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A

B

13 MATERIAL HANDLING CONCEPTS

With malice toward none, with charity for all, with firmness in the right, as God gives us to see the right, let us strive on to finish the work we are in . . .

—Abraham Lincoln (1809–1865)

In this lab we introduce you to various material handling concepts in ProModel. First we introduce you to the concepts of conveyors. In the next section we introduce manual and other discrete material handling systems, such as the forklift truck. Section L13.3 introduces the concepts of a crane system. For a more detailed discussion of modeling various material handling systems, please refer to Chapter 13.

L13.1 Conveyors

Conveyors are continuous material handling devices for transferring or moving objects along a fixed path having fixed, predefined loading and unloading points. Some examples of conveyors are belt, chain, overhead, power-and-free, roller, and bucket conveyors.

In ProModel, conveyors are locations represented by a conveyor graphic. A conveyor is defined graphically by a conveyor path on the layout. Once the path has been laid out, the length, speed, and visual representation of the conveyor can be edited by double-clicking on the path and opening the Conveyor/Queue dialog box (Figure L13.1). The various conveyor options are specified in the Conveyor Options dialog box, which is accessed by clicking on the Conveyor Options button in the Conveyor/Queue dialog box (Figure L13.2).

In an accumulating conveyor, if the lead entity comes to a stop, the trailing entities queue behind it. In a nonaccumulating conveyor, if the lead entity is unable to exit the conveyor, then the conveyor and all other entities stop.

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Part II Labs

FIGURE L13.1

The Conveyor/Queue dialog box.

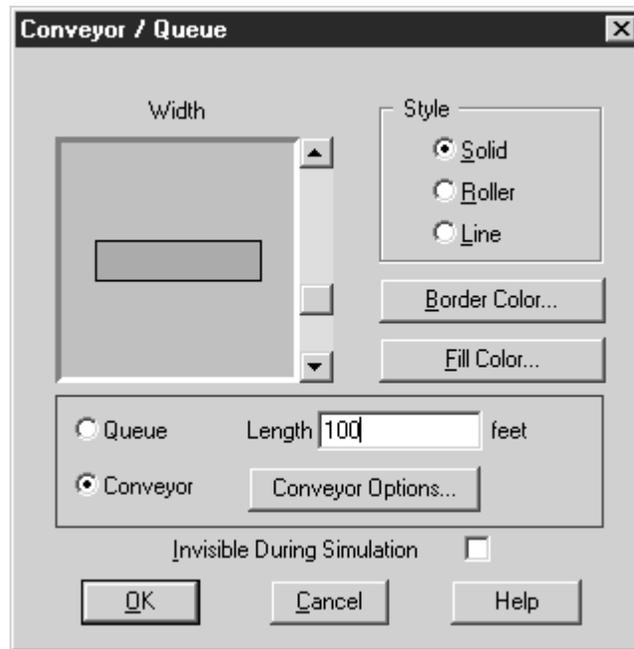
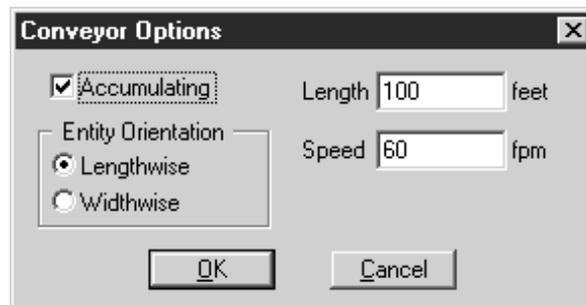


FIGURE L13.2

The Conveyor Options dialog box.



L13.1.1 Multiple Conveyors

Problem Statement

At **Ship'n Boxes Inc.**, boxes of type A arrive at Conv1 at the rate of one every five minutes (exponentially distributed). They are sent to the shipping conveyor. Boxes of type B arrive at Conv2 at the rate of one every two minutes (exponential) and are also sent to the shipping conveyor. The shipping conveyor takes boxes of both type A and B to the truck waiting at the shipping dock. The speed and length of the conveyors are given in Table L13.1. Develop a simulation model and run it for 10 hours. Figure out how many boxes of each type are shipped in 10 hours.

Four locations (Conv1, Conv2, Shipping, and Shipping_Dock) and two entities (Box_A and Box_B) are defined. The processes and layout are shown in Figures L13.3 and L13.4 respectively.

FIGURE L13.3

Processes and routings for the Ship'n Boxes Inc. model.

Entity	Location	Process		Routing			Move Logic
		Operation	Blk	Output	Destination	Rule	
Box_A	CONU1		1	Box_A	SHIPPING	FIRST	1
Box_B	CONU2		1	Box_B	SHIPPING	FIRST	1
Box_A	SHIPPING		1	Box_A	SHIPPING_DOCK	FIRST	1
Box_A	SHIPPING_DOCK	Inc Count_A	1	Box_A	EXIT	FIRST	1
Box_B	SHIPPING		1	Box_B	SHIPPING_DOCK	FIRST	1
Box_B	SHIPPING_DOCK	Inc Count_B	1	Box_B	EXIT	FIRST	1

FIGURE L13.4

Simulation model layout for Ship'n Boxes Inc.

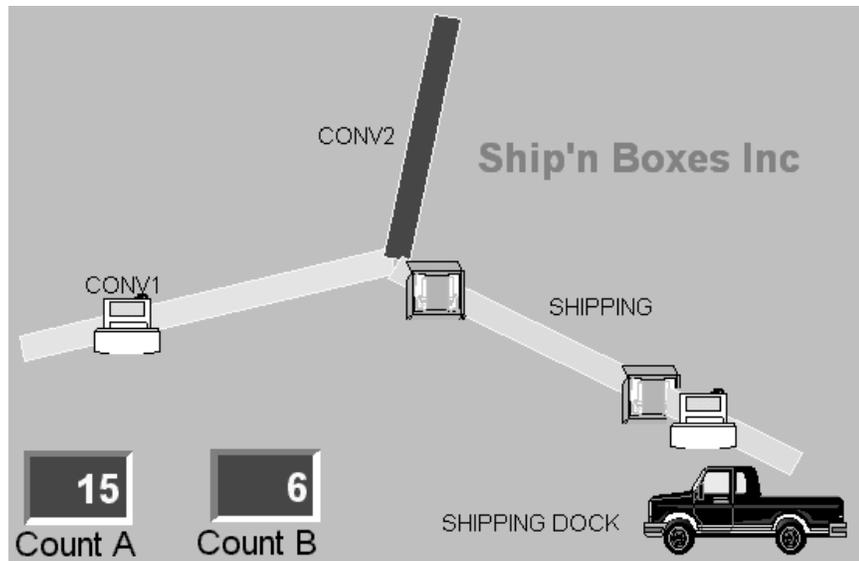


TABLE L13.1 Conveyor Lengths and Speeds

Name	Length	Speed
Conv1	100	30 feet/minute
Conv2	100	50 feet/minute
Shipping	200	20 feet/minute

L13.2 Resources, Path Networks, and Interfaces

A *resource* is a person, piece of equipment, or some other device that is used for one or more of the following functions: transporting entities, assisting in performing operations on entities at locations, performing maintenance on locations, or performing maintenance on other resources. In the following example, an operator is used as an example of a resource.

A *path network* defines the way a resource travels between locations. The specifications of path networks allow you to define the nodes at which the resource parks, the motion of the resource, and the path on which the resource travels. Path networks consist of nodes that are connected by path segments. A beginning node and an ending node define a path segment. Path segments may be unidirectional or bidirectional. Multiple path segments, which may be straight or joined, are connected at path nodes. To create path networks:

1. Select the Path button and then left-click in the layout where you want the path to start.
2. Subsequently, left-click to put joints in the path and right-click to end the path.

Interfaces are where the resource interacts with the location when it is on the path network. To create an interface between a node and a location:

1. Left-click and release on the node (a dashed line appears).
2. Then left-click and release on the location.

Multiple interfaces from a single node to locations can be created, but only one interface may be created from the same path network to a particular location.

L13.2.1 Manual Material Handling Systems

Problem Statement

At **Ghosh's Gear Shop**, a small automotive OEM facility, there are two NC lathes, a degreaser, and inspection equipment. Blanks are received at the receiving area. The blanks are machined on either NC lathe 1 or NC lathe 2 (machines are assigned by turn for successive blanks). After machining, the cogs go to the degreaser for washing. Then the cogs are inspected. An operator moves the parts from one area to another. The operator is also required to run the machines and perform the inspection procedure.

Blanks arrive at the rate of 10 per hour (exponentially distributed). The machining, washing, and inspection processes take Uniform(15 ± 5), Uniform(5 ± 1), and Normal(8, 4) minutes respectively. It takes Exponential(2) minutes to move the material between the processes. The operator is paid \$20 per hour. It costs the company \$0.10 for each hour the parts spend in processing in the manufacturing shop. The profit per item is \$20.00 after deducting direct material costs and all other overhead. Build a simulation model, run it for 100 hours, and determine how many operators the shop should hire (one, two, or three).

Five locations (Receive, NC_Lathe_1, NC_Lathe_2, Inspect, and Degrease), two entities (Blank and Cog), and a resource (Operator) are defined. The processes and routings are shown in Figure L13.5. The blanks arrive with an interarrival time that is exponentially distributed with a mean of 20 minutes. The simulation run hours are set at 100 in the Simulation Option menu. The model is titled Ghosh's Gear Shop in the General Information menu. The layout of Ghosh's Gear Shop is shown in Figure L13.6.

Lab 13 Material Handling Concepts

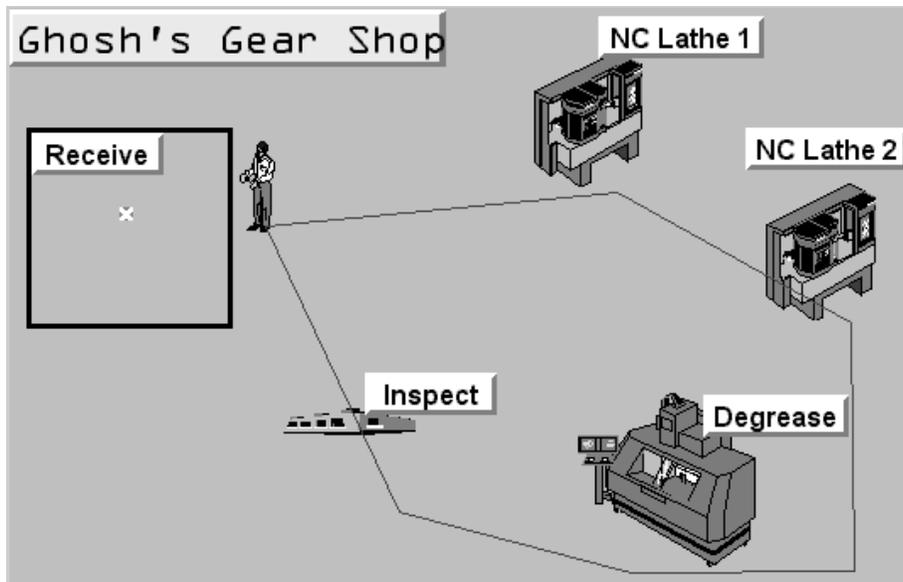
FIGURE L13.5

Process and routing logic at Ghosh's Gear Shop.

Entity	Location	Process		Routing			Move Logic
		Operation	Blk	Output	Destination	Rule	
Blank	Receive		1	Blank	NC_Lathe_1	TURN 1	Get Operator Move with Operator for E<2> min Free Operator Get Operator Move with Operator for E<2> min Free Operator
				Blank	NC_Lathe_2	TURN	
Blank	NC_Lathe_1	Get Operator Wait U<15,5> min Free Operator	1	Cog	Degrease	FIRST 1	Get Operator Move with Operator for E<2> min Free Operator
Blank	NC_Lathe_2	Get Operator Wait U<15,5> min Free Operator	1	Cog	Degrease	FIRST 1	Get Operator Move with Operator for E<2> min Free Operator
Cog	Degrease	Get Operator Wait U<5,1> min Free Operator	1	Cog	Inspect	FIRST 1	Get Operator Move with Operator for E<2> min Free Operator
Cog	Inspect	Get Operator Wait N<8,4> min Free Operator	1	Cog	EXIT	FIRST 1	

FIGURE L13.6

Layout of Ghosh's Gear Shop.



We ran this model with one, two, or three operators working together. The results are summarized in Tables L13.2 and L13.3. The production quantities and the average time in system (minutes) are obtained from the output of the simulation analysis. The profit per hour, the expected delay cost per piece, and the

TABLE L13.2 Production Performance at Ghosh’s Gear Shop

<i>Number of Operators</i>	<i>Production Quantity Per 100 Hours</i>	<i>Production Rate Per Hour</i>	<i>Gross Profit Per Hour</i>	<i>Average Time in System (minutes)</i>
1	199	1.99	39.80	2423
2	404	4.04	80.80	1782
3	598	5.98	119.60	1354

TABLE L13.3 Net Profit at Ghosh’s Gear Shop

<i>Number of Operators</i>	<i>Expected Delay Cost (\$/piece)</i>	<i>Expected Delay Cost (\$/hour)</i>	<i>Expected Service Cost (\$/hour)</i>	<i>Total Net Profit (\$/hour)</i>
1	\$4.04	\$8.04	\$20	\$11.76
2	\$2.97	\$12.00	\$40	\$28.80
3	\$2.25	\$13.45	\$60	\$46.15

expected delay cost per hour are calculated as follows:

$$\text{Profit per hour} = \text{Production rate per hour} \times \text{Profit per piece}$$

$$\text{Expected delay cost (\$/piece)} = [\text{Average time in system (min.)}/60] \times \$0.1/\text{piece/hr.}$$

$$\text{Expected delay cost (\$/hr.)} = \text{Expected delay cost (\$/piece)} \times \text{Production rate/hr.}$$

The total net profit per hour after deducting the expected delay and the expected service costs is

$$\text{Total net profit/hr.} = \text{Gross profit/hr.} - \text{Expected delay cost/hr.} - \text{Expected service cost/hr.}$$

The net profit per hour is maximized with three operators working in the shop. However, it must be noted that by hiring two operators instead of one, the increase in net profit per hour is about 145 percent, but the increase is only about 60 percent when three operators are hired instead of one.

L13.2.2 Manual versus Automated Material Handling Systems

We will now consider the impact of installing a conveyor system in the manufacturing facility described in the previous section. The conveyor will move all the material from one location to another and will replace the cell operator. The conveyor costs \$50 per foot to install and \$30,000 per year to maintain. The

additional throughput can be sold for \$20 per item profit. Should we replace one operator in the previous manufacturing system with a conveyor system? Build a simulation model and run it for 100 hours to help in making this decision.

The layout, locations, and processes and routings are defined as shown in Figures L13.7, L13.8, and L13.9 respectively. The length of each conveyor is 40 feet (Figure L13.10). The speeds of all three conveyors are assumed to be 50 feet/minute (Figure L13.11).

The results of this model are summarized in Tables L13.4 and L13.5. The production quantities and the average time in system (minutes) are obtained from the output of the simulation analysis. The profit per hour, the expected delay cost

FIGURE L13.7

Layout of Ghosh's Gear Shop with conveyors.

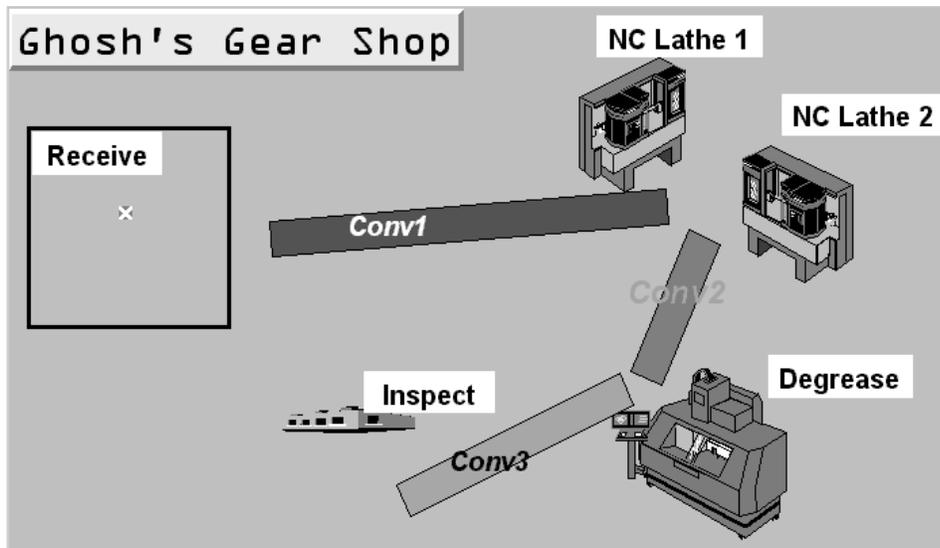


FIGURE L13.8

Locations at Ghosh's
Gear Shop with
conveyors.

```

*****
                                  Locations
*****
Name      Cap      Units  Stats      Rules
-----
Receive   inf      1      Time Series Oldest, ,
NC_Lathe_1 1      1      Time Series Oldest, ,
NC_Lathe_2 1      1      Time Series Oldest, ,
Inspect   1      1      Time Series Oldest, ,
Degrease  1      1      Time Series Oldest, ,
Conv1     INFINITE 1      Time Series Oldest, FIFO,
Conv2     INFINITE 1      Time Series Oldest, FIFO,
Conv3     INFINITE 1      Time Series Oldest, FIFO,
    
```

FIGURE L13.9

Process and routing at Ghosh's Gear Shop with conveyors.

Entity	Location	Process		Routing			Move Logic
		Operation	Blk	Output	Destination	Rule	
Blank	Receive		1	Blank	Conv1	FIRST 1	
Blank	Conv1		1	Blank Blank	NC_Lathe_1 NC_Lathe_2	TURN 1 TURN	
Blank	NC_Lathe_1	Wait U<15,5> min	1	Cog	Conv2	FIRST 1	
Blank	NC_Lathe_2	Wait U<15,5> min	1	Cog	Conv2	FIRST 1	
Cog	Conv2		1	Cog	Degrease	FIRST 1	
Cog	Degrease	Wait U<5,1> min	1	Cog	Conv3	FIRST 1	
Cog	Conv3		1	Cog	Inspect	FIRST 1	
Cog	Inspect	Wait N<8,4> min	1	Cog	EXIT	FIRST 1	

FIGURE L13.10

Conveyors at Ghosh's Gear Shop.

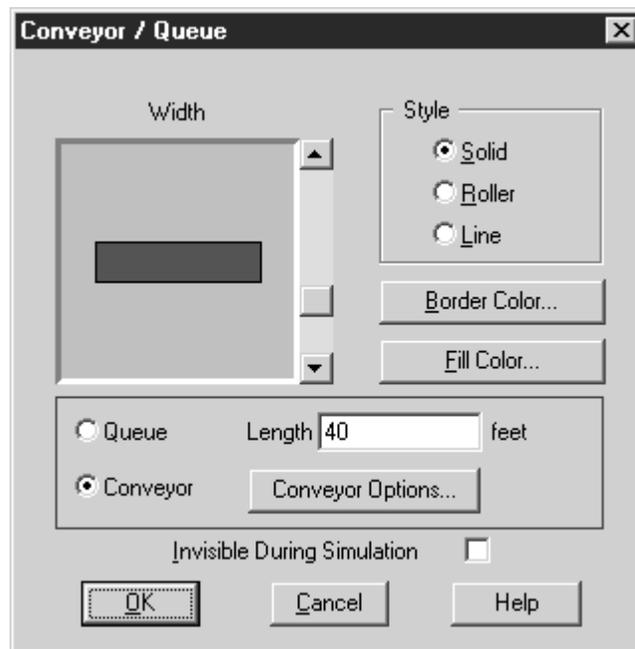


FIGURE L13.11

Conveyor options at Ghosh's Gear Shop.

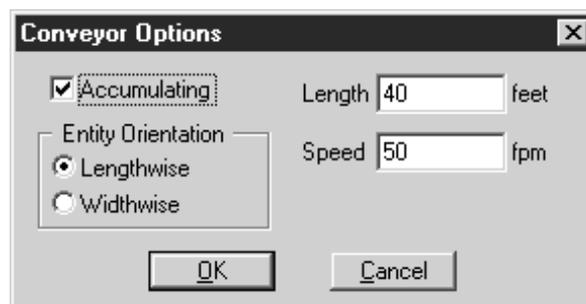


TABLE L13.4 Production and Gross Profit at Ghosh’s Gear Shop

<i>Mode of Transportation</i>	<i>Production Quantity Per 100 Hours</i>	<i>Production Rate Per Hour</i>	<i>Gross Profit Per Hour</i>	<i>Average Time in System (minutes)</i>
Conveyor	747	7.47	\$149.40	891

TABLE L13.5 Net Profit at Ghosh’s Gear Shop

<i>Mode of Transportation</i>	<i>Expected Delay Cost (\$/piece)</i>	<i>Expected Delay Cost (\$/hour)</i>	<i>Expected Service Cost (\$/hour)</i>	<i>Total Net Profit (\$/hour)</i>
Conveyor	\$1.485	\$11.093	\$16	\$122.307

per piece, and the expected delay cost per hour are calculated as follows:

$$\text{Profit per hour} = \text{Production rate/hour} \times \text{Profit per piece}$$

$$\text{Expected delay cost (\$/piece)} = (\text{Average time in system (min.)}/60) \times \$0.1/\text{piece/hour}$$

$$\text{Expected delay cost (\$/hour)} = \text{Expected delay cost (\$/piece)} \times \text{Production rate/hour}$$

To calculate the service cost of the conveyor, we assume that it is used about 2000 hours per year (8 hrs/day \times 250 days/year). Also, for depreciation purposes, we assume straight-line depreciation over three years.

$$\begin{aligned} \text{Total cost of installation} &= \$50/\text{ft.} \times 40 \text{ ft./conveyor segment} \\ &\quad \times 3 \text{ conveyor segments} \\ &= \$6000 \end{aligned}$$

$$\text{Depreciation per year} = \$6000/3 = \$2000/\text{year}$$

$$\text{Maintenance cost} = \$30,000/\text{year}$$

$$\begin{aligned} \text{Total service cost/year} &= \text{Depreciation cost} + \text{Maintenance cost} \\ &= \$32,000/\text{year} \end{aligned}$$

$$\text{Total service cost/hour} = \$32,000/2000 = \$16/\text{hour}$$

The total net profit per hour after deducting the expected delay and the expected service costs is

$$\begin{aligned} \text{Total net profit/hour} &= \text{Gross profit/hour} - \text{Expected delay cost/hour} \\ &\quad - \text{Expected service cost/hour} \end{aligned}$$

Comparing the net profit per hour between manual material handling and conveyorized material handling, it is evident that conveyors should be installed to maximize profit.

L13.2.3 Using Operator for Processing

In the following example we use an operator for material handling as well as some of the processing done in the shop.

Problem Statement

Modify the example in Section L7.7.1 by having a material handler (let us call him Joe) return the pallets from the shipping dock to the packing workbench. Eliminate the pallet return conveyor. Also, let's have Joe load the boxes onto pallets [Uniform(3,1) min] and the loaded pallets onto the shipping conveyor. Assume one pallet is in the system. Simulate for 10 hours and determine the following:

1. The number of monitors shipped.
2. The utilization of the material handler.

Seven locations (Conv1, Conv2, Shipping_Q, Shipping_Conv, Shipping_Dock, Packing_Table, and Load_Zone) are defined. The resource (Joe) is defined as shown in Figure L13.12. The path network for the resource and the processes and routings are shown in Figures L13.13 and L13.14 respectively. The arrivals of the entities are shown in Figure L13.15. The layout of Ship'n Boxes Inc. with conveyors is shown in Figure L13.16.

L13.2.4 Automated Manufacturing Cell

Problem Statement

Raja owns a manufacturing cell consisting of two mills and a lathe. All jobs are processed in the same sequence, consisting of arrival station, lathe, mill 1, mill 2,

FIGURE L13.12

Material handler as a resource.

Icon	Name	Units	DTs...	Stats...	Specs...	Search...	Logic...	Pts...	Notes...
	JOE	1	None	By Unit	Net1, N1	None	0	1	

FIGURE L13.13

Path network for the material handler.

Graphic	Name	Type	T/S	Paths...	Interfaces...	Mapping...	Nodes
	Net1	Passing	Speed & Distance	1	2	0	2

From	To	El	Distance
N1	N2	El	31.30

FIGURE L13.14

Processes and routings for the example in Section L13.2.3.

Process			Routing				
Entity	Location	Operation	Blk	Output	Destination	Rule	Move Logic
Monitor	CONU1		1	Monitor	Packing_Table	JOIN 1	
Empty_Box	CONU2		1	Empty_Box	Packing_Table	FIRST 1	
Empty_Box	Packing_Table	JOIN 1 Monitor WAIT N(5,1)					
Box	Shipping_Q	WAIT 0	1	Box	Shipping_Q	FIRST 1	
Pallet_	Load_zone	load 1 USE Joe FOR U(3,1)	1	Box	Load_zone	LOAD 1	
Pallet_	SHIPPING_CONU		1	Pallet_	SHIPPING_CONU	FIRST 1	
Pallet_	SHIPPING_DOCK	UNLOAD 1	1	Pallet_	SHIPPING_DOCK	FIRST 1	
Box	SHIPPING_DOCK		1	Box	EXIT	FIRST 1	MOVE WITH JOE THEN FREE

FIGURE L13.15

Arrivals for the example in Section L13.2.3.

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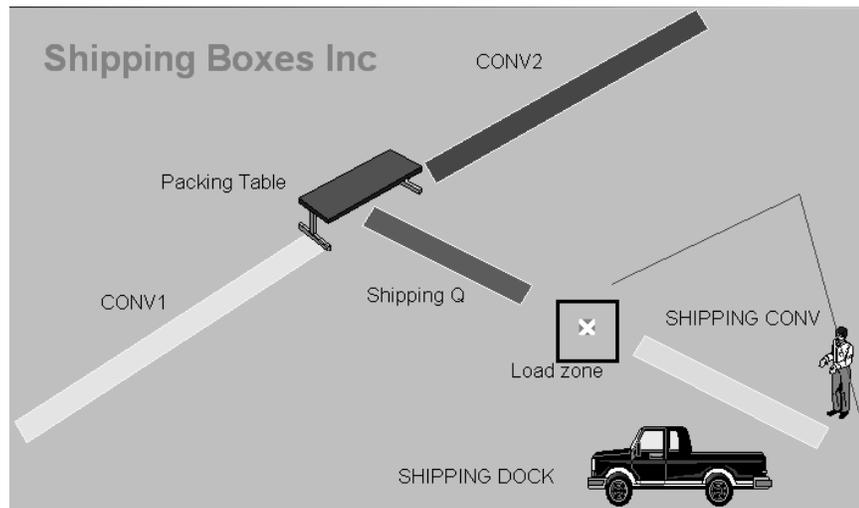
*****
Arrivals
*****

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Entity	Location	Qty each	First Time	Occurrences	Frequency	Logic
Monitor	CONU1	1	0	inf	E<15>	
Empty_Box	CONU2	1	0	inf	E<15>	
Pallet_	Load_zone	1	0	1	5	

FIGURE L13.16

The layout for
Shipping Boxes Inc.



and exit station. The processing time on each machine is normally distributed with a mean of 60 seconds and a standard deviation of 5 seconds. The arrival rate of jobs is exponentially distributed with a mean of 120 seconds.

Raja also transports the jobs between the machines and the arrival 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 L13.6. Raja can travel at the rate of 150 feet/minute when carrying no load. However, he can walk at the rate of only 80 feet/minute when carrying a load. Simulate for 80 hours.

The layout, locations, path networks, resource specification, and processes and routings are shown in Figures L13.17, L13.18, L13.19, L13.20, and L13.21, respectively.

FIGURE L13.17

Layout of Raja’s manufacturing cell.

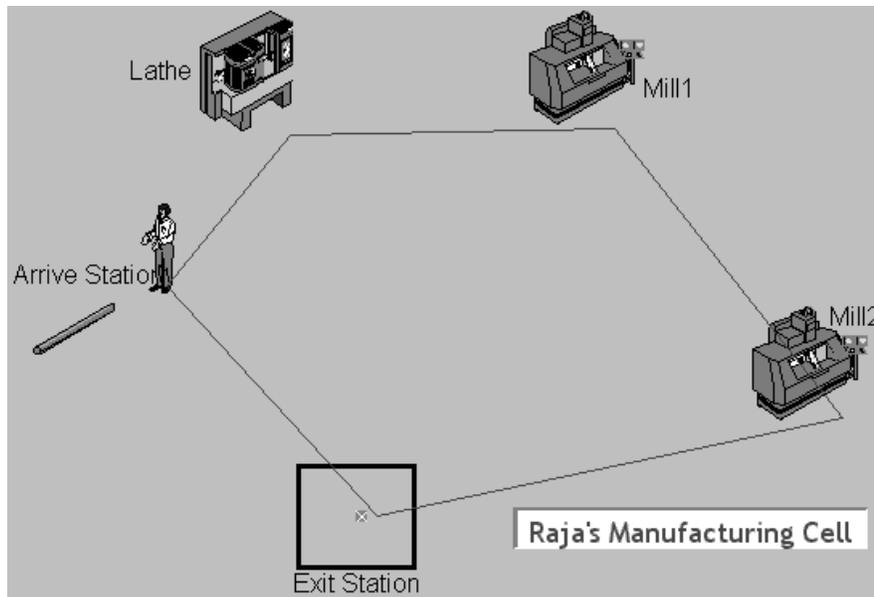


TABLE L13.6 Distances between Stations at Raja’s Manufacturing Cell

<i>From</i>	<i>To</i>	<i>Distance (feet)</i>
Arrival station	Lathe	40
Lathe	Mill 1	80
Mill 1	Mill 2	60
Mill 2	Exit	50
Exit	Arrive	80

FIGURE L13.18

Locations at Raja's manufacturing cell.

Locations						
Icon	Name	Cap.	Units	DTs...	Stats...	Rules...
	Lathe	1	1	None	Time Series	Oldest
	Mill1	1	1	None	Time Series	Oldest
	Mill2	1	1	None	Time Series	Oldest
	Arrive_Station	inf	1	None	Time Series	Oldest
	Exit_Station	inf	1	None	Time Series	Oldest

FIGURE L13.19

Path networks at Raja's manufacturing cell.

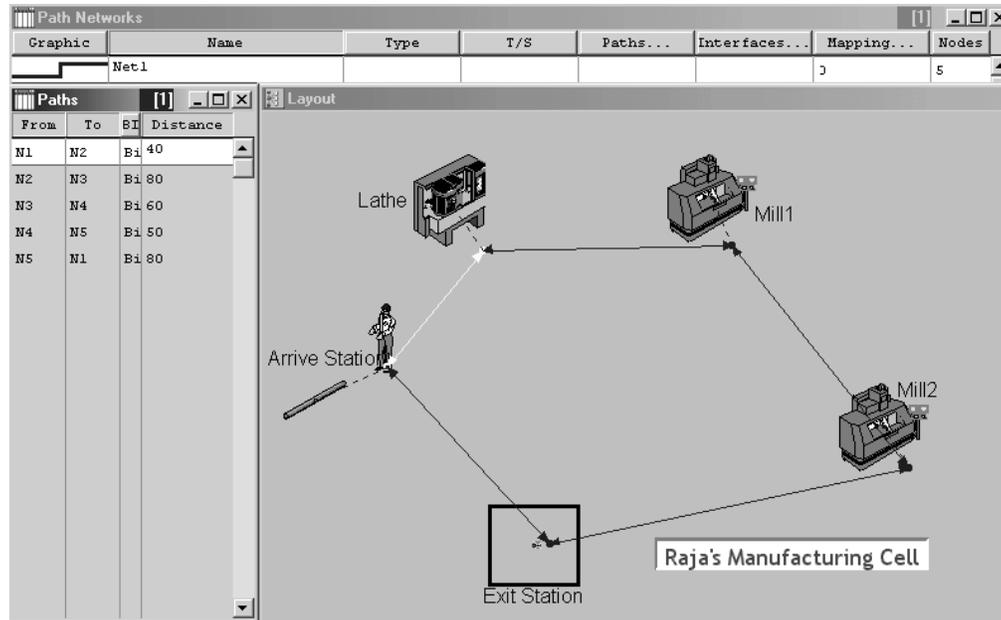


FIGURE L13.20

Resource specification at Raja's manufacturing cell.

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*****
Resources
*****

```

Name	Units	Stats	Res Search	Ent Search	Path	Motion	Cost
Raja	1	By Unit	Closest	Oldest	Net1 Home: N1	Empty: 150 fpm Full: 80 fpm	

FIGURE L13.21

Process and routing tables at Raja's manufacturing cell.

Entity	Location	Process		Routing			
		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		1	JOBS	EXIT	FIRST 1	

L13.3 Crane Systems

ProModel provides the constructs for modeling crane systems. The path networks module and the resources module provide modeling features for the crane systems. Modeling one or multiple cranes operating in the same bay is easily possible. Users can define the following regarding crane systems:

Crane envelope: The crane envelope is a parallelogram-shaped area represented by a crane-type path network. Two rails and two lines connecting the endpoints of the rails bound this envelope. The lines connecting the endpoints of the rails are the two extreme positions of the centerlines of the crane bridge.

Bridge separation distance: This is the minimum distance between the centerlines of any two neighboring cranes. Make sure to define the crane envelope as wide enough to allow sufficient space beyond any serviceable nodes.

Priorities: Two types of priorities are associated with the crane construct in ProModel: resource request priority and crane move priority.

1. *Resource request priorities* are used to resolve any conflicts between multiple entities requesting the same crane at the same time. Lower-priority tasks are preempted to serve higher-priority tasks.
2. *Crane move priorities* are used when multiple cranes are operating in the same work envelope to decide which crane has priority over another to move. Crane move priorities can be subdivided into three categories:
 - a. *Task move priority* is used as the base move priority for travel to pick up and travel to drop a load.
 - b. *Claim priority* is the same as the task move priority if the crane is moving to its ultimate (task) destination. Otherwise, if it is moving under the influence of another crane, claim priority is equal to the claim priority of the claim inducer bridge.
 - c. *Effective claim priority* applies only when there are three or more cranes operating in the same envelope. If multiple cranes are moving in the same direction with overlapping claims, the effective claim priority in the overlapping zone is the maximum of all the claim priorities of those cranes.

For more details on crane operations, and in particular to understand how zone claims are handled, please refer to the ProModel Reference Guide.

Problem Statement

Pritha takes over the manufacturing operation (Section L13.2.4) from Raja and re-names it **Pritha's manufacturing cell**. After taking over, she installs an overhead crane system to handle all the material movements between the stations. Job pickup and release times by the crane are uniformly distributed between six and eight seconds. The coordinates of all the locations in the cell are given in Table L13.7. The crane can travel at the rate of 150 feet/minute with or without a load. Simulate for 80 hours.

Five locations (Lathe, Mill 1, Mill 2, Exit_Station, and Arrive_Station) are defined for Pritha's manufacturing cell. The path networks, crane system resource, and processes and routings are shown in Figures L13.22, L13.23, and L13.24.

FIGURE L13.22

Path networks for the crane system at Pritha's manufacturing cell.

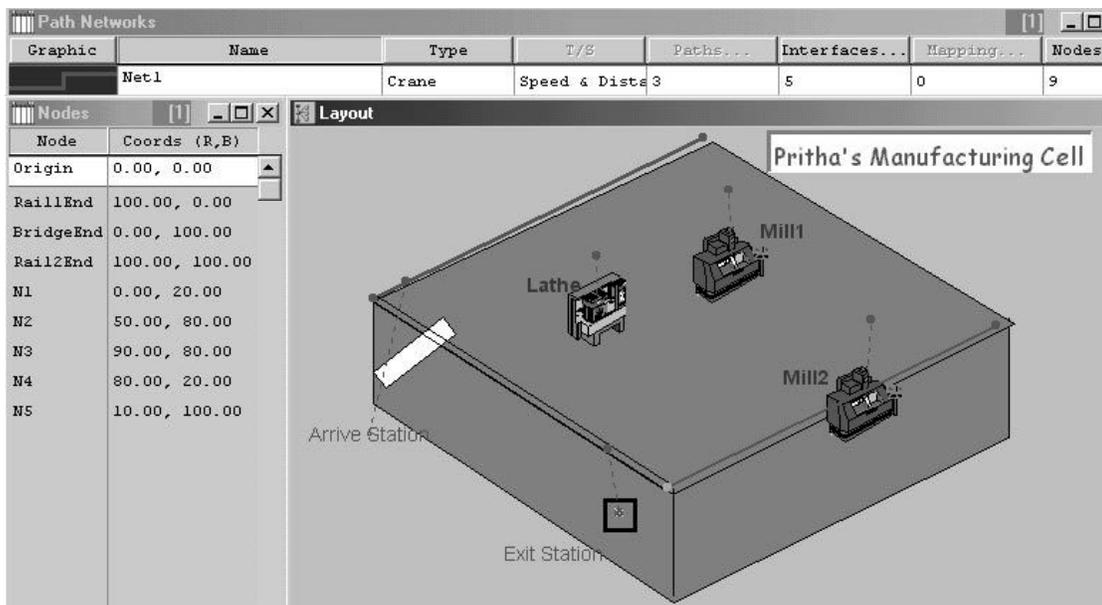


TABLE L13.7 Coordinates of All the Locations in Pritha's Manufacturing Cell (in feet)

Location	X (Rail)	Y (Bridge)
Arriving	10	100
Lathe	50	80
Mill 1	90	80
Mill 2	80	20
Exit	0	20

FIGURE L13.23

The crane system resource defined.

```

*****
Resources
*****

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Name	Units	Stats	Res Search	Ent Search	Path	Motion	Cost
Crane_System	1	By Unit	Closest	Oldest	Net1 Home: Origin	Empty: 150,150 fpm Full: 150,150 fpm Pickup: u(3,1) Seconds Deposit: u(3,1) Seconds	

FIGURE L13.24

Process and routing tables defined for Pritha's manufacturing cell.

Entity	Location	Process		Routing			
		Operation	Blk	Output	Destination	Rule	Move Logic
Jobs	Arrive_Station		1	Jobs	Lathe	FIRST 1	MOVE WITH Crane_System THEN FREE
Jobs	Lathe	wait n(60,5) sec	1	Jobs	Mill1	FIRST 1	MOVE WITH Crane_System THEN FREE
Jobs	Mill1	wait n(60,5) sec	1	Jobs	Mill2	FIRST 1	MOVE WITH Crane_System THEN FREE
Jobs	Mill2	wait n(60,5) sec	1	Jobs	Exit_Station	FIRST 1	MOVE WITH Crane_System THEN FREE
Jobs	Exit_Station		1	Jobs	EXIT	FIRST 1	

Select Path Network from the Build menu. From the Type menu, select Crane. The following four nodes are automatically created when we select the crane type of path network: Origin, Rail1 End, Rail2 End, and Bridge End. Define the five nodes N1 through N5 to represent the three machines, the arrival station, and the exit station. Click on the Interface button in the Path Network menu and define all the interfaces for these five nodes.

Select Resource from the Build menu. Name the crane resource. Enter 1 in the Units column (one crane unit). Click on the Specs. button. The Specifications menu opens up. Select Net1 for the path network. Enter the empty and full speed of the crane as 150 ft/min. Also, enter Uniform(3 ± 1) seconds as the pickup and deposit time.

L13.4 Exercises

1. Consider the **DumpOnMe** facility in Exercise 11 of Section L7.12 with the following enhancements. Consider the dump trucks as material handling resources. Assume that 10 loads of coal arrive to the loaders every hour (randomly; the interarrival time is exponentially distributed). Create a simulation model, with animation, of this system. Simulate for 100 days, eight hours each day. Collect statistics to estimate the loader and scale utilization (percentage of time busy). About how many trucks are loaded each day on average?
2. For the **Widgets-R-Us Manufacturing Inc.** example in Section L12.5.1, consider that a maintenance mechanic (a resource) will be hired to do the

repair work on the lathe and the mill. Modify the simulation model and run it for 2000 hours. What is the utilization of the maintenance mechanic?

Hint: Define maintenance_mech as a resource. In the Logic field of the Clock downtimes for Lathe enter the following code:

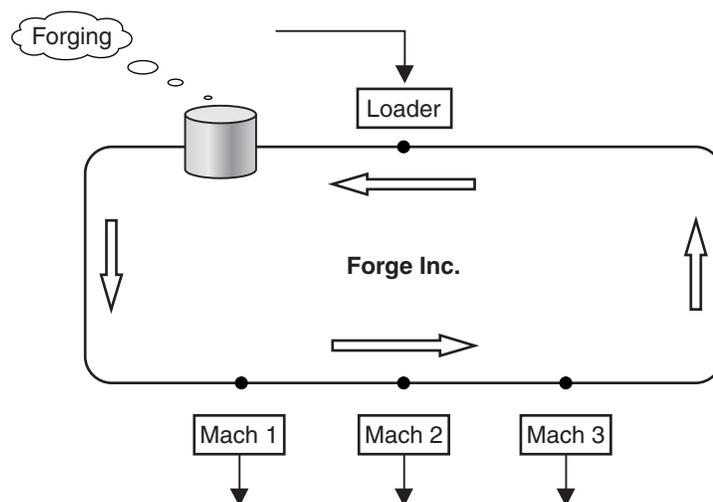
```
GET maintenance_mech
DISPLAY "The Lathe is Down for Maintenance"
Wait N(10,2) min
FREE maintenance_mech
```

Enter similar code for the Mill.

3. At **Forge Inc.** raw forgings arrive at a circular conveyor system (Figure L13.25). They await a loader in front of the conveyor belt. The conveyor delivers the forgings (one foot long) to three machines located one after the other. A forging is off-loaded to a machine only if the machine is not in use. Otherwise, the forging moves on to the next machine. If the forging cannot gain access to any machine in a given pass, it is recirculated. The conveyor moves at 30 feet per minute. The distance from the loading station to the first machine is 30 feet. The distance between each machine is 10 feet. The distance from the last machine back to the loader is 30 feet. Loading and unloading take 30 seconds each. Forgings arrive to the loader with an exponential interarrival time and a mean of 10 seconds. The machining times are also exponentially distributed with a mean of 20 seconds. Simulate the conveyor system for 200 hours of operation.
 - a. Collect statistics to estimate the loader and machine utilizations.
 - b. What is the average time a forging spends in the system?
 - c. What fraction of forgings cannot gain access to the machines in the first pass and need to be recirculated?
 - d. What is the production rate of forgings per hour at Forge Inc.?

FIGURE L13.25

Layout of Forge Inc.



4. **U.S. Construction Company** has one bulldozer, four trucks, and two loaders. The bulldozer stockpiles material for the loaders. Two piles of material must be stocked prior to the initiation of any load operation. The time for the bulldozer to stockpile material is Erlang distributed and consists of the sum of two exponential variables, each with a mean of 4 (this corresponds to an Erlang variable with a mean of 8 and a variance of 32). In addition to this material, a loader and an unloaded truck must be available before the loading operation can begin. Loading time is exponentially distributed with a mean time of 14 minutes for server 1 and 12 minutes for server 2.

After a truck is loaded, it is hauled and then dumped; it must be returned before it is available for further loading. Hauling time is normally distributed. When loaded, the average hauling time is 22 minutes. When unloaded, the average time is 18 minutes. In both cases, the standard deviation is three minutes. Dumping time is uniformly distributed between two and eight minutes. Following a loading operation, the loader must rest for five minutes before it is available to begin loading again. Simulate this system at the U.S. Construction Co. for a period of one year (2000 working hours) and analyze it.

5. At **Walnut Automotive**, machined castings arrive randomly (exponential, mean of six minutes) from the supplier to be assembled at one of five identical engine assembly stations. A forklift truck delivers the castings from the shipping dock to the engine assembly department. A loop conveyor connects the assembly stations.

The forklift truck moves at a velocity of five feet per second. The distance from the shipping dock to the assembly department is 1000 feet. The conveyor is 5000 feet long and moves at a velocity of five feet per second.

At each assembly station, no more than three castings can be waiting for assembly. If a casting arrives at an assembly station and there is no room for the casting (there are already three castings waiting), it goes around for another try. The assembly time is normally distributed with a mean of five minutes and standard deviation of two minutes. The assembly stations are equally distributed around the belt. The load/unload station is located halfway between stations 5 and 1. The forklift truck delivers the castings to the load/unload station. It also picks up the completed assemblies from the load/unload station and delivers them back to the shipping dock.

Create a simulation model, with animation, of this system. Run the simulation model until 1000 engines have been assembled.

- What is the average throughput time for the engines in the manufacturing system?
- What are the utilization figures for the forklift truck and the conveyor?
- What is the maximum number of engines in the manufacturing system?
- What are the maximum and average numbers of castings on the conveyor?

6. At the **Grocery Warehouse**, a sorting system consists of one incoming conveyor and three sorting conveyors, as shown in Figure L13.26. Cases enter the system from the left at a rate of 100 per minute at random times. The incoming conveyor is 150 feet long. The sorting conveyors are 100 feet long. They are numbered 1 to 3 from left to right and are 10 feet apart. The incoming conveyor runs at 10 feet per minute and all the sorting conveyors at 15 feet per minute. All conveyors are accumulating type. Incoming cases are distributed to the three lanes in the following proportions: Lane 1—30 percent; Lane 2—50 percent; and Lane 3—20 percent.

At the end of each sorting conveyor, a sorter (from a group of available sorters) scans each case with a bar code scanner, applies a label, and then places the case on a pallet. One sorter can handle 10 cases per minute on the average (normally distributed with a standard deviation of 0.5 minute).

When a pallet is full (40 cases), a forklift arrives from the shipping dock to take it away, unload the cases, and bring back the empty pallet to an empty pallet queue near the end of the sorting conveyor. A total of five pallets are in circulation. The data shown in Table 13.8 are available for the forklift operation.

FIGURE L13.26

The conveyor sorting system at the Grocery Warehouse.

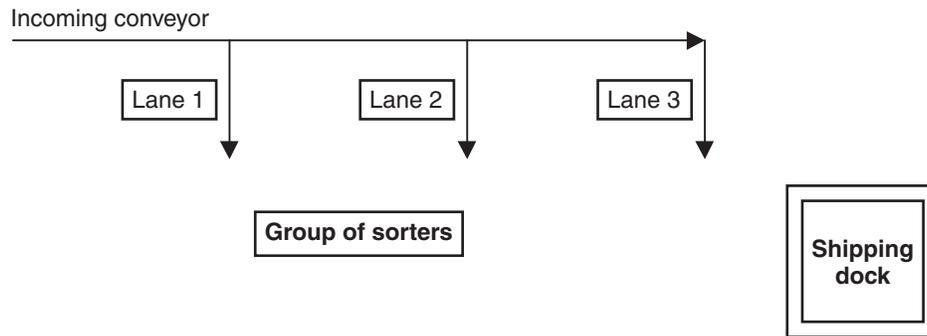


TABLE 13.8 Forklift Operation Data Collected at the Grocery Warehouse

Load time	1 min.
Unload time	3 min.
Travel speed (with and without load)	10 ft./min
Distance from shipping dock to sorting conveyors	250 ft.

Simulate for one year (250 working days, eight hours each day).

Answer the following questions:

- a. How many sorters are required? The objective is to have the minimum number of sorters but also avoid overflowing the conveyors.
 - b. How many forklifts do we need?
 - c. Report on the sorter utilization, total number of cases shipped, and the number of cases palletized by lane.
7. Repeat Exercise 6 with a dedicated sorter in each sorting lane. Address all the same issues.
 8. Printed circuit boards arrive randomly from the preparation department. The boards are moved in sets of five by a hand truck to the component assembly department, where the board components are manually assembled. Five identical assembly stations are connected by a loop conveyor.

When boards are placed onto the conveyor, they are directed to the assembly station with the fewest boards waiting to be processed. After the components are assembled onto the board, they are set aside and removed for inspection at the end of the shift. The time between boards arriving from preparation is exponentially distributed with a mean of five seconds. The hand truck moves at a velocity of five feet per second and the conveyor moves at a velocity of two feet per second. The conveyor is 100 feet long. No more than 20 boards can be placed on the belt at any one time.

At each assembly station, no more than two boards can be waiting for assembly. If a board arrives at an assembly station and there is no room for the board (there are already two boards waiting), the board goes around the conveyor another time and again tries to enter the station. The assembly time is normally distributed with a mean of 35 seconds and standard deviation of 8 seconds. The assembly stations are uniformly distributed around the belt, and boards are placed onto the belt four feet before the first station. After all five boards are placed onto the belt, the hand truck waits until five boards have arrived from the preparation area before returning for another set of boards.

Simulate until 100 boards have been assembled. Report on the utilization of the hand truck, conveyor, and the five operators. How many assemblies are produced at each of the five stations? (Adapted from Hoover and Perry, 1989.)

9. In this example we will model the assembly of circuit boards at four identical assembly stations located along a closed loop conveyor (100 feet long) that moves at 15 feet per minute. The boards are assembled from kits, which are sent in totes from a load/unload station to the assembly stations via the top loop of the conveyor. Each kit can be assembled at any one of the four assembly stations. Completed boards are returned in their totes from the assembly stations back to the loading /unloading station. The loading/unloading station (located at the left end of the conveyor) and the four assembly stations (identified by the letters A through D) are equally spaced along the conveyor, 20 feet

apart. The time to assemble each kit is $N(7,2)$ minutes. If an assembly station is busy when a tote arrives, it moves to the next station. Loading and unloading a tote to/from the conveyor takes $N(2,0.2)$ minutes each. Since each tote is one foot long, at most 100 totes will fit on the conveyor at one time. Kits arrive at the load/unload station with an average interarrival time of five minutes, exponentially distributed. Simulate for 1000 hours. Answer the following questions:

- a. What are the average and maximum numbers of kits in the system?
 - b. What is the number of assemblies produced and shipped per hour?
 - c. What are the average and maximum times spent by a kit in the system?
 - d. What are the utilizations of the four assembly stations?
 - e. What percentage of kits go around the conveyor more than once before being assembled?
 - f. Should we consider installing more assembly stations? Fewer?
10. At the **Assam Plywood Mill**, logs arrive to the mill in truckloads of 15 each, according to a Poisson process distributed with a mean of 1.3 feet and a standard deviation of 0.3 foot. The logs are precut to a standard length of 8 feet, 16 feet, or 24 feet before their arrival to the mill, with a distribution by length of 20 percent, 50 percent, and 30 percent respectively. The arriving logs are unloaded into a bin, from which they are loaded one at a time onto a conveyor. Sensor devices automatically control this loading operation so that the next log is kicked onto the conveyor as soon as sufficient space is available.

The conveyor moves the logs at a speed of 40 feet/minute to a peeling machine, which debarks the logs and peels them into wood strips. These strips are dried and glued together in subsequent phases of the operation to produce plywood. The peeling machine accepts only logs that are 8 feet long. Therefore, the 16-foot and the 24-foot logs must be cut into 8-foot sections before arriving to the peeling machine. This sectioning is done at an automatic cutting station located 32 feet from the start of the conveyor. Whenever the leading end of a 16-foot or 24-foot log reaches the 40-foot mark, the conveyor is automatically stopped and a vertical cut is made at the 32-foot mark. This operation requires 0.5 minute, after which the conveyor can be restarted.

The peeling machine is located beginning at the 48-foot mark along the conveyor. Whenever the trailing end of a log reaches this point, the conveyor is stopped and the log is ready to be moved from the conveyor and loaded into the peeling machine. The loading operation requires 0.8 minute. At the end of this time the conveyor can be restarted, and the debarking/peeling operation begins. The peeling machine processes one 8-foot log at a time at the rate of 20 cubic feet of log per minute.

Simulate the system for 2400 minutes to determine the throughput of wood in cubic feet, the utilization of the peeler, and the number of feet of conveyor occupied.

11. At **Orem Casting Company**, rough castings arrive for machining according to a normal distribution with a mean of 60 seconds and a

standard deviation of 15 seconds. An inspector examines the castings for cracks. Approximately 15 percent of the castings are rejected and scrapped. Three automatic CNC milling machines are used to machine the remaining castings. Two loaders (material handlers) load the mills in a time that is uniformly distributed from 35 to 95 seconds. The loaders will always try to load a casting into an empty machine before waiting for a mill to become available. The milling operation takes a time that varies according to a triangular distribution with a minimum, mode, and maximum of 50, 100, and 130 seconds. The loaders also remove the milled castings in a time that is uniformly distributed from 30 to 60 seconds. Simulate the operation of the company until 1000 castings are machined.

- a. What is the average number of castings in the shop?
 - b. What is the maximum number of castings in the shop?
 - c. How many castings did the inspector reject?
 - d. What is the utilization of the loaders and the machines?
 - e. Should we increase the number of loaders? Should we decrease them?
12. At the **Washington Logging Company**, a logging operation involves cutting a tree, which takes 25 minutes on the average. This time is normally distributed with a standard deviation of 10 minutes. The weight of a tree varies uniformly from 1000 to 1500 pounds, based on the density of fir. The logging company has five trucks with a capacity of 30 tons each. The truck will not move the trees to the sawmill until at least 15 tons of trees are loaded. The trip to the sawmill takes two hours, and the return trip also requires two hours. The truck takes 20 minutes to unload at the sawmill. Develop a simulation model of this facility. Determine whether the logging operation has sufficient capability to deliver all the trees cut in one month. The logging operation runs eight hours each day, 20 days a month.

Embellishments:

- a. Include in the model the logging of alder trees in addition to fir trees. The alder trees are also cut in 25 minutes and segregated at the cutting site. The alder trees have weights ranging from 1500 to 2000 pounds, uniformly distributed. The trucks transport the alder and fir trees in separate trips.
 - b. Vary the minimum requirement of trees that are loaded on a truck from 15 to 20 to 25 tons to determine the effect on throughput of this decision variable.
13. **Rancho Cucamonga Coil Company** is considering implementing a crane system as shown in Figure L13.27. Two cranes operate on separate tracks. Crane 1 serves only input station A and is used to transport steel cables to either output station C or D. Crane 2 transports copper cables from input station B to either output station D or E. The distances between the input and output stations are shown in Table 13.9.
- The arrival rate of steel cables to input station A is four rolls per hour (exponential), with 50 percent of the rolls sent to output station C

FIGURE L13.27

Crane system at the
Rancho Cucamonga
Coil Company.

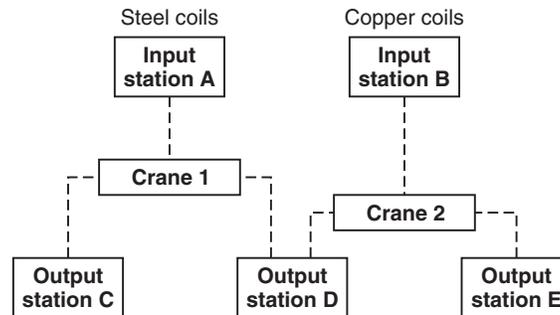


TABLE 13.9 Distances Between Stations at the Rancho Cucamonga Coil Company

<i>From</i>	<i>To</i>	<i>Distance (feet)</i>
Input A	Output C	100
Input A	Output D	150
Input A	Input B	300
Input B	Output E	100

and 50 percent to output station D. The arrival rate of copper cables to input station B is two rolls per hour (exponential), with 40 percent of the rolls sent to output station D and 60 percent to output station E. The travel speeds of both the cranes are 20 feet/minute without load and 10 feet/minute with load. The pickup and drop-off times are two minutes each. Simulate the crane system and collect statistics on the throughput from each input station to each output station.

Embellishments:

- What will be the impact on throughput if the cranes run on a single track with output station D being on the common path of both the cranes? Model the interference in reaching output station D.
- Establish a cost structure to evaluate and compare the single track (with interference) versus the separate track crane systems.
- Evaluate the impact of giving priority to jobs that do not require the common track—that is, to jobs destined for output stations C and E.

Reference

S. V. Hoover and R. F. Perry, *Simulation: A Problem Solving Approach*, Addison Wesley, 1989, pp. B93–B95.