Use of Computer Simulation in Designing and Evaluating a Proposed Rough Mill for Furniture Interior Parts

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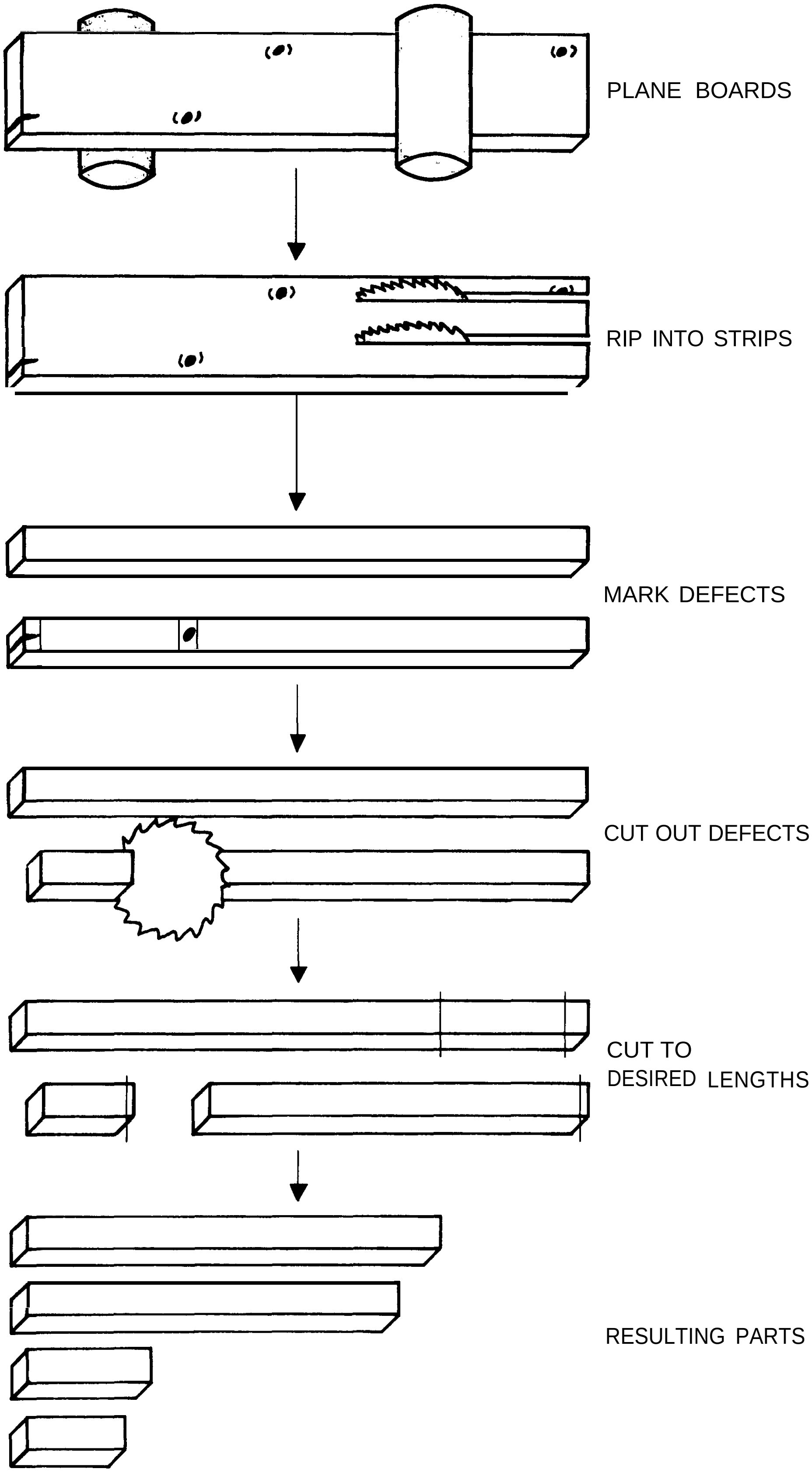
ABSTRACT

The design of a rough mill for the production of interior furntirue parts is used to illustrate a simulation technique for analyzing and evaluating established and proposed sequential production systems. Distributions representing the real-world random characteristics of lumber, equipment feed speeds and delay times are programmed into the simulation. An example is given of how bottlenecks are found and removed in order to design on paper a layout that will meet a set of goals before a single piece of equipment has been purchased. GPSS (a General Purpose Simulation System language) was used.

Keywords: models, simulation, operations research, systems analysis, plant layout, computer programs

Figure 1.—Sequence of operations used to produce interior parts from lumber



INTRODUCTION

THE TASK OF DESIGN and layout for many wood-processing systems can present very complex problems, especially where random events or elements have important effects on production. Converting rough lumber into furniture and dimension parts is a case in point. Because of the random occurrence of defects in rough lumber, it is usually not possible to predict exactly how much time it will take to complete each step in the manufacturing process. Other elements are also at work: the desired output changes from order to order; workers don't always work at the same speed; the capabilities of various machines differ; production rules can have unexpected or even bizarre effects on output; and different grades of lumber will also affect output.

This paper describes the use of a computer simulation technique for solving a design and layout problem of this type. The technique is widely applicable in the evaluation of proposed or existing systems. The development of a proposed automated rough mill for producing furniture interior parts is used as an illustration. Interior parts are frame parts used in the construction of furniture. Typically, they are cut to one thickness, but vary in length. Although made of sound material, they may contain defects.

WHY SIMULATION?

Simulation is the general process of developing and testing a model of a real system. There are a number of advantages to using the computer simulation approach to build and evaluate a hypothetical model of a rough mill. Simulation permits the designer to observe the model's performance before any equipment has been purchased and installed, thus reducing greatly the possibility of costly errors. Another advantage is flexibility. The model of the rough mill can be changed easily. Different equipment, different grades of lumber, and different cutting bills can be tested separately or in combination.

Simulation can generate test data that will show the effects on the whole system of any change in part of the system. Conclusions and decisions do not have to be based solely on data about productivity. Information about utilization, e.g., percent use (use time ÷ total time x 100) of manpower and equipment can be determined. Such information can be used to discover and eliminate production bottlenecks. In general, with computer-simulation techniques, one can see at once things that will occur over a period of time.

THE PROBLEM

Several possible manufacturing sequences for making interior parts from 4/4 yellow-poplar lumber were tested at the Forest Products Marketing Laboratory (*Lucas and Araman* ***1975,*** *Araman and Lucas* 1975). The sequences showed no differences in yield of parts, so the sequence considered best from a standpoint of automation and production control was selected for further development.

The manufacturing sequence was divided into four major segments (fig. 1): 1. Planing kiln-dried lumber to a uniform thickness; 2. Producing strips of standard width by gang-ripping the lumber; 3. Removing objectionable defects from the strips by crosscutting and 4. Crosscutting the defect-free strips into several lengths, with the longest obtainable desired length being cut first. We needed to develop a layout for the sequence that would be capable of producing a specified amount of parts. And we needed to know what effect different grades of input lumber would have on the parts production per shift. Our objective was to design an efficient manufacturing system for interior parts that was capable of producing from either No. 1 or No. 2A Common 4/4 yellow-poplar lumber approximately 4,000 board feet of finished parts per 8-hour shift.

SIMULATION - THREE BASIC PARTS

There are three basic parts to any simulation: the model of the system being simulated; the required input information; and the interpretation of the output information.

THE SYSTEM

The initial system for the interior parts rough mill to be simulated contains the following sequence of operations (fig. 2):

1. *Lumber infeed*
   Rough, kiln-dried 4/4 yellow-poplar lumber, in random widths and in random lengths up to 16 feet, starts into the mill on a tilted breakdown hoist (l).

2. *Conveyor*
   The lumber is unstacked one layer at a time onto a cross conveyor (2).

3. *Infeed station*
   Worker A feeds the boards one at a time onto the planer infeed belt (3).

4. *Planer*
   The planer or facer and planer (4) skip planes the boards on both sides to a standard thickness.

5. *Canted infeed rolls*
   Coming out of the planer, the boards go onto a canted roller conveyor (5) that aligns the boards against a fence for feeding into the gang ripsaw.

6. *Gang ripsaw*
   The gang ripsaw (6) cuts the boards into standard-width strips.

7. *Offbearer station*
   Worker B tails the ripsaw and moves the edgings off and out of the way.

8. *Cross conveyor*
   From the tail of the ripsaw, the strips pass onto a cross conveyor (7) that takes the strips over to the marking station.

9. *Marking station conveyor*
   The strips move one at a time onto the marking station conveyor (8).

10. *Defect-marking station*
    Worker C inspects each strip on the conveyor and quickly marks it where it is to be cut to remove defects. If a strip has a defect at the end, such as a split or a knot, he makes a single mark to show where the bad end is to be cut off. Otherwise, the strip is marked on both sides of the defect. Marks are made with a conducting electrolytic solution.

11. *Automated defect saw*
    As the strip moves into the defect saw (9), an electronic sensing device locates the marks that worker C has made and trips a circuit that activates the automatic saw.

12. *Conveyor*
    Once the defects have been cut out, the resulting strips are of random lengths. A conveyor (10) carries them to another automated saw where they will be cut to the various lengths of interior furniture parts.

13. *Automatic cut-to-length saw*
    An automatic cut-to-length saw (11) can be controlled by a mini-computer or electronic circuit, Before a production run starts, information about the number of parts required of each desired length is fed into the controlling device. No operator is required to operate the saw. Cutting to length is done automatically as follows:
    a. The strip is advanced and is measured for the longest obtainable desired length,
    b. The strip is stopped and crosscut, producing a part,
    c. After the first cut has been made, the remaining section of strip is measured and cut to the next longest obtainable desired length. This procedure is continued until the piece remaining is shorter than the shortest desired part,
    d. After each part has been cut, the computer deducts one unit from the quantity required for that length,
    e. When no more cuttings are required, the counter for that length goes to zero,
    f. When all cutting requirements have been satisfied, the system stops and is reset for the next run.

After the strips have been cut to the desired lengths, they are moved on to an automatic sorter (not shown in figure 2). Then the parts are cut to final dimensions by molding and tenoning.

Figure 2.—Flow chart of the interior parts mill, initial layout.

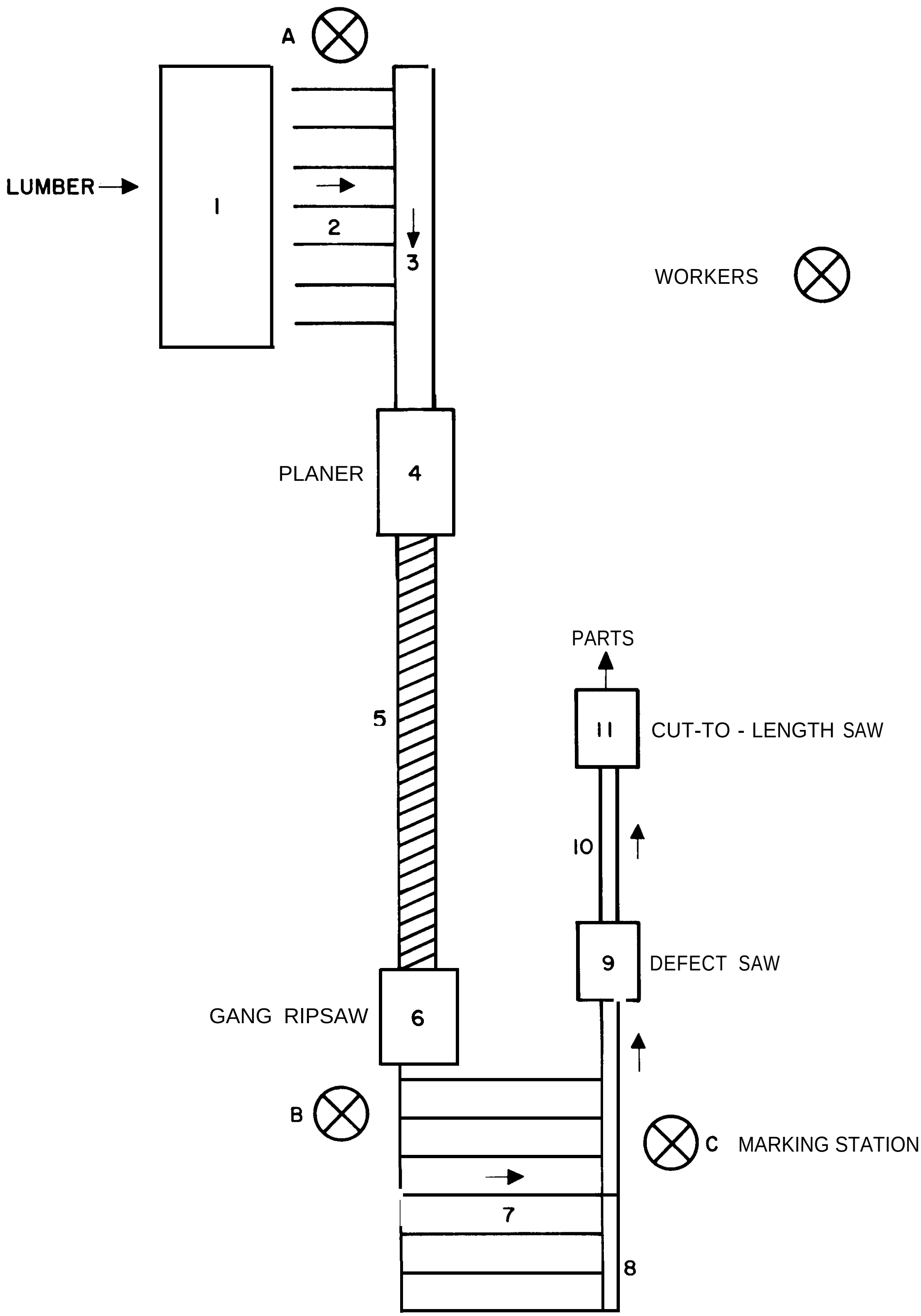


Table 1.—Cutting bills

A		B		C	
Cutting length	Number required	Cutting length	Number required	Cutting length	Number required
inches		*inches*		*inches*	
73	118	70	118	70	236
62	165	60	165	60	330
56	47	54	47	54	94
37	329	40	329	40	658
30	71	30	71	30	142
24	400	24	400	24	800
22	71	22	71	22	142
16	1081	16	1081	16	2162
13	71	13	71	13	142

The width of all parts is 1-11/16 inches.

THE INPUT

The information needed to simulate the system includes cutting bills, lumber-yield information for various grades of lumber, and instructions for operating the system.

Cutting Bills

The cutting bills, which list the parts required, must be typical of the system being studied. For our evaluation, we used three cutting bills (table 1). Each cutting bill contains nine cutting lengths and the number of each needed. The width for all parts was 1-11/16 inches and the lengths were changed from cutting bill A to develop cutting bill B and the quantities required were doubled to create cutting bill C.

Lumber-yield information

The raw material must be defined in terms of grade of lumber and the yield of parts for the system being evaluated. A description of the input lumber and the material left after each step in the manufacturing sequence must be developed by yield studies. This information is used in the simulation program to describe the material entering each operation in the sequence.

Our analysis of the production of interior parts from No. 1 and No. 2A Common 4/4 yellow-poplar lumber gave us the following lumber-input information for each grade, which was required to run the simulation:

1. A frequency distribution of the lengths of boards as they enter the system. The same distribution also describes the lengths of the strips

Table 2.—Distribution of board lengths

Length	No. 1 Common	No. 2A Common
ft.	*no.*	*no.*
5	1	0
6	0	2
7	0	1
8	15	5
10	5	16
12	25	20
13	1	1
14	18	23
15	1	0
16	10	7

Table 3.—Distribution of numbers of strips (1 -11/16 inches wide) cut from each board

Number of strips per board	Number of boards	
	No. 1 Common	No. 2A Common
1	0	1
2	20	17
3	25	25
4	26	25
5	4	3
6	1	4

Table 4.—Distribution of numbers of defects per strip

Objectionable defects per strip	Number of strips	
	No. 1 Common	No. 2A Common
0	171	149
1	49	50
2	25	37
3	0	13

Table 5.—Lengths (in inches) of pieces remaining after removal of objectionable defects in the strips (assuming that defects are spaced equally along the strip)

Length of strips	Number of defects			
	0	1	2	3
60	60	27	18	13
72	72	33	22	16
84	84	39	26	19
96	96	44	30	22
120	120	56	37	28
144	144	67	44	33
156	156	72	48	36
168	168	77	51	39
180	180	83	55	42
192	192	89	59	44
Number of strips	1	2	3	4

cut from these boards by gang ripping (length is not affected by gang-ripping; table 2).

2. A frequency distribution of the number of strips produced by gang-ripping each board (table 3).

3. A frequency distribution of defects per strip describing the number of defects that have to be marked and cut out by the mark-sensing defect saw (table 4). This distribution depends on the quality of parts desired. For our study, defects that impaired the strength of a part or occurred on the ends of parts were objectionable.

4. A distribution of the usable lengths of the defect-free strips remain after defects have been cut out (table 5). For this simulation I assumed that the defects were spaced equally along the strips.

Operating instructions

Operating instructions and information needed to simulate the rough mill setup included a lumber-infeed rate, equipment speeds, belt speeds, time delays for marking strips, time delays for crosscutting, and travel distances. All of these are shown in table 6.

A lumber-infeed rate of five boards per minute was used. Worker A controls the flow by placing the boards on the planer infeed belt one at a time. To prevent overflows on the cross conveyor after the gang ripsaw, worker A stops feeding lumber into the system for 10 minutes when 100 or more strips are on the transfer belt.

Feed speeds for the planer-infeed belt, lumber planer, gang-rip-canted-infeed rolls, and gang ripsaw were all set at 100 feet per minute. Worker B is at the rear of the gang ripsaw to remove edgings. The cross conveyor has a feed speed of 25 feet per minute.

The time per strip required by the marker depends on the number of objectionable defects per strip, plus a fixed inspection time.

The two crosscut saw infeed belts are set for 60 feet per minute, and we used a l-second delay for each crosscut,

In addition to the time delays, feed speeds, and distances, there was a constraint on the productivity of the marker: To insure the proper flow of materials through the defect and cut-to-length saws, the marker must wait for each

Table 6.—Information needed to simulate the rough mill setup

Equipment or operation	Length	Feed speed	Comments
	ft.	ft./rein.	
Lumber infeed	7		Operator = controlled release rate = 5 boards/minute
Planer infeed belt	20	100	
Planer	8	100	
Canted infeed roll conveyor	25	100	
Gang ripsaw	6	100	
Cross conveyor	18	25	
Defect marking	4	60	1 second delay for inspection plus time delay for marking defects
Automated defect saw	4	60	1 second delay for each cut
Conveyor	8	60	
Automatic cut-to-length saw	4	60	1 second delay for each cut

strip to clear the defect saw before he marks the next strip. This delay at the marking station was measured to see if it was creating a bottleneck in the system.

THE OUTPUT

Production statistics provided by the simulation include equipment and worker-utilization summaries and system-production rates. The equipment-use summaries will tell us if we need additional equipment where there are bottlenecks in the process. It could tell us that we have an inefficient operation, with too much equipment. The system-production rates will tell us if we have achieved the goal of designing a plant that will produce at least a minimum number of parts per 8-hour shift.

SIMULATING AND DESIGNING

Simulating and designing is a trial and error approach used to create a manufacturing layout that will satisfy a set of goals (fig. 3). For example, results from the initial layout simulation may show that the production rate is low. Then the bottleneck that is holding back production must be located and removed by redesigning the layout. Simulation with the redesigned layout may show adequate production rates, but also some inefficiencies in design. These can be removed, and the new design tested. The input raw material can be changed and the effect of this change can be studied,

The first step is to develop a program for simulating the initial design that includes all of the operating characteristics, the lumber-supply characteristics, and the desired product distributions. Once the simulation program has been written, you can begin testing and redesigning the layout (fig. 3).

RESULTS FROM THE INITIAL LAYOUT

We simulated operation of the system with No. 2A and then No. 1 Common yellow-poplar lumber as the input material. Production rates per 8-hour shift achieved for each grade were as follows:

	Rough lumber	*Finished parts*
	--------- *bd.*	*ft.* ------
No. 1 Common	3100	2400
No. 2A Common	3100	2200

The difference in finished-parts footage is due to the lower yield of parts from the No. 2A Common lumber.

The production rates achieved did not meet the goal of approximately 4,000 board feet of finished parts per 8-hour shift. Therefore, the system was checked for bottlenecks by evaluating equipment use.

Table 7.—Percentage of time equipment was in use in initial layout

Item	Lumber grade	
	No. 1 Common	No. 2A Common
Planner	21	19
Gang ripsaw	24	21
Lumber delay	68	72
Marking station	100	100
Marker	25	26
Defecting saw	71	72
Cut-to-length saw	81	74

This analysis (table 7) showed that the marking station, which consists of the marker and the defecting saw, was the bottleneck in the system; it was 100 percent utilized. The percentage of use was low for the planer and gang ripsaw; each of these machines is capable of four times the present production. The lumber feed was delayed 68 and 72 percent of the production time. The defecting saw was used about 71 percent of the time with either grade.

The cut-to-length saw was used 81 percent of the production time for No. 1 Common lumber, but only 74 percent for No. 2A Common lumber. This difference was caused by two factors:

1. More material was removed from a No. 2A Common lumber before it reached the cut-to-length saw; and
2. Although the total time the cut-to-length saw was used was the same for both grades, the total production time was longer when No. 2A Common lumber was used, and this reduced the percentage utilization.

The equipment-use summary shows that the marker is working only 25 percent of the time, but he must wait for each strip to clear the defecting saw before he can feed the next strip.

The solution we chose for removing the hindrance at the marking station was to add a second defecting and cut-to-length saw combination after the marker. Each saw would have to

Figure 3.—Flow chart of design process using systems simulation to design a mill layout for specific needs.

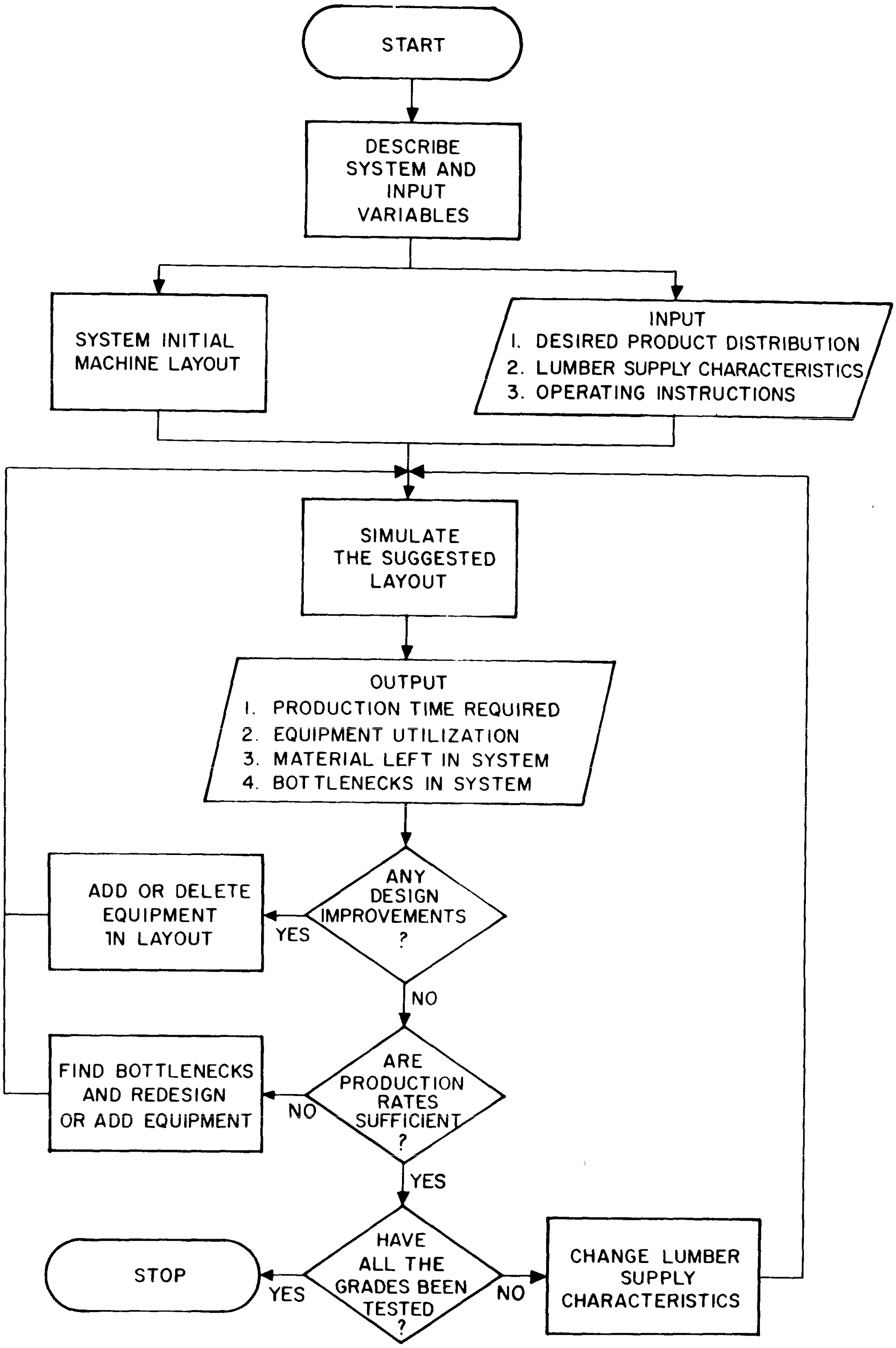
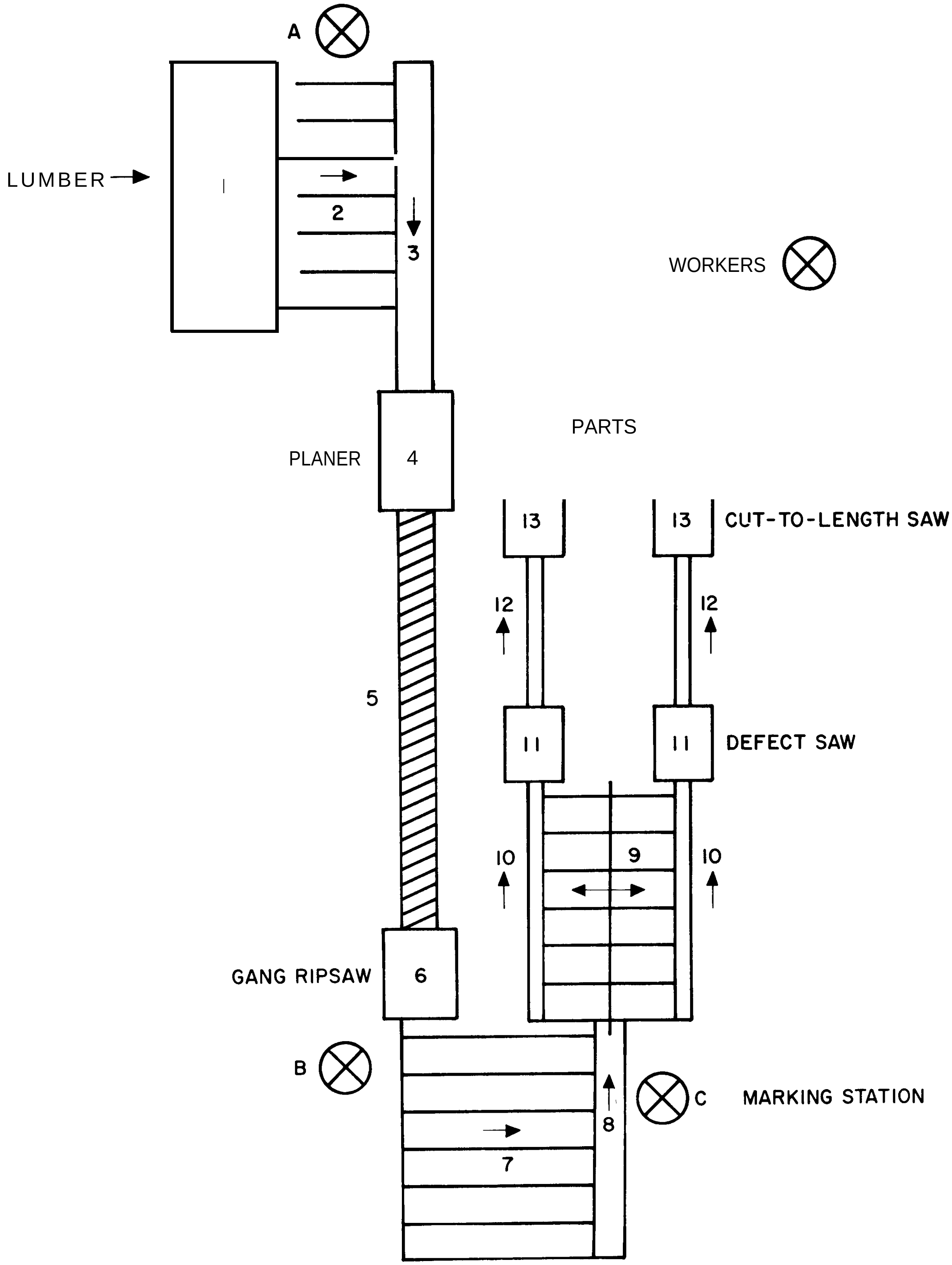


Figure 4.—Flow chart of the interior parts mill, modified layout.



remove defects only from every other strip. This modified layout is shown in figure 4.

RESULTS FROM THE MODIFIED LAYOUT

Simulations with the modified layout gave these production rates:

	Rough lumber	*Finished parts*
	------- *bd. ft*-------	
No. 1 Common	5700	4400
No. 2A Common	5500	3900

We have achieved the objective of obtaining approximately 4,000 board feet of finished parts per 8-hour shift.

The use summary for the modified plant is presented in table 8. The effective use of the marker has almost doubled, although there is still a bottleneck at the marking station. But because production has been almost doubled by the addition of the second crosscutting line, the objective has been satisfied.

THE SIMULATION LANGUAGE

The simulation language we used was GPSS (General Purpose Simulation System), a package program available from IBM.

Listings of the programs used to evaluate and design the interior parts plant can be obtained from the author. Information about the language and its use is available in the literature *(Gordon* 1969, *IBM* 1969, *IBM* 1971, *IBM 1971b, Schriber 1974).*

Table 8.—Percentage of time equipment was in use in modified layout

Item	Lumber grade	
	No. 1 Common	No. 2A Common
Planner	29	27
Gang ripsaw	36	30
Lumber delay	59	56
Marking station	100	100
Marker	46	47
Line No. 1		
Defecting saw	65	66
Cut-to-length saw	74	67
Line No. 2		
Defecting saw	67	62
Cut-to-length saw	76	64

SUMMARY

Simulation has allowed us to design an interior parts plant that will meet a production goal set at 4,000 board feet of interior parts produced in an 8-hour shift. It has also allowed us to compare the effects of the use of No. 1 Common and No. 2A Common lumber on production rate and equipment utilization.

This technique is applicable to many systems, but is especially valuable in the analysis of random-input processes, such as the interior parts plant in this case. Similar problems, such as designing furniture-finishing lines or sawmill setups, could be investigated through computer simulation. However, there are several requirements for simulating a system:

1. The problem to be solved must be clearly stated;
2. The model should contain only pertinent activities of the system. Minor details in the system that do not influence production should be omitted;
3. The model should show the interactions of manpower and equipment as a function of time;
4. The model should be flexible, allowing for changes; and
5. Good quality input and description data must be used. The results are only as good as the input information provided.

In general, simulation permits a designer to observe the system's performance before any equipment is purchased and installed, thus reducing greatly the possibility of costly design errors.

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