang is getting old and can walk only 20 feet/minute with a load and 30 feet/minute without a load. Simulate for 100 hours.

Priorities of resource requests can be assigned through a `GET`, `JOINTLY GET`, or `USE` statement in operation logic, downtime logic, or move logic or the subroutines called from these logics. Priorities for resource downtimes are assigned in the Priority field of the Clock and Usage downtime edit tables.

Note that the priority of the resource (Mr_Wang) is assigned through the `GET` statement in the operation logic (Figure L12.38). The domestic orders have a resource request priority of 1, while that of the export orders is 10.

FIGURE 12.36

Resource defined for Wang's Export Machine Shop.

```
*******************************************************************************
*                                  Resources                                  *
*******************************************************************************

                              Res      Ent
 Name      Units Stats    Search   Search Path        Motion        Cost
 --------  ----- -------- -------  ------ ----------  ------------- -----
 Mr_Wang   1     By Unit  Closest  Oldest Net1        Empty: 30 fpm
                                          Home: N1    Full: 20 fpm
```

TABLE L12.7 Distances between Stations at Wang's Export Machine Shop

From	*To*	*Distance (feet)*
Machining_Center_E	Machining_Center_D	200
Machining_Center_D	Outgoing	200
Outgoing	Machining_Center_E	200

FIGURE L12.37

Path network defined at Wang's Export Machine Shop.

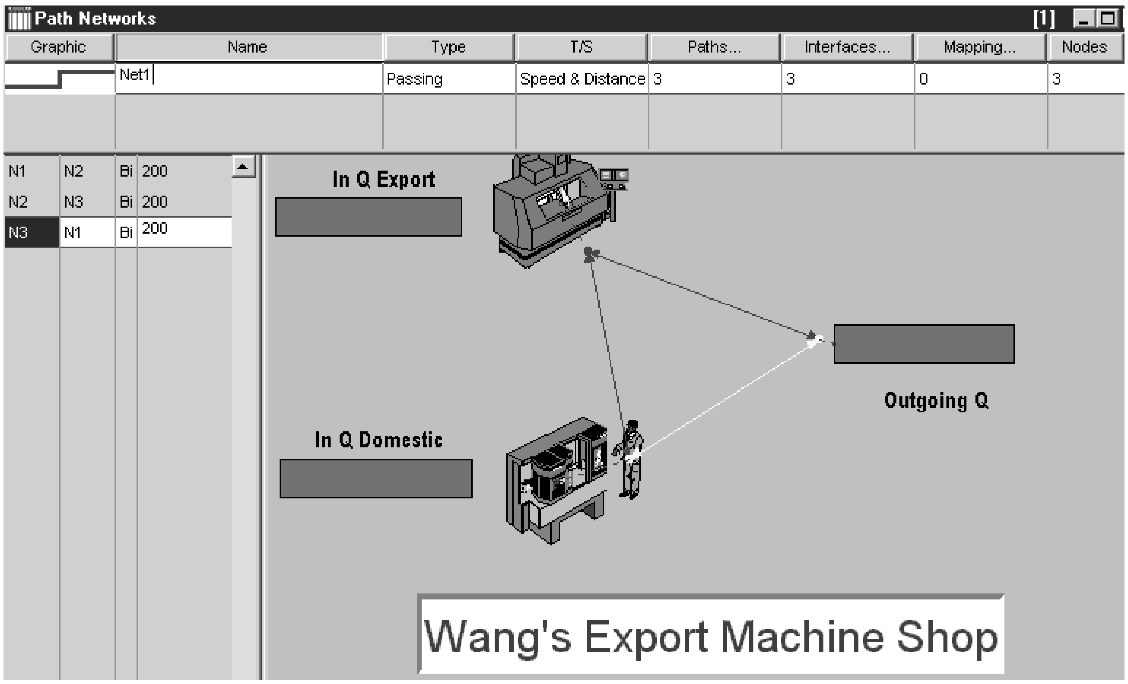


FIGURE L12.38

Processes and routings defined at Wang's Export Machine Shop.

Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Domestic	In_Q_Domestic		1	Domestic	Machining_Center_D	FIRST 1	
Domestic	Machining_Center_D	Get Mr_Wang, 1 wait t(10,12,18) min Free Mr_Wang					
			1	Domestic	Outgoing_Q	FIRST 1	Move with Mr_Wang Then Free
Domestic	Outgoing_Q		1	Domestic	EXIT	FIRST 1	
Export	In_Q_Export		1	Export	Machining_Center_E	FIRST 1	
Export	Machining_Center_E	Get Mr_Wang, 10 wait t(10,12,18) min Free Mr_Wang					
			1	Export	Outgoing_Q	FIRST 1	Move with Mr_Wang Then Free
Export	Outgoing_Q		1	Export	EXIT	FIRST 1	

The results (partial) are shown in Figure L12.39. Note that the average time waiting for the resource (Mr_Wang) is about 50 percent more for the domestic jobs (with lower priority) than for the export jobs. The average time in the system for domestic jobs is also considerably more than for the export jobs.

FIGURE L12.39

Part of the results showing the entity activities.

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

Entity Activity for lab_L11_8_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)
Domestic	81	35	894	53	755	14	72
Export	81	21	643	53	504	14	72

L12.9 Modeling a Pull System

A pull system is a system in which locations produce parts only on downstream demand. There are two types of pull systems:

1. Those based on limited buffer or queue sizes.
2. Those based on more distant "downstream" demand.

The first type of pull system is modeled in ProModel by defining locations with limited capacity. In this type of system, upstream locations will be able to send parts to downstream locations only when there is capacity available.

L12.9.1 Pull Based on Downstream Demand

The second type of pull system requires the use of a `SEND` statement from a downstream location to trigger part movement from an upstream location.

Problem Statement

In the **Milwaukee Machine Shop,** two types of jobs are processed within a machine cell. The cell consists of one lathe and one mill. Type 1 jobs must be processed first on the lathe and then on the mill. Type 2 jobs are processed only on the mill (Table L12.8). All jobs are processed on a first-in, first-out basis.

Brookfield Forgings is a vendor for the Milwaukee Machine Shop and produces all the raw material for them. Forgings are produced in batches of five every day (exponential with a mean of 24 hours). However, the customer supplies them only on demand. In other words, when orders arrive at the Milwaukee Machine Shop, the raw forgings are supplied by the vendor (a pull system of shop loading). Simulate for 100 days (2400 hours). Track the work-in-process inventories and the production quantities for both the job types.

Six locations (Mill, Lathe, Brookfield_Forgings, Order_Arrival, Lathe_Q, and Mill_Q) and four entities (Gear_1, Gear_2, Orders_1, and Orders_2) are defined. The arrivals of various entities are defined as in Figure L12.40. Four variables are defined as shown in Figure L12.41. The processes and routings are

FIGURE L12.40

Arrival of orders at the Milwaukee Machine Shop.

```
********************************************************************************
*                                  Arrivals                                    *
********************************************************************************

 Entity    Location             Qty each    First Time Occurrences Frequency  Logic
 --------  -------------------- ----------  ---------- ----------- ---------- -----
 Gear_1    Brookfield_Forgings 5           0          inf         e(24)
 Gear_2    Brookfield_Forgings 5           0          INF         e(24)
 Orders_1 Orders_Arrival       1           0          inf         e(8)
 Orders_2 Orders_Arrival       1           0          inf         e(10)
```

FIGURE L12.41

Variables defined for the Milwaukee Machine Shop.

```
****************************************************
*                 Variables (global)               *
****************************************************

 ID          Type          Initial value Stats
 ----------  ------------  ------------- -----------
 wip1        Integer       0             Time Series
 wip2        Integer       0             Time Series
 prod1       Integer       0             Time Series
 prod2       Integer       0             Time Series
```

TABLE L12.8 Order Arrival and Process Time Data for the Milwaukee Machine Shop

Job Type	*Number of Orders*	*Time between Order Arrival*	*Processing Time on Lathe*	*Processing Time on Mill*
1	120	E(8) hrs	E(3) hrs	U(3,1) hrs
2	100	E(10) hrs	—	U(4,1) hrs

shown in Figure L12.42. Note that as soon as a customer order is received at the Milwaukee Machine Shop, a signal is sent to Brookfield Forgings to ship a gear forging (of the appropriate type). Thus the arrival of customer orders pulls the raw material from the vendor. When the gears are fully machined, they are united (JOINed) with the appropriate customer order at the orders arrival location. Figure L12.43 shows a layout of the Milwaukee Machine Shop and a snapshot of the simulation model.

L12.9.2 Kanban System

The kanban system is one of the methods of control utilized within the Toyota production system (TPS). The basic philosophy in TPS is total elimination of

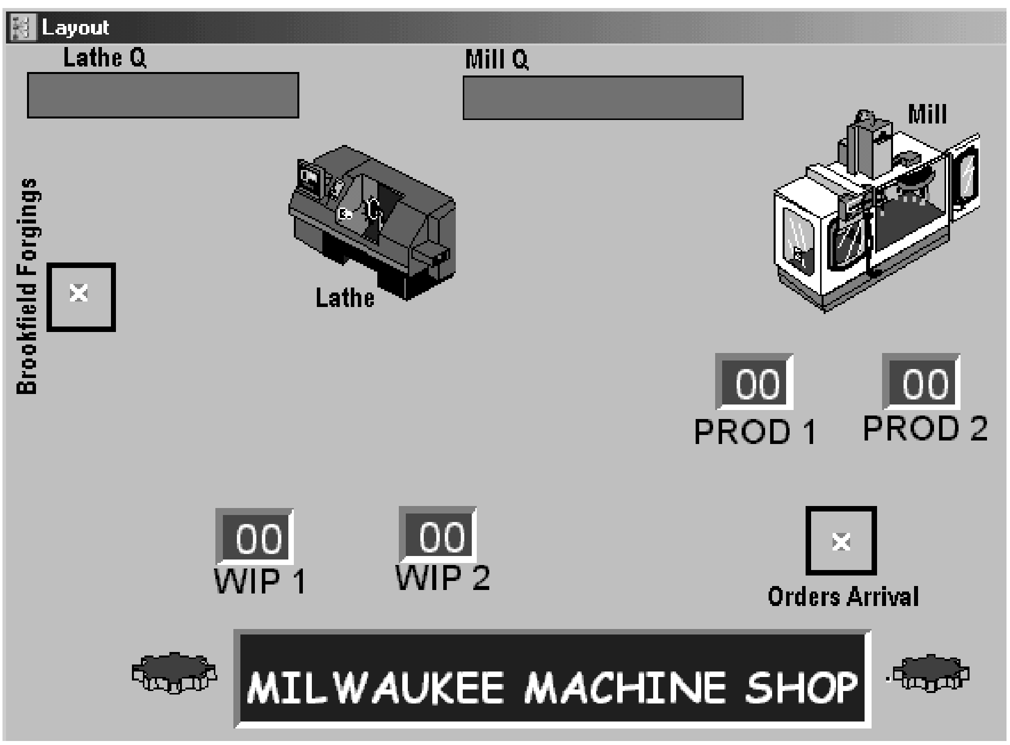
FIGURE L12.42

Processes and routings defined for the Milwaukee Machine Shop.

		Process			Routing		
Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Gear_1	Brookfield_Forgings		1	Gear_1	Lathe_Q	SEND 1	WIP1=WIP1+1
Gear_1	Lathe_Q		1	Gear_1	Lathe	FIRST 1	
Gear_1	Lathe	WAIT E(3)	1	Gear_1	Mill_Q	FIRST 1	
Gear_1	Mill_Q		1	Gear_1	Mill	FIRST 1	
Gear_1	Mill	WAIT U(3,1)	1	Gear_1	Orders_Arrival	JOIN 1	
Gear_2	Brookfield_Forgings		1	Gear_2	Mill_Q	SEND 1	wip2=wip2+1
Gear_2	Mill_Q		1	Gear_2	Mill	FIRST 1	
Gear_2	Mill	WAIT U(4,1)	1	Gear_2	Orders_Arrival	JOIN 1	
Orders_1	Orders_Arrival	SEND 1 GEAR_1 TO LATHE_Q JOIN 1 GEAR_1 wip1=wip1-1 prod1=prod1+1	1	Orders_1	EXIT	FIRST 1	
Orders_2	Orders_Arrival	SEND 1 GEAR_2 TO MILL_Q JOIN 1 GEAR_2 wip2=wip2-1 prod2=prod2+1	1	Orders_2	EXIT	FIRST 1	

FIGURE L12.43

Simulation model for the Milwaukee Machine Shop.



waste in machines, equipment, and personnel. To make the flow of things as close as possible to this ideal condition, a system of just-in-time procurement of material is used—that is, obtain material when needed and in the quantity needed.

"Kanban" literally means "visual record." The word *kanban* refers to the signboard of a store or shop, but at Toyota it simply means any small sign displayed in front of a worker. The kanban contains information that serves as a work order. It gives information concerning what to produce, when to produce it, in what quantity, by what means, and how to transport it.

Problem Statement

A consultant recommends implementing a production kanban system for Section 12.9.1's **Milwaukee Machine Shop.** Simulation is used to find out how many kanbans should be used. Model the shop with a total of five kanbans.

The kanban procedure operates in the following manner:

1. As soon as an order is received by the Milwaukee Machine Shop, they communicate it to Brookfield Forgings.
2. Brookfield Forgings holds the raw material in their own facility in the forging queue in the sequence in which the orders were received.
3. The production of jobs at the Milwaukee Machine Shop begins only when a production kanban is available and attached to the production order.
4. As soon as the production of any job type is finished, the kanban is detached and sent to the kanban square, from where it is pulled by Brookfield Forgings and attached to a forging waiting in the forging queue to be released for production.

The locations at the Milwaukee Machine Shop are defined as shown in Figure L12.44. Kanbans are defined as virtual entities in the entity table (Figure L12.45).

The arrival of two types of gears at Brookfield Forgings is shown in the arrivals table (Figure L12.46). This table also shows the arrival of two types of customer orders at the Milwaukee Machine Shop. A total of five kanbans are generated at the beginning of the simulation run. These are recirculated through the system.

FIGURE L12.44

Locations at the Milwaukee Machine Shop.

```
**********************************************************************
                               Locations
**********************************************************************

Name                 Cap      Units Stats       Rules          Cost
-------------------- -------- ----- ----------- -------------- -----
Mill                 1        1     Time Series Oldest, ,
Lathe                1        1     Time Series Oldest, ,
Brookfield_Forgings  INF      1     Time Series Oldest, ,
Orders_Arrival       INF      1     Time Series Oldest, ,
Lathe_Q              INFINITE 1     Time Series Oldest, FIFO,
Mill_Q               INFINITE 1     Time Series Oldest, FIFO,
kanban_square        5        1     Time Series Oldest, ,
Order_Q              INFINITE 1     Time Series Oldest, FIFO,
```

Figure L12.45

Entities defined for Milwaukee Machine Shop.

Entities

Name	Speed (fpm)	Stats	Cost
Gear_1	150	Time Series	
Gear_2	150	Time Series	
Orders_1	150	Time Series	
Orders_2	150	Time Series	
kanban	150	Time Series	

Figure L12.46

Arrival of orders at Milwaukee Machine Shop.

Arrivals

Entity	Location	Qty each	First Time	Occurrences	Frequency	Logic
Gear_1	Brookfield_Forgings	5	0	inf	e(24)	
Gear_2	Brookfield_Forgings	5	0	INF	e(24)	
Orders_1	Orders_Arrival	1	0	inf	e(8)	
Orders_2	Orders_Arrival	1	0	inf	e(10)	
kanban	kanban_square	5	0	1	0	

Figure L12.47

Simulation model of a kanban system for the Milwaukee Machine Shop.

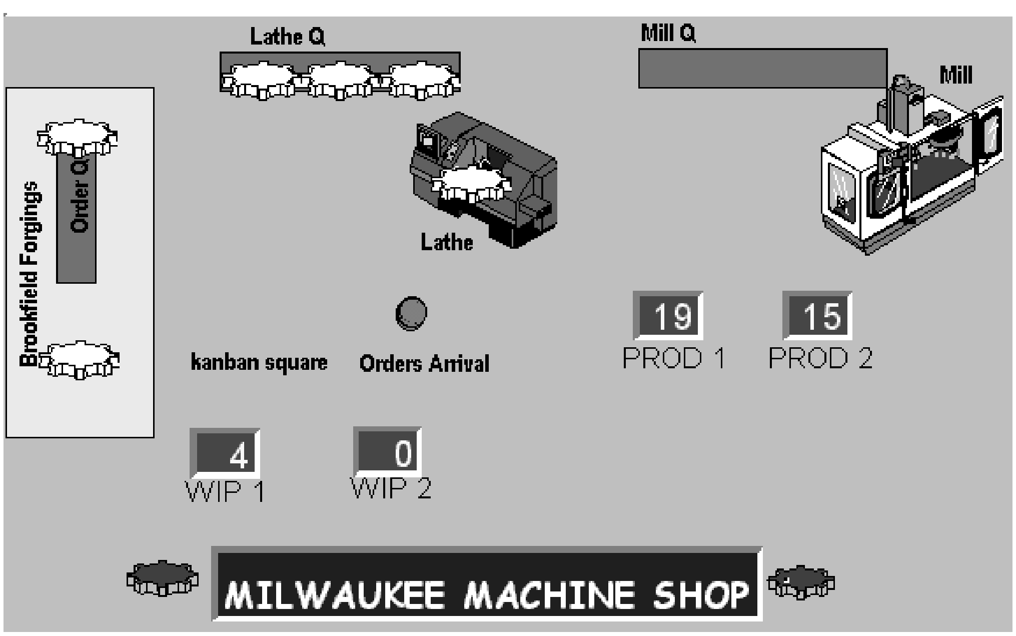


FIGURE L12.48

Process and routing tables for the Milwaukee Machine Shop.

Process			Routing			
Entity	**Location**	**Operation**	**Blk**	**Output**	**Destination**	**Rule**
kanban	kanban_square		1	kanban	Order_Q	LOAD 1
Gear_1	Brookfield_Forgings		1	Gear_1	Order_Q	SEND 1
Gear_1	Order_Q	Load 1				
			1	Gear_1	Lathe_Q	FIRST 1
Gear_1	Lathe_Q	wip1=wip1+1	1	Gear_1	Lathe	FIRST 1
Gear_1	Lathe	WAIT E(3)	1	Gear_1	Mill_Q	FIRST 1
Gear_1	Mill_Q		1	Gear_1	Mill	FIRST 1
Gear_1	Mill	WAIT U(3,1) Unload 1 wip1=wip1-1				
			1	Gear_1	Orders_Arrival	JOIN 1
kanban	Mill		1	kanban	kanban_square	FIRST 1
Gear_2	Brookfield_Forgings		1	Gear_2	Order_Q	SEND 1
Gear_2	Order_Q	Load 1				
			1	Gear_2	Mill_Q	FIRST 1
Gear_2	Mill_Q	wip2=wip2+1	1	Gear_2	Mill	FIRST 1
Gear_2	Mill	WAIT U(4,1) UNLOAD 1 wip2=wip2-1				
			1	Gear_2	Orders_Arrival	JOIN 1
Orders_1	Orders_Arrival	SEND 1 GEAR_1 TO Order_Q JOIN 1 GEAR_1 prod1=prod1+1	1	Orders_1	EXIT	FIRST 1
Orders_2	Orders_Arrival	SEND 1 GEAR_2 TO Order_Q JOIN 1 GEAR_2 prod2=prod2+1	1	Orders_2	EXIT	FIRST 1

Figure L12.47 shows the layout of the Milwaukee Machine Shop. The processes and the routings are shown in Figure L12.48. The arrival of a customer order (type 1 or 2) at the orders arrival location sends a signal to Brookfield Forgings in the form of a production kanban. The kanban is temporarily attached (LOADed) to a gear forging of the right type at the Order_Q. The gear forgings are sent to the Milwaukee Machine Shop for processing. After they are fully processed, the kanban is separated (UNLOADed). The kanban goes back to the kanban square. The finished gear is united (JOINed) with the appropriate customer order at the orders arrival location.

L12.10 Tracking Cost

ProModel 6.0 includes a cost-tracking feature. The following costs can be monitored:

1. Location cost
2. Resource cost
3. Entity cost

The cost dialog can be accessed from the Build menu (Figure L12.49).

FIGURE 12.49

The Cost option in the Build menu.

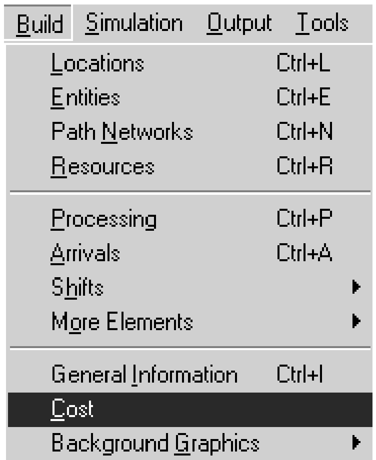
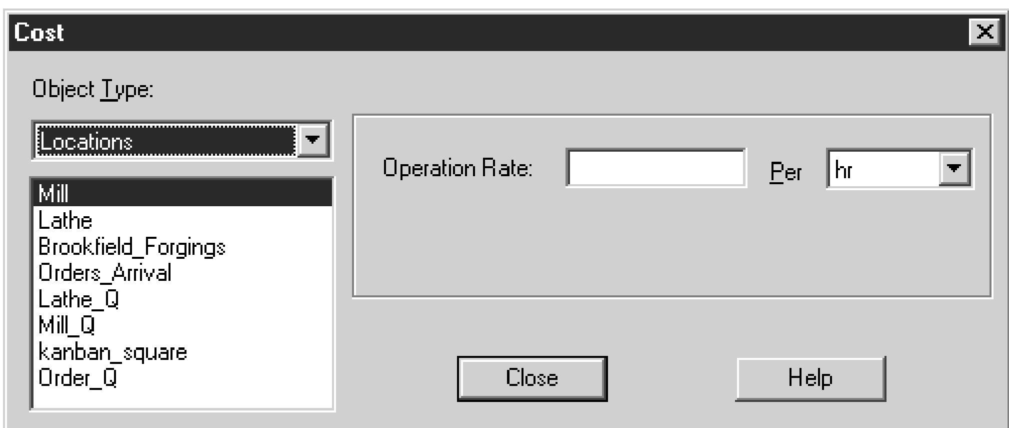


FIGURE L12.50

The Cost dialog box—Locations option.



Locations

The Locations Cost dialog box (Figure L12.50) has two fields: Operation Rate and Per Operation Rate specifies the cost per unit of time to process at the selected location. Costs accrue when an entity waits at the location or uses the location. Per is a pull-down menu to set the time unit for the operation rate as second, minute, hour, or day.

Resources

The Resources Cost dialog box (Figure L12.51) has three fields: Regular Rate, Per, and Cost Per Use. Regular Rate specifies the cost per unit of time for a resource used in the model. This rate can also be set or changed during run time

FIGURE L12.51
The Cost dialog box—Resources option.

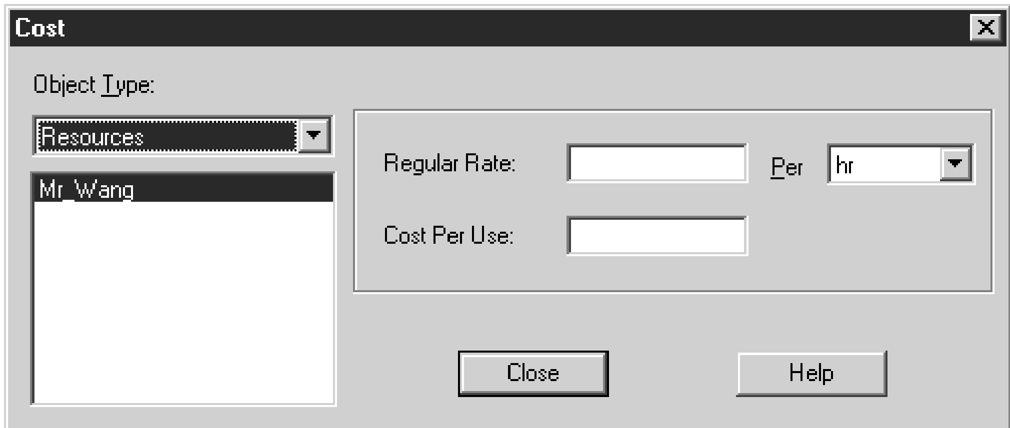
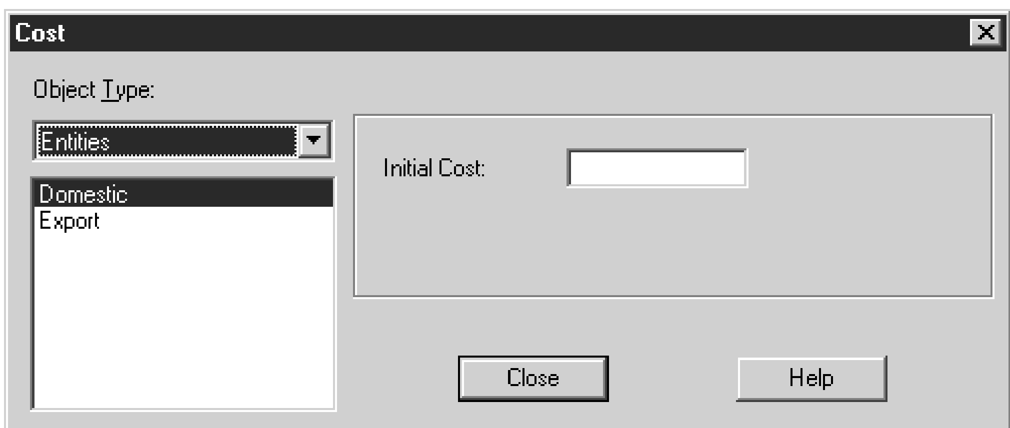


FIGURE L12.52
The Cost dialog box—Entities option.



using the SETRATE operation statement. Per is a pull-down menu, defined before. Cost Per Use is a field that allows you to define the actual dollar cost accrued every time the resource is obtained and used.

Entities

The Entities Cost dialog box (Figure L12.52) has only one field: Initial Cost. Initial Cost is the cost of the entity when it arrives to the system through a scheduled arrival.

Increment Cost

The costs of a location, resource, or entity can be incremented by a positive or negative amount using the following operation statements:

- `IncLocCost`—Enables you to increment the cost of a location.
- `IncResCost`—Enables you to increment the cost of a resource.
- `IncEntCost`—Enables you to increment the cost of an entity.

For more information on the cost-tracking feature of ProModel, refer to Lab 6 of the ProModel manual.

Problem Statement

Raja owns a manufacturing cell consisting of two mills and a lathe. All jobs are processed in the same sequence, consisting of an arriving station, a lathe, mill 1, mill 2, and an exit station. The processing time on each machine is normally distributed with a mean of 60 seconds and standard deviation of 5. The arrival rate of jobs is exponentially distributed with a mean of 120 seconds.

Raja, the material handler, transports the jobs between the machines and the arriving and exit stations. Job pickup and release times are uniformly distributed between six and eight seconds. The distances between the stations are given in Table L12.9. Raja can walk at the rate of 150 feet/minute when carrying no load. However, he can walk only at the rate of 80 feet/minute when carrying a load.

The operation costs for the machines are given in Table L12.10. Raja gets paid at the rate of $60 per hour plus $5 per use. The initial cost of the jobs when they enter the system is $100 per piece. Track the number of jobs produced, the total cost of production, and the cost per piece of production. Simulate for 80 hours.

TABLE L12.9 Distances between Stations

From	*To*	*Distance (feet)*
Arriving	Lathe	40
Lathe	Mill 1	80
Mill 1	Mill 2	60
Mill 2	Exit	50
Exit	Arrive	80

TABLE L12.10 Operation Costs at Raja's Manufacturing Cell

Machine	*Operation Costs*
Lathe	$10/minute
Mill 1	$18/minute
Mill 2	$22/minute

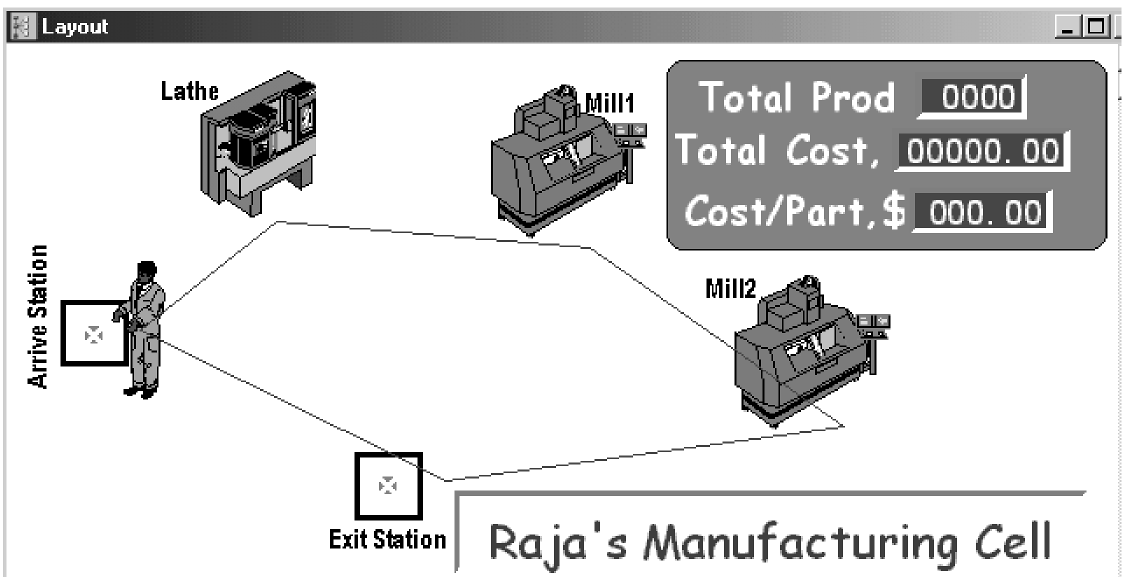
FIGURE L12.53

Processes and routings at Raja's manufacturing cell.

Process			Routing				
Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Jobs	Arrive_Station		1	Jobs	Lathe	FIRST 1	MOVE WITH Raja THEN FREE
Jobs	Lathe	wait n(60,5) sec	1	Jobs	Mill1	FIRST 1	MOVE WITH Raja THEN FREE
Jobs	Mill1	wait n(60,5) sec	1	Jobs	Mill2	FIRST 1	MOVE WITH Raja THEN FREE
Jobs	Mill2	wait n(60,5) sec	1	Jobs	Exit_Station	FIRST 1	MOVE WITH Raja THEN FREE
Jobs	Exit_Station	Inc Total_Cost, GetCost()					
			1	Jobs	EXIT	FIRST 1	Inc Total_Prod Cost_Per_Part=Total_Cost/Total_prod

FIGURE L12.54

Simulation model of Raja's manufacturing cell.



Five locations (Lathe, Mill1, Mill2, Arrive_Station, and Exit_Station) and three variables (Total_Prod, Cost_Per_Part, and Total_Cost) are defined. The processes are shown in Figure L12.53. The simulation model is shown in Figure L12.54.

L12.11 Importing a Background

Background graphics work as a static wallpaper and enhance the look of a simulation model. They make the model realistic and provide credibility during presentations. Many different graphic formats can be imported such as .BMP, .WMF, .GIF, and .PCX. Drawings in CAD formats like .DWG must be saved in one of these file formats before they can be imported. .BMPs and .WMFs can be copied to the clipboard from other applications and passed directly into the background.

AutoCAD drawings can also be copied to the clipboard and pasted into the background. The procedure is as follows:

1. With the graphic on the screen, press <Ctrl> and <C> together. Alternatively, choose Copy from the Edit menu. This will copy the graphic into the Windows clipboard.
2. Open an existing or new model file in ProModel.
3. Press <Ctrl> and <V> together. Alternatively, choose Paste from the Edit menu.

This action will paste the graphic as a background on the layout of the model.

Another way to import backgrounds is to use the Edit menu in ProModel:

1. Choose Background Graphics from the Build menu.
2. Select Front of or Behind grid.
3. Choose Import Graphic from the Edit menu.
4. Select the desired file and file type. The image will be imported into the layout of the model.
5. Left-click on the graphic to reposition and resize it, if necessary.

"Front of grid" means the graphic will not be covered by grid lines when the grid is on. "Behind grid" means the graphic will be covered with grid lines when the grid is on.

L12.12 Defining and Displaying Views

Specific areas of the model layout can be predefined and then quickly and easily viewed in ProModel. Each view can be given a unique name and can have a suitable magnification. These views can be accessed during editing of the model by selecting Views from the View menu (Figure L12.55) or by using the keyboard shortcut key. Views can also be accessed in real time during the running of the model with a `VIEW "mill_machine"` statement.

Problem Statement

For the **Shipping Boxes Unlimited** example in Lab 7, Section L7.7.2, define the following six views: Monitor Queue, Box Queue, Inspect Queue, Shipping Queue, Pallet Queue, and Full View. Each view must be at 300 percent magnification. Show Full View at start-up. Show the Pallet Queue when an empty pallet arrives at the pallet queue location. Go back to showing the Full View when the box is at the shipping dock. Here are the steps in defining and naming views:

1. Select the View menu after the model layout is finished.
2. Select Views from the View menu.

The Views dialog box is shown in Figure L12.56. Figure L12.57 shows the Add View dialog box. The Full View of the Shipping Boxes Inc. model is shown in Figure L12.58.

FIGURE L12.55

Views command in the View menu.

FIGURE L12.56

The Views dialog box.

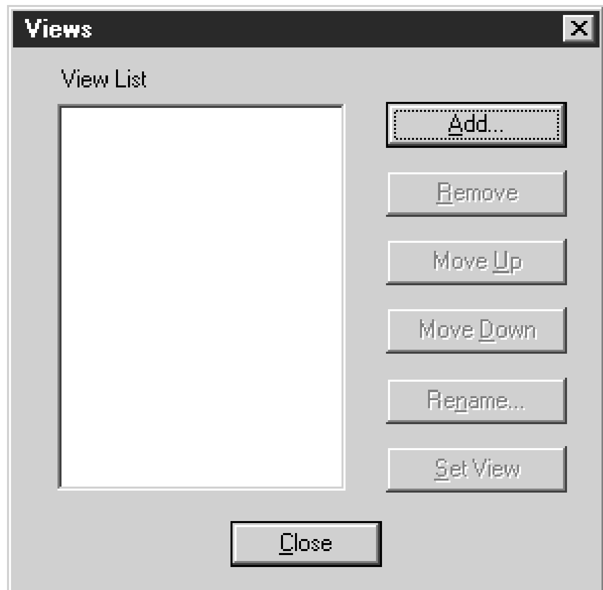


FIGURE L12.57

The Add View dialog box.

Referencing a View in Model Logic

1. Select General Information (Figure L12.59) from the Build menu. Select Initialization Logic and use the `VIEW` statement:

```
View "Full View"
```

2. Select Processing from the Build menu. Use the following statement in the Operation field when the Pallet Empty arrives at the Pallet Queue location (Figure L12.60):

```
View "Pallet Queue"
```

Also, use the following statement in the Operation field when the box arrives at the shipping dock:

```
View "Full View"
```

FIGURE L12.58
Full View of the Shipping Boxes Inc. model.

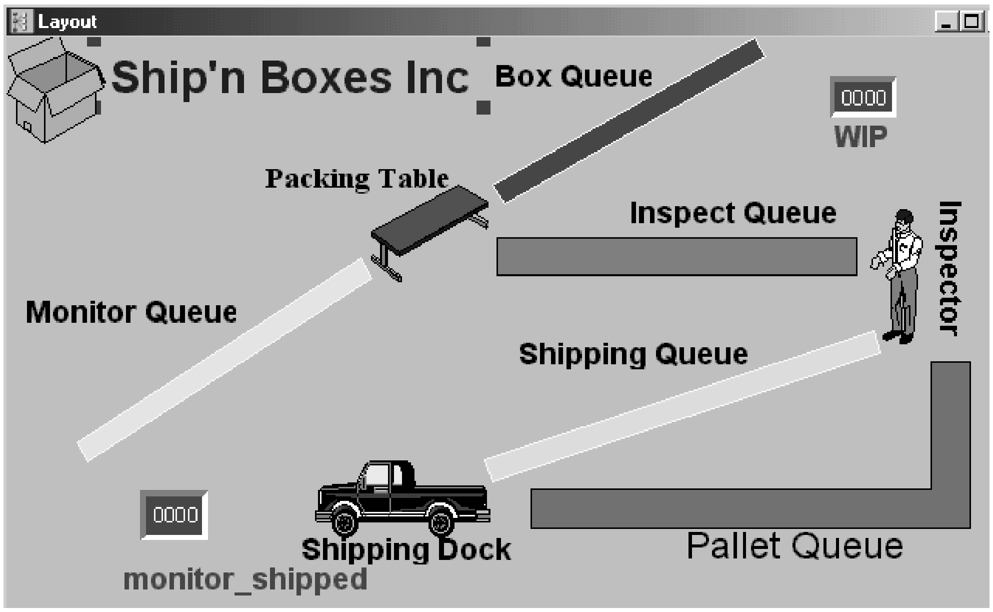


FIGURE L12.59
General Information for the Shipping Boxes Inc. model.

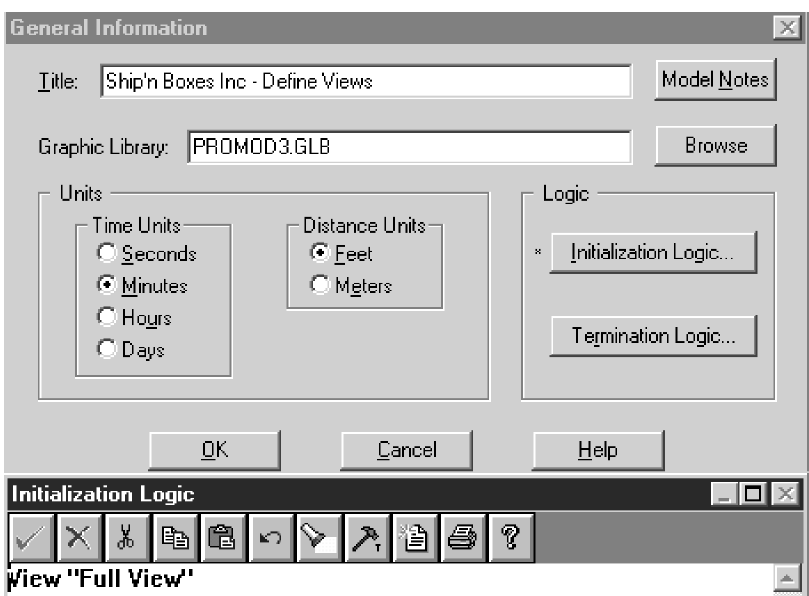


FIGURE L12.60

Processes and routings at Shipping Boxes Inc. incorporating the change of views.

```
                                              Process                            Routing

Entity       Location       Operation              Blk  Output       Destination    Rule
------------ -------------- ------------------     ---- ------------ -------------- -------
Monitor      Monitor_Queue  wip = wip + 1
                                                   1    Monitor      Packing_Table  JOIN 1
Empty_Box    Box_Queue                             1    Empty_Box    Packing_Table  FIRST 1
Empty_Box    Packing_Table  JOIN 1 Monitor
                            WAIT N(5,1)
                                                   1    Box          Inspect_Queue  FIRST 1
Box          Inspect_Queue  WHILE Contents(Inspect_Queue) <= 3 DO
                              Wait 60  min
                            wait n(3,1) min        1    Box          Inspector      LOAD 1
Pallet_empty Inspector      Load 1
                            RENAME AS Pallet_Full
Pallet_Full  Inspector                             1    Pallet_Full  Shipping_Queue FIRST 1
Pallet_Full  Shipping_Queue unload 1
                            wait U(3,1) min
                                                   1    Pallet_empty Pallet_Queue   FIRST 1
Box          Shipping_Queue                        1    Box          Shipping_Dock  FIRST 1
Box          Shipping_Dock  View "Full View"
                            monitor_shipped = monitor_shipped + 1
                            wip = wip -1           1    Box          EXIT           FIRST 1
Pallet_empty Pallet_Queue   View "Pallet Queue"
                                                   1    Pallet_empty Inspector      FIRST 1
```

L12.13 Creating a Model Package

ProModel has an innovative feature of creating a package of all files associated with the model file. This package file is titled <model name>.PKG—for example, ATM.pkg. The package file can then be archived or distributed to others. This file includes the model file (*.MOD), the graphic library (unless you check the Exclude Graphics Library option), and any external files you defined (such as read files, arrivals files, and shift files); the model package automatically includes bitmaps imported into the background graphics. The package file can be subsequently unpackaged by the receiver to run.

Use the following steps to create a model package:

1. Select Create Model Package from the File menu.
2. Enter the name you wish to use for the model package. ProModel uses the name of the model file as the default name of the package. So ATM.mod will be packaged as ATM.pkg. You can also Browse . . . to select the model name and directory path.
3. Check/uncheck the Exclude Graphics Library box, if you want to include/exclude the graphics library.
4. Check the Protect Model Data box if you want to protect the data in your model and prevent other users from changing and even viewing the model data files.
5. Click OK.

Example

For the **Widgets-R-Us** example in Section L12.6, make a model package that includes the model file and the shift file for operator Joe. Save the model package in a floppy disk. Figure L12.61 shows the Create Model Package dialog.

Unpack

To unpack and install the model package, double-click on the package file. In the Unpack Model Package dialog select the appropriate drive and directory path to install the model file and its associated files (Figure L12.62). Then click Install. After the package file has been installed, ProModel prompts you (Figure L12.63) for loading the model. Click Yes.

FIGURE L12.61

Create Model Package dialog.

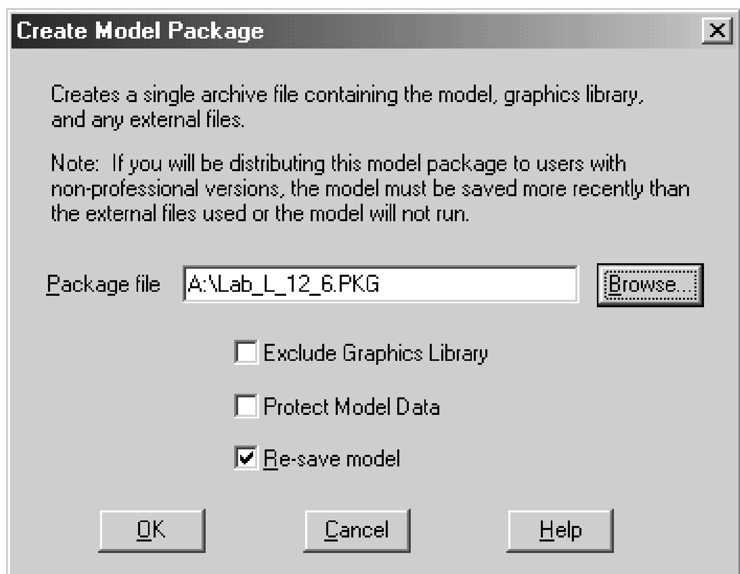


FIGURE L12.62

Unpack Model Package dialog.

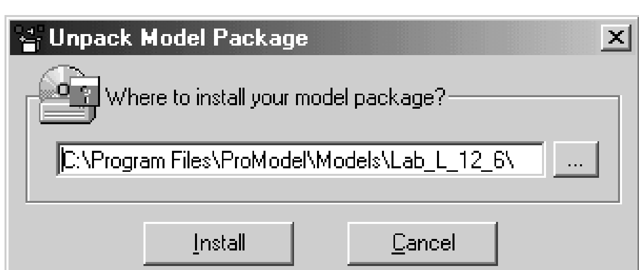
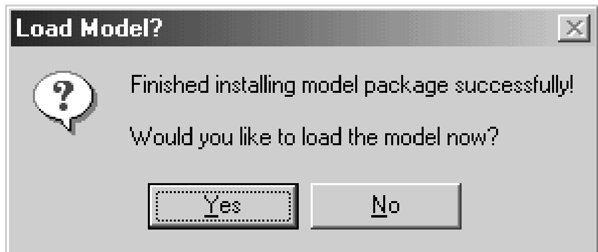


FIGURE L12.63
Load Model dialog.



L12.14 Exercises

1. Five different types of equipment are available for processing a special type of part for one day (six hours) of each week. Equipment 1 is available on Monday, equipment 2 on Tuesday, and so forth. The processing time data follow:

Equipment	*Time to Process One Part (minutes)*
1	5 ± 2
2	4 ± 2
3	3 ± 1.5
4	6 ± 1
5	5 ± 1

   Assume that parts arrive at a rate of one every 4 ± 1 hours, including weekends. How many parts are produced each week? How large a storage area is needed for parts waiting for a machine? Is there a bottleneck at any particular time? Why?

2. Customers visit the neighborhood barbershop **Fantastic Dan** for a haircut. Among the customers there are 30 percent children, 50 percent women, and 20 percent men. The customer interarrival time is triangularly distributed with a minimum, mode, and maximum of 8, 11, and 14 minutes respectively. The haircut time (in minutes) depends on the type of customer, as shown in this table:

	Haircut Time (minutes)	
Customers	*Mean*	*Half-Width*
Children	8	2
Women	12	3
Men	10	2

The initial greetings and signing in take Normal (2, ⋅2) minutes, and the transaction of money at the end of the haircut takes Normal (3, ⋅3) minutes. Run the simulation model for 100 working days (480 minutes each).

a. About how many customers of each type does Dan process per day?
b. What is the average number of customers of each type waiting to get a haircut? What is the maximum?
c. What is the average time spent by a customer of each type in the salon? What is the maximum?

3. **Poly Castings Inc.** receives castings from its suppliers in batches of one every eleven minutes exponentially distributed. All castings arrive at the raw material store. Of these castings, 70 percent are used to make widget A, and the rest are used to make widget B. Widget A goes from the raw material store to the mill, and then on to the grinder. Widget B goes directly to the grinder. After grinding, all widgets go to degrease for cleaning. Finally, all widgets are sent to the finished parts store. Simulate for 1000 hours.

Widget	*Process 1*	*Process 2*	*Process 3*
Widget A	Mill [N(5,2) min.]	Grinder [U(11,1) min.]	Degrease [7 min.]
Widget B	Grinder [U(9,1) min.]	Degrease [7 min.]	

Track the work-in-process inventory of both types of widgets separately. Also, track the production of finished widgets (both types).

4. The maintenance mechanic in the problem in Section L12.5.1 is an independent contractor and works four hours each day from 10 A.M. until 2 P.M., Monday through Friday, with no lunch break. The rest of the shop works from 8 A.M. until 4 P.M. What will be the impact on the shop (average cycle time and number of widgets made per day) if we hire him full-time and have him work from 8 A.M. until 4 P.M. instead of working part-time?
5. Consider the **United Electronics** Exercise 7, in Section L7.12, with the following enhancements. The soldering machine breaks down on average after every 2000 ± 200 minutes of operation. The repair time is normally distributed (100, 50) minutes. Create a simulation model, with animation, of this system. Simulate this manufacturing system for 100 days, eight hours each day. Collect and print statistics on the utilization of each station, associated queues, and the total number of jobs manufactured during each eight-hour shift (average).
6. Consider the **Poly Casting Inc.** example in Lab 7, Section L7.4, and answer the following questions:

a. What is the average time a casting spends in the system?
b. What is the average time a casting waits before being loaded on a mill? After a mill processes 25 castings, it is shut down for a uniformly distributed time between 10 and 20 minutes for cleaning and tool change.

c. What percentage of the time does each mill spend in cleaning and tool change operations?
d. What is the average time a casting spends in the system?
e. What is the average work-in-process of castings in the system?

7. Consider the **NoWaitBurger** stand in Exercise 13, in Section L7.12, and answer the following questions.
a. What is the average amount of time spent by a customer at the hamburger stand?
b. Run 10 replications and compute a 90 percent confidence interval for the average amount of time spent by a customer at the stand.
c. Develop a 90 percent confidence interval for the average number of customers waiting at the burger stand.

8. Sharukh, Amir, and Salman wash cars at the **Bollywood Car Wash.** Cars arrive every 10 ± 6 minutes. They service customers at the rate of one every 20 ± 10 minutes. However, the customers prefer Sharukh to Amir, and Amir over Salman. If the attendant of choice is busy, the customers choose the first available attendant. Simulate the car wash system for 1000 service completions (car washes). Answer the following questions:
a. Estimate Sharukh's, Amir's, and Salman's utilization.
b. On average, how long does a customer spend at the car wash?
c. What is the longest time any customer spent at the car wash?
d. What is the average number of customers at the car wash?

Embellishment: The customers are forced to choose the first available attendant; no individual preferences are allowed. Will this make a significant enough difference in the performance of the system to justify this change? Answer questions *a* through *d* to support your argument.

9. Cindy is a pharmacist and works at the **Save-Here Drugstore.** Walk-in customers arrive at a rate of one every 10 ± 3 minutes. Drive-in customers arrive at a rate of one every 20 ± 10 minutes. Drive-in customers are given higher priority than walk-in customers. The number of items in a prescription varies from 1 to 5 (3 ± 2). Cindy can fill one item in 6 ± 1 minutes. She works from 8 A.M. until 5 P.M. Her lunch break is from 12 noon until 1 P.M. She also takes two 15-minute breaks: at 10 A.M. and at 3 P.M. Define a shift file for Cindy named Cindy.sft. Model the pharmacy for a year (250 days) and answer the following questions:
a. Estimate the average time a customer (of each type) spends at the drugstore.
b. What is the average number of customers (of each type) waiting for service at the drugstore?
c. What is the utilization of Cindy (percentage of time busy)?
d. Do you suggest that we add another pharmacist to assist Cindy? How many pharmacists should we add?

e. Is it better to have a dedicated pharmacist for drive-in customers and another for walk-in customers?

f. Create a package file called SaveHere.pkg that includes the simulation model file and the shift file Cindy.sft.

10. A production line with five workstations is used to assemble a product. Parts arrive to the first workstation at random exponentially distributed intervals with a mean of seven minutes. Service times at individual stations are exponentially distributed with a mean of three minutes.

a. Develop a simulation model that collects data for time in the system for each part.

b. Additional analysis shows that products from three different priority classes are assembled on the line. Products from different classes appear in random order; products from classes 1, 2, and 3 have highest, medium, and lowest priorities respectively. Modify the simulation program to reflect this situation. Determine the mean time in the system for the three different priority classes.

Class	1	2	3
Probability	0.3	0.5	0.2

c. The assembly process is modified so that each product to be assembled is placed on a pallet. The production supervisor wants to know how many pallets to place in operation at one time. It takes Uniform(8 ± 2) minutes to move the pallet from station 5 to station 1. Pallet loading and unloading times are Uniform(3 ± 1) minutes each. Modify the simulation model to reflect this situation. Is it better to use 5 or 20 pallets?

11. Two types of parts arrive at a single machine where they are processed one part at a time. The first type of part has a higher priority and arrives exponentially with a mean interarrival time of 30 minutes. The second lower-priority type also arrives exponentially with a mean interarrival time of 30 minutes. Within priority classes, the parts are serviced in FIFO order, but between priority classes the higher-priority type will always be processed first. However, a lower-priority part cannot be interrupted once it has begun processing. The machine processing times for higher- and lower-priority types of parts are uniformly distributed (20 ± 5) and (8 ± 2) minutes, respectively. Simulate the system for 1000 hours.

a. What are the average time in queue and average time in system for each type of part?

b. What are the average production rates of each type of part per hour?

12. The manufacture of a certain line of composite aerospace subassembly involves a relatively lengthy assembly process, followed by a short

firing time on an oven, which holds only one sub-assembly at a time. An assembler cannot begin assembling a new sub-assembly until he or she has removed the old one from the oven. The following is the pattern of processes followed by each assembler:

a. Assemble next subassembly.
b. Wait, first-come, first-served, to use the oven.
c. Use the oven.
d. Return to step *a*.

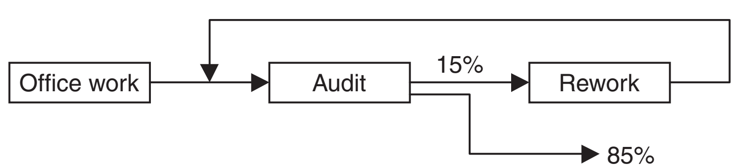
Here are the operating times and relevant financial data:

Operation	*Time Required (minutes)*
Assemble	30 ± 5
Fire	8 ± 2

Item	*Cost Information ($)*
Assembler's salary	$35/hour
Oven cost	$180 per 8-hour workday (independent of utilization)
Raw material	$8 per sub-assembly
Sale price of finished sub-assembly	$40 per sub-assembly

Build a simulation model of this manufacturing process. Use the model to determine the optimal number of assemblers to be assigned to an oven. The optimal number is understood in this context to be the one maximizing profit. Base the determination on simulations equivalent to 2000 hours of simulated time. Assume there are no discontinuities within a working day, or in moving between consecutive eight-hour working days. (Adapted from T. Schriber, *Simulation using GPSS,* John Wiley, 1974.)

13. For the following office work, the likelihood of needing rework after audit is 15 percent. Interarrival times are exponentially distributed with a mean of 5 minutes, rework times are exponentially distributed



with a mean of 4 minutes, audit time is uniformly distributed between 2 ± 1 minutes, and work times are normally distributed with an average time of 4.5 minutes and standard deviation of 1.0 minute.

a. What is the mean time in the system for the first 200 reworked office files?
b. Develop a histogram of the mean time in the system for the first 1000 departures.
c. Modify the simulation program so that office work is rejected if it fails a second audit. How many office files are inspected twice? How many of these fail the audit a second time?
d. Modify the program to count the number of office files staying in the system longer than a specified length of time. What percentage of the office work stays in the system for more than 12 minutes?
e. Modify the part *a* simulation program so that it takes uniform (3 ± 1) minutes to move the office file from one station to another.
f. Modify the part *a* simulation program so that files to be reworked for second or more times have a lower priority than files needing rework for the first time. Does it seem to make a difference in the overall mean time in the system?